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DIPLOMOVÁ PRÁCE

INTEGRATION OF FINANCIAL MARKETS

Empirical analysis on relations of financial markets and their volatilities.

Case of the Czech Republic and the Euro area.

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Prohlášení

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ABSTRAKT

Diplomová práce se zabývá empirickou analýzou vztahů mezi finančními trhy České republiky a zeměmi eurozóny za období 1999 až 2008. Jako teoretický základ naší analýzy používáme finanční integraci a výsledky předchozího výzkumu v této oblasti. V naší empirické analýze zkoumáme podobnosti ve vývoji volatility a možné přenosy volatility jako doplňující pohled na vzájemnou propojenost finančních trhů. Naše metodologie vychází z modelů volatility typu GARCH, které používáme ke zjištění podoby a vztahů mezi podmíněnými volatilitami na trzích devizovém, akciovém a dluhopisovém. Výsledky naší empirické analýzy nám ve většině případů neumožnily učinit závěr o signifikanci transferů volatility a potvrdit tak naší hypotézu. Tu jsme formulovali jako existenci signifikantních vazeb mezi finančními trhy České republiky a eurozóny na základě jejich volatilit. Jsme však přesvědčeni, že námi prezentované údaje poskytují doplňkový pohled na provázanost finančních trhů České republiky a eurozóny a na jejich časový vývoj v posledních několika letech. Zjištěné korelace mezi fluktuacemi výnosů naznačují nejpokročilejší stupeň vzájemného vztahu na devizovém trhu.

ABSTRACT

In our thesis we offer an empirical analysis of relations between financial markets of the Czech Republic and the Euro area countries in the period between 1999 and 2008. We use the theoretical background of financial integration and existing research findings on it as groundwork for our analysis. In our empirical analysis we examine the similarities in volatility behavior and possible volatility transmissions to offer an additional perspective on the financial market interdependencies. Our methodology is based on the GARCH family of models that we use to assess the pattern and relationships between the conditional volatilities in the foreign exchange, equities and bond markets. Results of our empirical analysis did not allow us in most cases to conclude on significant volatility spillovers and therefore to confirm our hypothesis, which we formulated as existence of significant relationships between the Czech and Euro area financial markets in terms of their volatilities. However we believe that the indications that we have presented bring some additional insights on the interdependencies between the Czech and Euro area financial markets and their evolution over the past years. The correlations between the fluctuations indicate the strongest degree of interrelatedness in the foreign exchange market.

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To my family for their immense love and support.

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ABBREVIATIONS

10-year/5-year	stands for 10-year/5-year maturity instrument
AIC	Akaike information criteria
ARIMA	Autoregressive integrated moving average
ARCH	Autoregressive conditional heteroskedasticity
BEKK-GARCH	Multivariate GARCH specification (after Babba, Engle, Kraft, Kroner)
BIS	Bank for International Settlements
bn	billion
bps	basis points
CAPM	Capital Asset Pricing Model
CEEC	Central and eastern European countries
CEE-4	refers to Czech Republic, Hungary, Poland, and Slovakia.
CNB	Czech National Bank
CR	Czech Republic
CZK	Czech crown (currency)
DJ	Dow Jones (Dow Jones Stoxx 600 index)
GER	Germany (used in empirical part notations)
GDP	gross domestic product
ECB	European Central Bank
ECU	European currency unit
EMH	Efficient market hypothesis
ERM II	Exchange Rate Mechanism
EMU	Economic and Monetary Union
EU	European Union
y_{EU}	EU as subscript denotes the European counterpart market in empirical analysis part.

EU-4	refers to Czech Republic, Hungary, Poland, Slovakia
EU-12	refers to Eurozone members excluding recent joiners (Slovenia, Cyprus, Malta)
EUR	Euro (currency)
Euro area/ Eurozone:	Countries of the European Union that use Euro as their national currency: Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, Malta, The Netherlands, Portugal, Spain, Slovenia
FESE	Federation of European Securities Exchanges
FX	Foreign exchange (market, rate)
G-7	Group of 7 countries: Canada, France, Germany, Italy, Japan, USA, UK
GARCH	General autoregressive conditional heteroskedasticity
IPO	Initial public offering
ISMA	International Securities Market Association
LL	Log-Likelihood (function)
NMS	New Member States (of the European Union)
PRIBOR	Prague Interbank Offer Rate
PSE	Prague Stock Exchange
PX	Prague stock exchange main price index from 2006, replaced PX50
PX50	Prague stock exchange main price index until March 2006
SC	Schwartz information criteria
SEPA	Single European Payment System
STOXX	Group of stock market indices provided by STOXX
UK	United Kingdom
US/ USA	United States of America
USD	United States dollar (currency)
US SEC	United States´ Securities and Exchange Commission

INTRODUCTION

The motivation for selecting subject of our thesis is the recent turbulent development on world financial markets. This inspired us to study the interconnections between markets and the ways they affect each other. We use the theoretical background of financial integration in terms of increased linkages between international financial markets to study relationships between the markets in terms of their volatilities.

The integration of Czech financial markets is monitored by the authorities and also has been a subject of various empirical studies. With respect to integration to the Euro area, the existing results suggest a high degree of integration on exchange rate markets and a considerable degree of integration on bonds markets. For the other segments of financial markets the results either suggest increasing integration or the evidence is inconclusive. We want to contribute to the existing recent analysis on the speed or degree of integration between the Czech financial markets and their Euro area counterparts by analyzing the pattern in the market volatilities. We try to identify whether there is higher synchronization between the markets in terms of their volatilities. This can be regarded as complementary information to the assessment of market behavior linkages.

We choose the Euro area as a reference system, due to strong economic and institutional relations and Czech Republic's legal obligations and the process of Euro adoption. This makes the integration with the Euro area a source of possible benefits but also a possible transmitting channel of shocks to Czech economy and financial markets. The Czech Republic as a European Union (EU) state is already part of the Economic and Monetary Union (EMU) and participates in the Stability and Growth Pact in terms of the commitment to fulfill the convergence criteria and has a commitment to adopt Euro as a national currency in the future. The convergence to Euro area is crucial for assessment of the preparedness for the entry in the Exchange Rate Mechanism (ERM II) and the subsequent Euro adoption and participation in the Euro area as a final stage of EMU.

Our study does not aim at measuring the convergence or degree of financial integration; we believe that the recent coverage of the topic is quite rich. Rather we examine the similarities in volatility behavior and possible volatility transmissions as an additional perspective on the financial market interdependencies. For this we use the existing findings on financial integration as groundwork for our analysis.

The volatility on markets expresses the risks and reflects the uncertainty that is expected by the markets regarding their future behavior. Higher levels of volatility imply more uncertainty regarding their future changes. This can have important implications for investors as well as policy makers. The co-movements between volatilities of several markets can point to symmetry in reaction of these markets to unexpected events.

As financial integration constitutes a theoretical background for our motivation, we dedicate considerable attention to it. As will be shown below in the text, financially integrated markets should react to shocks and frictions symmetrically. This may lead to greater alignment between the markets and their volatilities, which can be seen as an additional sign of synchronization of their behavior. Understanding these patterns can be of great interest for investors, policy makers and other market participants.

For the empirical analysis we use the GARCH family of models. These are widely applied in financial studies for volatility modeling. Moreover their multivariate forms can be conveniently used to study volatility transmissions between assets and market as we discuss in our work.

Our aim is to answer the question what is the pattern of volatility dynamics of the Czech financial markets and the Euro area financial markets and whether this pattern shows any similarities. What is the nature of the relationship between financial markets in the Czech Republic and Euro area through their conditional volatilities? We focus on the period between 1999 and 2008 and the development on the foreign exchange market, equities market and market for government bonds.

For the relationships between the volatilities in foreign exchange markets our results indicate strong co-movements in terms of correlation between fluctuations in the markets and some signs of significant volatility spillover from the EUR/USD market to the CZK/USD one. Our results are in accordance with the findings of previous studies (such as Babetskaia-Kukharchuk, et al., 2007) who also suggest that high correlations between fluctuations in the exchange rates point to synchronizations of the shocks.

For the equities markets we find significant strong persistence of conditional volatility on its past values in each of the markets. The derived conditional correlation coefficient is very volatile and perhaps slightly increasing since approximately mid 2005, suggesting increasing tendencies for similarities of the market volatilities. However our results are only indicative as the overall model performance is poor.

For the bond markets we identify different pattern in conditional volatility dynamics for each of the two bonds studied, the 10-year Czech and German government bonds. The German bond yields show persistence on its own past conditional volatility. The results on the mutual volatility relationship are however poor. We find a stable and quite high level of conditional correlation, however without the support of a well performing model. For the case of the bonds market the selected approach may not be appropriate.

Our thesis consists of theoretical and empirical part. The first chapter of the theoretical part introduces the theoretical background on financial integration. We discuss different definitions, issues related to financial integration and we also provide a review of recent studies related to the financial integration/convergence of the Czech Republic with the Euro area. Our attempt is to show that the issue of market interconnections is very complex and also difficult to grasp. It can therefore be studied from various viewpoints. The approach of investigating the relationships through the volatilities and their transmissions between the markets is one of them. The second chapter of the theoretical part discusses various possible approaches to the measurement of integration. We introduce the motivation for the selected method of volatility measuring using the GARCH family of models. As a final step of this part we present the GARCH and multivariate GARCH model formalization in order to highlight their main characteristics.

The second, empirical part consists of four chapters. The first one describes the methodology steps that we follow in the empirical exercise. Each of the subsequent three chapters is dedicated to the individual market. We first present the results for the foreign exchange market, secondly the results for the equities market and finally the results for the bonds market. Each chapter follows a similar structure, which includes market characteristics, existing findings of related research and empirical results for the volatility and their relationships between the market in the Czech Republic and the Euro area. We conclude the main findings at the end of each chapter.

Finally, the conclusion summarizes the main findings of our thesis. We also report on the detailed estimation of the results in appendix to each chapter, included at the end of our thesis.

I. THEORETICAL PART

CHAPTER I.1: FINANCIAL INTEGRATION - THEORY AND REVIEW OF LITERATURE

In this chapter we discuss several issues. We first look at the theoretical background of financial integration, definitions of it, its most frequently recognized benefits and associated risks. We discuss different implications of integration in the context of financial markets referring to existing research and evidence. Then we turn our attention to the interaction of markets in terms of their volatility and we formulate our hypothesis. We also review several studies related to our topic. Firstly we present the ones devoted to the financial integration of the Czech Republic and the European Union and secondly we briefly review studies on volatility transmission between markets as another possible viewpoint to study market interconnections.

1.1 FINANCIAL INTEGRATION

1.1.1 DEFINING FINANCIAL INTEGRATION

The word integration has many specific definitions in various fields of study. The meaning of the word *integrate* is "to unite with something else, to incorporate into a larger unit, to end the segregation of and bring into equal membership in society or an organization"[1]. Building on this definition, we could define financial integration as a process or state in which one or more financial markets are brought into an equal position or are incorporated into a larger market.

Grasping the aspect of financial integration is not straightforward and in fact ambiguity exists with respect to its definition. Many definitions in literature mention integrated markets as

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[1] Merriam-Webster dictionary online.

the ones where the same conditions apply for all participants when trading both between markets and within them and where arbitrage opportunities are eliminated. Bekaert and Harvey (2002) differentiate financial integration, which can be defined as a state in which foreign investors have a free access to local capital markets and vice-versa, economic integration as removing of barriers in trade and regulatory liberalization as the official abandoning of the barriers to entry in domestic capital markets that does not have to lead to market integration due to low credibility or other market imperfections (Bekaert, Harvey, 2002, p.431)[2].

The idea of the law of one price[3] represents a rationale for the definition of financial integration. As an example we present the definition mentioned in CNB (2006c): "Financial market integration occurs when assets (currencies, shares or bonds) having same risk factor and yield are priced identically by the markets no matter where they are traded. This follows from the law of one price."(CNB, 2006c, p.29). In reality, the law of one price suffers from the problem of the similarity of the assets. It is hard to judge what are the similar (or in the strict form identical) risk-return profiles of financial assets which are often very heterogeneous. Therefore one needs to distinguish when the law of one price can present a real evidence of markets integration and when additional or stricter measures need to be adopted (as is discussed for example by Komárková, 2006 or Baltzer, et al., 2008). In line with this argumentation, Fratzscher (2001) in his analysis of equity market integration argues that equity markets cannot be sufficiently defined and measured by the law of one price. The arbitrage opportunities would not always be exploited in an otherwise integrated market, because of the home-bias of investors[4]. Therefore he adopts a definition of integrated market, which directly measures the transmission of shocks among markets.

A broader definition was adopted by the European Central Bank (ECB): "…it considers the market for a given set of financial instruments or services to be fully integrated when all potential market participants in such a market (i) are subject to a single set of rules when they decide to deal with those financial instruments or services, (ii) have equal access to this set of financial instruments or services, and (iii) are treated equally when they operate in the market."

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[2] Authors argue that integration can actually take place before liberalization through different channels. (Bekaert, Harvey, 2002, p.431)

[3] The law of one price states "that two markets are integrated when identical goods or assets are priced identically across borders" (Levy-Yeyati, et al., 2006, p.1).

[4] The home-bias is a situation when investors prefer to invest in local assets, despite such choice might lead to suboptimal portfolio choice. Reasons mentioned for this include uncertainty, transaction, information costs or exchange rate risk.(Fratzscher, 2001)

(ECB, 2007, p.5)[5]. This definition contains the institutional factors and non-discriminatory environment in integrated markets and it also is in line with the law of one price. One important feature of this definition as it is highlighted by Baele, et al. (2004) is that markets can be partially integrated, that is even when some barriers exist - what matters for integration is that they effect the markets in a symmetric way. "Rather, integration is concerned with the symmetric or asymmetric effect of existing frictions on different areas." (Baele, et al., 2004, p.6).

For our purposes we use a rather broad definition of financial integration as *increased openness and subsequent strengthening of linkages between financial markets.* This enables us to examine the developments in co-movements between financial markets and their volatilities. (For example Capiello, et al. (2006, p.7) mention that: "A quite general definition relates market and economic integration to a strengthening of the financial and real linkages between economies" and following this approach they study the co-movements between market returns.) When referring to the results of other studies on financial integration, we do so in a sense of the definition considered in the particular study.

1.1.2 THEORETICAL BACKGROUND OF FINANCIAL INTEGRATION

Financial integration is frequently discussed because of its benefits, its importance for financial stability issues as well as for potential risks. Its monitoring is important for all authorities and institutions whose activities are related to functioning of the financial markets so as to enable them to profit from the benefits and eliminate possible risks. As such for example monetary authorities, whose policies are transmitted through financial markets, are especially active in such monitoring process, as is for example the case of the ECB.

What financial integration does is it changes the conditions, structure and level of development of financial markets. Therefore its benefits extend possibilities of utilizing the functions of financial markets. Among the main ones belong efficient capital allocation, risk sharing, increased possibilities of risk diversification or better possibilities for investments through financial transfers among deficit and surplus capital holders. Financial integration should imply better functioning of financial markets, lower costs of financing capital and better

[5] Baele, et al. (2004) or Komárková (2006) also mention this definition of financial integration.

possibilities for capital transfers, more efficient capital allocation and higher market efficiency.

Market efficiency (in terms of informational efficiency following the efficient market hypothesis (*EMH*)) means, that the asset prices fully reflect all relevant information in the market (for example Samuelson, Nordhaus, 1989, p.981)[6]. As Bekaert and Harvey (2002) mention the emerging markets are in this sense less efficient compared to the developed ones (Bekaert and Harvey, 2002, p.439). Higher information efficiency may therefore also be supported by the financial integration.

Other benefits include increased competition in financial services by creating pressures on their higher efficiency, possibility of inter-temporal consumption smoothing and potential for higher welfare and economic growth (for example Baele, et al., 2004). It is clear that the financial integration can be beneficial for financial markets participants at all levels - investors, firms, individuals and for participating countries as a whole.

- ***financial stability***

Financial integration and its implications on financial stability represent an important dimension of financial markets development. On one hand integration can induce higher stability of a financial system through positive impact on its efficiency (ECB, 2007, p.21).

However financial integration can also have a destabilizing effect on the economy. This stems from the higher openness of financially integrated markets and increased capital flows. Komárková (2006) mentions the following theoretical caveats of financial integration: Concentration of capital and asymmetric access to capital for developing countries (depending on business cycle); controversial benefits of capital inflow for investments if these are not properly invested to lead to long-term growth, potential loss of macroeconomic stability (in form of inflationary pressure, real exchange rate appreciation and current account deficit); pro-cyclical short-run capital flow especially for developing countries (which can arise from asymmetric information for investors and more shocks in these countries, which results in the fact that they are perceived as more risky) or herd behavior, contagion and volatility of capital flows (Komárková, 2006, p.21- 24).

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[6] Different forms of market efficiency are distinguished in the financial markets theory depending on the information that is reflected in the price as strong (all information), semi-strong (publicly available information) and weak (historical information).

The stability of the financial system can be affected by increased free capital flows or fast development in financial innovations. The latter ones can on one hand increase liquidity, facilitate the financial transactions, effective risk sharing and are one of the driving forces behind financial markets globalization as notes Erbenová (2005, p.1). On the other hand these developments can make the financial system more complex and sometimes less transparent as to the risk exposures (such as securitization). A potential danger of increased volatility and financial system destabilization also changes with existing market environment (such as low transparency, or highly leveraged portfolios through derivatives and credit financing) (BD, 2005, p. 61). The increased global linkages in the financial markets make these markets more effective but also make the risks of one market common for the others. In this aspect financial integration is therefore relevant and creates many challenges for policy makers as well as market regulators (Erbenová, 2005).

- ***financial integration and the real economy***

Evidence on the impact of integration is often presented in line with its impact on the real economy.

Brooks, et al. (2003) address in their article the existence and complexity of the links between financial and real economies´ co-movements. They discuss that financial integration may in some cases lead to a decrease in real co-movements due to an increase in the specialization of the countries; on the other hand herding behavior of investors and moving capital flows may increase the real co-movements. Evidence on co-movements of financial markets versus the co-movements in real economies suggest that in advanced countries the synchronization is high for the former ones and lower for the real ones (high correlations for the stock markets and low for the GDP growths between US and other G-7 countries). Authors mention that the financial openness led to increased correlations between financial markets and they also offer some existing empirical evidence that financial markets´ co-movements are driven by the factors from the real economy (international business participation or trade linkages). Convergences in institutional features (such as international norms and regulations) or productivity growth are named as other factors increasing financial markets co-movements. The authors conclude that "…financial integration is still high, and shocks to large financial markets will continue to be transmitted to other countries" (Brooks, et al., 2003, p.49).

Bekaert and Harvey (2002) investigate findings from different research on emerging markets integration. Authors present, among others various aspects of and evidence on links between the real economy and finance following emerging markets liberalization and a process of gradual integration. These include an inflow of foreign capital, decrease in expected returns or increased investments financed by foreign capital. Authors also inform of evidence on real GDP growth following capital market liberalization but not the evidence on increased personal consumption. They remind that the impacts on growth and benefits of integration depend on the state of the economy's development. Moreover they do not find support for increased volatility in economic growth after market liberalizations but rather for the positive impact on growth volatility (decrease) by better risk sharing (Bekaert, Harvey, 2002, p.440).

- ***institutional framework***

As we have already emphasized earlier, financial integration is also closely monitored and supported by monetary authorities[7]. Therefore another viewpoint for the assessment of financial integration can be taken in terms of actions and implementation of common frameworks in the area of financial markets. The support can take the form of creating and encouraging an institutional environment that supports the financial market integration process, international cooperation and smooth cross-border activities of financial market participants.

An example of the integration promoting activities in the European Union (EU) is the so called "Lamfalussy approach". This consisted originally of recommendations for institutional arrangements to promote integration of the securities markets and was later extended to the banking, insurance and investment funds sectors (ECB, 2007, p.38). The four-level concept is based on the assumed improved efficiency and responsiveness of EU legislative process in the area, the consistent implementation of EU directives and convergence in supervisory practices of the EU regulators and efficient enforcement of the EU legislation (Roldan, 2006, p.25-26). Another example of EU integration initiatives is the creation of the Single European Payment System (SEPA) aimed at removing the barriers in Euro area retail banking infrastructure. We do not discuss this issue of financial regulation and supervisory or financial infrastructure integration in detail as it is beyond the scope of our work, for details we

[7] "The ECB fosters European financial integration within its field of competence. A well-integrated financial system contributes to a smooth and effective implementation of monetary policy throughout the euro area and increases the efficiency of the euro area economy. Moreover, a deeper financial integration may have an impact on to the stability of the whole financial system" ECB, <http://www.ecb.int/stats/finint/html/index.en.html>, [cit. 2008-4-7].

refer for example to ECB (2007).

- ***portfolio diversification***

Financial integration can also have important implications for investors in terms of portfolio diversification. Equal access to foreign as to the domestic financial markets implies larger pool of possibilities for diversification. As some authors argue, this may increase the international correlation between the markets and therefore have important implications for portfolio diversification (for example Longin, Solnik, 1995). The portfolio optimization theory suggests, that the agents trade-off risk and return in asset and combine different assets based on their correlations to achieve highest possible returns with minimal risks; the higher the correlation between the assets, the lower the benefit from diversifying the idiosyncratic risk (for example Bannock, Baxter, Davis, 1987, p.318-319).

Imagine the extreme case when full integration would have taken place in all markets and all assets with same characteristics would be perfectly correlated, priced identically and facing all the same common systemic risk. Then the international diversification would loose its meaning because the identity of risk-return profiles would not bring any benefits to the investors. The argument for integration as a factor enabling more diversification opportunities would be limited as the diversification would be possible only between different asset classes or on cross-industry basis. The implications for portfolio diversification are relevant even when we do not consider only our extreme case of identical assets with identical risk-returns profiles. This is because increased correlation between the markets simply changes the possibilities for international diversification. This has further significant implications for portfolio allocation, hedging strategies and risk management.

Correlations of equities markets may increase because of more intensive international activities of national firms profiting from financially integrated markets. Subsequent increases of influence of world/ common factors on these firms may lead to higher correlation between the equities markets as is discussed for example by Longin and Solnik (1995)[8]. Moreover authors also find a positive result related to the argument that the correlation among markets increases when global factors dominate and affect all markets (Longin, Solnik, 1995, p.15).

[8] Authors also find some positive evidence of it. They estimate simple linear trend in correlation coefficient for US and six other developed equity markets. On the data for 30 years they find that the approximate average yearly increase is 0.01. (Longin, Solnik, 1995, p.14)

According to Bekaert and Harvey (2002), the evidence supports the increased correlations between markets following liberalizations, although in theory this does not always have to be the case (such as in the case of structurally different countries that may react differently to various factors (Bekaert, Harvey, 2002, p.434)). The implications of higher integration implying lower possibilities of diversification within the Euro area is also noted for example in Fratzscher (2001).

- ***financial integration and market volatility***

The impact of financial integration on market volatility is rather vague and depends on particular circumstance and other factors affecting each market. Bekaert and Harvey (2002, p.433-434) also mention this point among the findings of research on emerging markets. The argument for increased volatility is for example a case when foreign investors withdraw from these (emerging) markets when they become perceived as more risky, nevertheless evidence does not give clear-cut results. Based on existing research authors indicate that evidence of "equity market liberalizations do not significantly impact market volatility" (Bekaert, Harvey, 2002, p.434). They also suggest that the impact of integration on volatility should be evaluated using measures, which test what portion of the volatility in returns is in fact caused by global factors and which by local factors. Indeed this is the approach used to test financial integration in many of the applied studies (Bekaert and Harvey (1997), Fratzscher (2001) or Baltzer, et al. (2008)).

The determinants that affect market volatility are numerous. The volatility reflects uncertainty about future asset price development. This can be in turn influenced by many factors. It can be the factors specific to the asset (such as firm specific factors) or it can by common market factors such as GDP volatility (financial volatility tends to be countercyclical due to higher risk aversion in recessions) or financial markets developments (BIS, 2006). The report on financial markets volatility patterns (BIS, 2006) presents different factors that have impact on volatility in attempt to identify the low volatility on the financial markets observable between the years 2003 and 2006. Among others, the financial markets structure is identified to be a factor having impact on market volatility. The factors that are identified as contributing to lower volatility and better ability to keep financial stability in recent past few years are especially increased market liquidity, improved financial conditions, expansion of institutional investors and better risk management.

BRIEF SUMMARY

Some, rather general, conclusions from the above presented theoretical framework can be summarized as follows.

Financial integration can bring important benefits for all market participants but is also related to potential risks. Our discussion of some of the implications of financial integration suggests that *integration may have rather a stabilizing effect on the markets* by increasing market efficiency and better risk sharing or smooth monetary policy transmission. This view is also supported by some evidence (Bekaert, Harvey (2002) or BIS (2006)). Moreover the *increased international cooperation* in regulatory standards and supervision could have a stabilizing impact on financial systems. "It is widely believed that the benefits outweigh the costs, provided that mechanisms of controlling for financial stability are implemented". (Babetskii, Komárek, Komárková, 2007, p.3)

With respect to financial stability the theory allows also for destabilizing impact of financial integration. This lies in the increased market openness and capital flows of international markets may lead to herding behavior. The *free capital mobility could have destabilizing effects o financial systems* and subsequently also on real economy. However evidence on this is not clear. We have learned that *we cannot make direct inference between financial integration and financial market volatility* in terms of simple causality relationships.

Arguments can be found that *financial integration has implications on correlation between markets* which in turn can have further implications for portfolio diversification possibilities ("although looking at correlations alone one cannot reach conclusions with regard to market integration" (Longin, Solnik, 1995, p.7)). Higher correlation is also found in periods when markets are more affected by common factors.

We have adopted a broad *definition of financial integration- as increased openness and subsequent strengthening of linkages between the financial markets*. We can argue that stronger linkages between financial markets increase exposure to common risks. (Even more so when markets become more connected for example through large institutional investors and different financial innovations and are facing possible risks of destabilization in case of increased volatility in markets.). We can therefore suggest that financial integration may be accompanied by higher synchronization in the market behavior (for ex. Égert, Kočenda, 2007, p.2).

1.1.3 MOTIVATION AND HYPOTHESIS

The increasing integration represents a motivation to assess the market interconnections and similarities in the patterns of market behavior. Financial integration constitutes a theoretical background for this work. However our study does not aim to measure the speed or degree of integration, we believe that the recent coverage of the topic is quite rich. Our approach is to study the relations between the Czech financial markets and their Euro area counterparts through the dynamics and pattern of conditional volatilities of the markets.

We therefore base our hypothesis on the assumption that stronger financial integration increases the exposure of the individual markets to common factors. We suggest that this may be accompanied by higher synchronization in the market behavior. We use the existing findings on financial integration of the Czech financial markets as groundwork for our analysis and we examine the possible market co-movements and volatility transmissions as an additional perspective on the financial market interdependencies. Volatilities and their transmissions are important for all market participants that are all exposed to financial markets risks. Therefore our approach can be regarded a complementary information to the assessment of linkages between the studied markets.

Specifically in our work we try to answer the following questions: What is the pattern of volatility dynamics of the Czech financial markets and their Euro area counterparts? Is there synchronization between the Czech and Euro area financial markets and are there significant relationships between these markets through their conditional volatilities? What form do the relationships take? Our hypothesis, which we test on the foreign exchange market, equities market and government bond markets, may be formulated as follows:

There are significant relationships between the financial markets of the Czech Republic and the Euro area through their volatility.

In our empirical analysis we also try to identify whether these relationships take the form of volatility spillovers or co-movements. In the empirical part we therefore use the following terms:

We use the term ***volatility spillovers*** for the transmission of volatility *between different* *markets*. (This could also be described as cross-market volatility spillovers). In our approach these spillovers are expressed as the dependence of the conditional volatility in one market at one period on the volatility of the other market in the past period[9]. This will be explained later in the methodology part.

For our purpose we use the term ***volatility co-movements*** in the sense of correlations between the fluctuations in the two markets. In our approach these correlations are changing in time and reflect similarities in the volatility behavior in two markets. As Babetskaia-Kukharchuk, et al. (2007, p.3) argue in the context of foreign exchange markets: "The higher GARCH correlations mean similar behavior of volatility of exchange rates, which can also be interpreted as synchronization of exchange rates´ shocks across countries."

1.2 LITERATURE REVIEW- INTEGRATION & VOLATILITY TRANSMISSION

In this part we try to review some of the recent findings on the achieved level of integration in the Euro area and the Czech Republic that are presented in the recent surveys. The coverage of this topic is very broad and we do not aim to cover all of the studies. We focus on the most recent ones, some other we mention only briefly. We also briefly review literature on volatility transmission to present some of the applied studies on the market interconnections from this point of view.

1.2.1 FINANCIAL INTEGRATION IN EURO AREA AND IN THE CZECH REPUBLIC- REVIEW OF RESEARCH FINDINGS

Below we try to present a broad picture of the achieved level of integration in the Euro area and in the Czech Republic as they are presented in recent surveys. We review some detailed results in the chapters devoted to the empirical assessment of individual markets.

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[9] Therefore the spillovers represent effects of past conditional volatilities and effects of past shocks from other market. For example Balasubramanyan, (2004, p.11) uses the specification of spillover as effect of lagged shocks and co-movements as effect of contemporaneous shocks. However we do not test the impact of contemporaneous shocks from other markets on current volatility in our approach.

The European Central Bank (ECB) follows closely the integration of financial markets in Euro area because of the importance on financial system efficiency and monetary policy implementation and transmission, as we have already emphasized above. The bank publishes regularly a set of financial integration indicators with large scope for different markets segments[10].

In summary, the European financial integration report (ECB, 2007) assesses the financial integration as being dependent on the market segment and being high mainly on the money markets (full in the unsecured money market). High integration is also found in government bonds markets and following Euro introduction also in corporate bonds markets. Stock markets of Euro area are largely affected by common factors suggesting their increased integration. Segmentation is persisting mainly in the area of retail banking markets. The results also point to correlation between the degree of integration in various market segments and degree of integration of the underlying financial infrastructure (ECB, 2007, p.11).

An interesting point that the report makes is on the importance of development of credit risk transfer instruments contributing to the Euro area bonds market integration. This can be seen as an illustration of how financial innovations can increase integration by promoting better functioning and access to credit risk markets. On the other hand the recent troubled behavior on the credit risk markets, such as the US sub-prime mortgage market problems in the past year, uncovered fragilities and risks of this market segment. These range from the complexity of these instruments to difficulties with information on the total exposure of financial institutions´ risk (for example ECB, 2008).

We can see that even highly integrated countries, such as are the Euro area ones do not have all financial markets completely integrated[11]. Nevertheless they are found to be

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[10] To name several of them: cross-country standard deviations of different interest rates of various maturities among Euro area countries, degree of cross-border holdings of short term debt securities or equities issued by euro area residents, share of inter member states payments, large value payment systems, government bond yield spreads for different maturities, investment funds' holdings of equity issued in other euro area countries, Euro area and US shock spillover intensity, banks cross boarder presence and many others. ECB, <http://www.ecb.int/stats/finint/html/index.en.html>, [cit. 2008-4-9].

[11] The London Economics (2002) attempt to quantify the impact that a full European financial markets integration would have on cost of equity and bond finance and the standards of living in EU. With respect to equity markets, the trading costs and the cost of equity capital financing should fall (for the costs of equity the estimated fall should be around 40 basis points). With respect to the corporate bond markets, the study estimates that these will become more liquid and deep and should lead to lower the required credit risk spread. Finally the simulations based on authors´ model show that "result of the combined reduction in the cost of equity, bond and bank finance, together with the increase in the share of bond finance in total debt finance" result in an increase of the EU real GDP and GDP per capita as well as increase in business investment and private consumption as well as total employment. The lowered cost of equity financing is considered to contribute the most to the GDP growth.

significantly more integrated (based on selected integration measure) compared to new EU member states (NMS) as shows the recent study by Baltzer, et al. (2008). The NMS however show signs of increasing financial integration especially after the accession to EU. Authors for example find decreasing dispersion in overnight, 1M and 12M maturities lending rates against Euro area rates. This points to increasing integration with high convergence after 2000. Authors note that the development at the end of their sample (ranges until 2006) is more or less similar to the one of the Euro area countries prior to the monetary union (Baltzer, et al., 2008, p.14).

The effect of the unification process on financial integration is also discussed in the already mentioned work of Fratzscher (2001) in relation to the stock markets. Some positive evidence of the impact of EMU is found. This is for example the importance of Euro area market in explaining individual European market's returns compared to previously dominant US market since mid 1990s. Author also tries to identify the impact of exchange rate stability, real convergence and monetary policy convergence on equity market integration. "It is found that it was in particular the reduction and elimination of exchange rate volatility, and to some extent also monetary policy convergence, that has played central role in explaining the increased financial integration among EMU members.", (Fratzscher, 2001, p.7).

Comprehensive picture on the integration of four new EU member states (EU-4) including the Czech Republic is offered in the study of Komárková and Komárek (2008)[12]. Authors present an assessment of integration of the Czech foreign exchange market, money market, credit market, bonds and equity markets. Their analysis uses various methods of measuring financial integration to assess the state and dynamics of integration of Czech Republic[13]. Some of their main conclusions (Komárková, Komárek, 2008, p. 129 -133) on the various segments of financial markets are summarized below.

The Czech and Euro *foreign exchange markets* are found to be to large degree aligned as is found using various methods of measurement, the speed of convergence is found close to

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(London Economics, 2002, p.1-6)

[12] The study follows the previous work of the author Komárková (2006) that we also quote in our work. The other countries that the authors study are Hungary, Poland and Slovakia.

[13] Analysis of alignment, beta and sigma convergence using regression methods, state space models and panel regressions and additional methods such as GARCH and EGARCH volatility models, news based measures. The beta convergence is used as a measure for speed of convergence; the sigma convergence expresses the degree of existing integration among the countries.

the ideal value and the variability in the exchange rate pairs CZK/USD and EUR/USD as quite low and continuously decreasing since EU accession. Using the speculative efficiency concept authors find negative results (that is the forward exchange rates are not reliable predictors of the spot exchange rates for the studied countries).

For the *money markets* authors stress that their development strongly reflects the monetary policy rates settings. They find that degree of integration for the Czech Republic is relatively high since already 2001. The *credit market* developments do not bring clear-cut results. The Czech Republic seems to be aligned with the Euro area in terms of interest rate differential on lending and borrowing rates, however, the speed of integration is suggested as very low and the sigma convergence even shows divergence of the Czech market from Euro zone.

The *government bond market* is found to be highly integrated. This is confirmed in the Czech case (for 10-year government bonds) by high degree of correlation with German bonds (used as a benchmark for Euro area). The speed of integration showed a slowdown after EU accession, which is in line with the very high level of integration reached by the Czech bond market. Finally the *stock market* integration suggests some positive development especially after EU accession. The correlations among the returns with Euro zone are around 0.5. The speed of integration is found to be higher in the period after 1999, which is in line with convergence process. The sigma convergence analysis (degree of integration) indicates divergence between the Czech stock index and the Euro zone benchmark (visible since the EU accession). As authors note this reflects the fact that the EU enlargement was followed by the growth in the new member states´ markets, which did not happened in the Euro zone market. The analysis evaluating the impact of common EU market "news" shows that these have an important impact on the Czech stock market development.

The Czech National Bank (CNB) in the analysis of Czech Republic's economic alignment with the Euro area (CNB, 2007) provides, among others, an assessment of the situation on financial markets and of the level of financial integration of the Czech Republic with respect to Euro area. The methodology applied is similar to the one in Komárková, Komárek, (2008) and the results bring similar findings[14]. Results of some other studies related

[14] Financial integration is assessed using the beta and sigma convergence. The integration is studied on different

to the Czech markets financial integration with the European countries are discussed in details in the chapters related to empirical analysis of the individual markets.

1.2.2 VOLATILITY TRANSMISSION

We now present some of the works that relate to volatility developments and patterns of volatility transmission across markets. We do so as to bring closer the aim of our empirical study in which we examine the possible market co-movements and volatility transmissions as an additional perspective on the financial market interactions.

Volatility transmission literature is often motivated by examining the spillovers between markets and contagion effects that increase the market linkages during a crisis compared to the calm periods. The attention in literature has often been given to the spillovers in the foreign exchange markets (Colavecchio, Funke, 2006 or Kearney, Patton, 2000) or between equity markets. Other area of application is on different market segments or industry sectors with the focus on implications to portfolio diversification and hedging strategies (for example Hassan, Malik, 2007).

Kearney and Patton (2000) examine the volatility transmissions of exchange rate volatility in European states between 1979 and 1997, that is prior to the monetary union. They apply the multivariate GARCH techniques on exchange rate volatility of European currencies (German mark, French frank, ECU, Italian lira and British pound) using different subsystems of three, four and five variable models on both daily and weekly data. One of their interesting finding is that while on the daily data there can be found significant interactions between volatilities, when aggregated to weekly data the currencies show almost no transmission of volatility.

Authors identify different patterns of transmissions of volatility, either direct (through

market segments for various EU countries, with respect to Euro area (EU-12). The results for the Czech Republic show that the *speed of convergence* is high especially in the bond market (5-year government bonds) and the foreign exchange market, on which it has been moderately increasing in the course of time. Results for the stock market show an increasing speed of convergence when comparing periods 1995-2000 and 2000-2007 (-0.74 against -0.89, closer to -1 means higher speed of convergence). The lowest speed of convergence is identified in the money market compared to other markets as well as to other countries.
The results for the *degree of integration* that has been reached (sigma convergence) suggest the downward trend of the sigma convergence, which points to an increasing degree of integration of all except the money market. (This trend is observable since the announcement of EU enlargement in December 2002), (CNB, 2007, p.40-43).

past volatilities) or indirect (through covariances) between exchange rates. Some of the relationships they identify are in both directions (such as transmission and reception of volatility of ECU to German mark and vice versa) and some only in one direction such as the French franc receiving volatility from ECU but not transmitting it[15]. Based on different model specifications they suggest that the German mark played a dominant role between the other currencies studied (ECU, French frank, British pound and Italian lira). It did not receive directly any volatility from the other currencies; rather its volatility is affected by co-movements with other currencies. Their work gives an example of the complexity of the mutual volatility transmission that may be transferred by different channels.

Colavecchio and Funke (2006) evaluate the dependence between Chinese exchange rate and seven other Asian countries exchange rates through their volatility. Authors try to estimate whether the markets are related through their volatilities and whether there is correlation between the individual exchange rates and the dominant Chinese one[16]. They argue that co-movement between markets may arise when information from price changes in one markets is used to evaluate the price on another market and so the two markets that used the same information move together. They find positive correlation of all the markets with respect to Chinese exchange rate and similar pattern in the dynamic correlation following the speculative attacks on some of the Asian currencies in 1997 (the conditional correlations firstly dropped and then rose sharply). Despite the evidence they however remind that "testing the hypothesis that conditional correlations increase in volatile times is …a difficult exercise due to potentially spurious relationship between volatility and co-movements.", (Colavecchio, Funke, 2006, p. 21).

The patterns in the Asian market currencies´ correlations indicate some differences in terms of magnitude and strength of the relationship for different countries[17]. Authors therefore try to evaluate the underlying factors behind these co-movements. The trade openness is found as one of factors increasing correlations between the exchange rate market returns. Financial integration, which they approximate by the degree of financial openness (as total foreign direct

[15] Illustrations were taken from their three variable model. The different model specifications show lead to different conclusions as to the transmissions of volatilities, the caution must be taken in making any conclusions.
[16] Authors use for their analysis the non-deliverable forward exchange rate contracts. Their methodological approach is constant and dynamic conditional correlation GARCH model.
[17] Such as very low conditional correlations between Malaysia and China and stronger ones between Hong-Kong and China.

investments (FDI) and bilateral FDIs) is found as associated with higher degree of co-movements between the exchange rates. Finally their tests on the dependence of the observed correlations and the exchange rate regimes do not provide clear results.

In the following chapter we address some of the existing approaches to measurements of market linkages such as financial integration to which we referred as well as the methodology of the GARCH (General Autoregressive Conditional Heteroskedasticity) models that we use for the assessment of volatility spillovers.

CHAPTER I.2: APPROACHES TO MEASURING INTEGRATION AND VOLATILITY TRANSMISSIONS

As we have already mentioned, ambiguity exists in defining financial integration. This is reflected in the different approaches to quantification or measurement of integration, which depend on the way each author defines the integration. Different measures are also applied to different markets according to the possibilities of measurements or international comparisons. For example if the law of one price can be applied to assets, these can be compared directly[18].

In what follows, we first review some of the different approaches that can be taken to evaluate financial integration. We have already emphasized earlier that our approach is to offer additional perspective by evaluating the market interconnections through their volatilities. Therefore the second part of this chapter focuses on methods of evaluating these relationships. We discuss some issues related to volatility and subsequently the motivations of its measurement using GARCH family of models. We conclude this chapter by the model formalization.

[18] As we have mentioned the law of one price assumes that identical assets should be traded for an identical prices irrespectively their location. However the problem remains of identifying two "identical" assets.

2.1. APPROACHES TO QUANTIFICATION AND MEASUREMENT OF FINANCIAL INTEGRATION

Baele, et al. (2004) summarize and discuss set of financial integration measures that they classify in three broad categories: *price based, news based and quantity based measures*. Their framework is based on asymmetry of the effects with which market frictions affect the individual regions[19]. It is assumed that the frictions are reflected in the information that is incorporated in the equilibrium prices and the assumption that the law of one price holds enables to construct the different financial integration measures (Baltzer, et al., 2004, p.11). In our study, we do not measure the degree or speed of financial integration; however we often refer to other works (such as the different ECB studies, Komárková and Komárek, 2008 or CNB, 2007), who also use these integration indicators. Therefore we find it convenient to present the main categories briefly. We use the work of Baele, et al. (2004) and Baltzer, et al. (2008) as reference and for completeness we also present the formalization of the main indicators in the Box AI.1 in appendix to this chapter.

Price based measures include indicators that either directly compare prices and yields on assets from different regions or the measures adjusted for the different characteristics of the assets (such as risk factors). Among this class of measures belongs for example the *β-convergence* or *σ-convergence*. The *news based measures (*such as *variance ratios)* are based on the idea that integrated markets should be to high extent influenced by common factor, while the local factors should have little or no significance. In integrated markets the local shocks should be diversifiable away and so (ceteris paribus) the higher the degree of integration, the greater portion of the price variation expressed by global factors. *Quantity based measures* depend on the considered market segment and include for example cross border activities or structure of portfolio holdings related to home bias.

Number of applied literature is based on expressing the financial integration in terms of *proportion of variance in market returns that is driven by common or global shocks* and is often combined with modeling volatility using the GARCH models[20]. For example Bekaert and Harvey (1997) argue that “increasing influence in world factors on volatility in some countries is consistent with increased market integration” (Bekaert, Harvey, 1997, p.2). Authors apply

[19] Authors adopt definition as presented in previous part for ECB.
[20] Among these we can name for ex. the mentioned news based measures as applied in Baltzer, et al. (2008).

the concept in a model in which conditional mean and variance equations depend on local and global factors and they permit dynamics in these influences.

Similarly Capiello, et al. (2006) use an approach to measuring integration that is also based on the proportion of variance in returns explained by common factors. They argue for use of this measure on the ground that the law of one price cannot be applied to measuring integration of asset returns, because of their heterogeneity. But as they say the impact of global shocks and exposure to common factors is higher in integrated markets. "In the broader economic sense … increased integration induces stronger cross-market linkages, increased exposure to common factors and reduced impact of local shocks." (Capiello, et al.,2006, p. 11)[21].

Fratzscher (2001) mentions different approaches for measuring financial integration, based on interest rate parity conditions or using capital asset pricing model (CAPM). The financial integration measured using the CAPM is used to express the excess returns on a local asset (or portfolio). Under the full integration the local risk premium should be null and returns on a local asset should be affected only by the global risk. The uncovered interest rate party is presented to test for financial integration in money markets as a definition for financial integration that "measures a 'country premium' … and allows for an 'exchange rate risk premium'" (Fratzscher, 2001, p.8). As author notes, the latter one is often considered to be the main factor that causes departure from this condition in developed countries. This would be in line with the findings mentioned earlier with respect to the Euro area, where the unsecured money market is found as fully integrated, suggesting that the country premium does not present a barrier to integration in this market segment.

The approach to integration Fratzscher (2001) adopts measures the extent of transmission of shocks across equity returns across markets. The author stresses the need to account for changes in integration over time when trying to model it and also the need to distinguish between different factors that may be behind these changes (such as real and financial convergence, phase of business cycle or exchange rate risk). The degree of integration is therefore expressed in his model as the sensitivity of local returns to global shocks[22].

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[21] Their integration indicator therefore expresses the degree of variance of an asset return expressed by common shocks. As they show it is analogous to the correlation coefficient between the asset returns in the two markets. If on two markets the portion of returns´ variance explained by global factors increases, the correlation between the returns increases.

[22] Author constructs the integration measure using a model that accounts for country specific factors as well as

CORRELATION

One of basic indicators of strength of a relationship between two variables (such as two markets) can be expressed in terms of their *correlations.* Simple correlation between two variables expresses the linear relationship between them. Limitations of using a simple correlation coefficient can be that it is constant and therefore does not capture the dynamics in the relationship and that it does not indicate other then linear relationship between variables (for ex. Komárková, Komárek,2008). A correlation analysis between markets, using both static and rolling correlation coefficient, is applied for example in Komárková and Komárek (2008).

A coefficient of correlation can be formalized as:

$$corr(X,Y) = \frac{\operatorname{cov}(X,Y)}{\sqrt{\operatorname{var} X}\sqrt{\operatorname{var} Y}} \ ,$$

where cov(X,Y) is the covariance between variables X and Y, and √varX and √varY denote the standard deviations of variables X and Y.[23] The correlation gives the strength of the relationship. The highest possible correlation is one (perfect positive correlation when the two variables behave identically one with the other in the same direction); the lowest is minus one (perfect negative correlation, when two variables move exactly in the opposite direction). When correlation is zero that means there is no linear relationship between the variables.

2.2. MODELING VOLATILITY AND VOLATILITY TRANSMISSIONS

This part deals with the theoretical background of methods used in our empirical exercise. Our approach is based on our definition of financial integration in a broad sense as increased openness and subsequent strengthening of linkages between financial markets in different countries. As we have emphasized earlier, we do not aim to measure the degree of or the speed of integration. Rather we want to extend the findings of recent research on Czech

global returns and their correlation with the local ones. Moreover the tendency of negative shocks to affect returns more than the positive ones is also introduced in the model. Their model of the conditional mean returns incorporates the excess returns based on local and global fundamental variables and innovations that are based on regional shocks, global shocks and a specific innovation component with a conditional heteroskedastic variance. For formalization we refer to Fratzscher (2001, p. 10-13).

[23] The covariance is the measure that expresses the relationship between the variables. When it is zero, the two variables are independent. When it is positive, then higher values of one variable are associated with higher values of the other, when covariance is negative, the higher values of one variable are associated with lower values off the other variable.

financial markets integration for describing the behavior of the returns´ volatilities and their linkages with their Euro area counterparts. We are more specifically interested in the development, relationships and interactions between volatilities on the foreign exchange, equities and bond markets.

To investigate the patterns of volatility behavior in the Czech and Euro area markets we first model volatility on each of the markets individually using the GARCH (*general autoregressive conditional heteroskedastic*) family of models. We are also interested in existence of volatility transmissions as spillovers and co-movements between these markets. To examine these relationships and to test or hypothesis we use the multivariate GARCH model, namely its BEKK specification[24].

We first present the GARCH models and some arguments for their convenience for volatility modeling. Further, we discuss the multivariate GARCH in the context of application to volatility spillovers as it is often used in literature. Finally we turn to formalization of the model. We first introduce the univariate GARCH and then we turn our discussion to the multivariate version of the model, namely the bivariate BEKK-GARCH. The model description aims to highlight main features of the models as they serve as a main tool for our empirical analysis. Obviously, it is not our goal to present an exhausting econometric background behind these estimations. We based this discussion mainly on the literature by Brooks (2002), Engle (2001, 2003), Enders (2004) or Bauwens, et al. (2006).

Before moving to the discussion on the volatility modeling we want to briefly discuss some important features concerning volatility and its dynamics. We focus on the case of volatility with regard to the financial markets.

2.2.1 VOLATILITY

Volatility is a crucial concept in financial markets as it is a measure of risk and of uncertainty on future development of asset return. "The term volatility describes the extent to which asset prices fluctuate over a given period" (DB, 2005, p.60).

Firstly volatility reflects some level of fluctuations in prices that happen due to arrivals

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[24] BEKK stands for Babba, Engle, Kraft, Kroner.

of new information that leads to re-adjustment of the prices (for ex. DB, 2005), such as because of changes in the underlying determinants of the asset prices. The uncertainty about these fluctuations in the future is central for investors because it determines the risk to which they are exposed to. The risk consists of the extent to which the returns will deviate from their expected value; therefore the simple measure of volatility is a variance or a standard deviation of returns from their expected value.

Volatility as a measure of risk is therefore crucial for risk management and different financial applications. It reflects the level of risk in terms of uncertain future returns and affects expectation about possible future price development. As the volatility changes in time the ability to forecast is then central in all areas of risk management and financial applications.

Moreover volatility also reflects changes in perception of risk in the market, such as increased nervousness as it is discussed for example in DB (2005). When new information brings large unexpected changes in asset returns and act as shocks to the market (especially the negative ones) this may cause many problems. Apart from the fluctuation in the price or return they cause, these shocks can change the perception of risk on the market and risk aversion of market participants. The assessment of the prices after new information arrives can therefore be skewed by the prevailing negative sentiment and high volatility may persist. The large shocks that impact whole markets and that trigger high volatility (which tends to persist) may destabilize the markets and in severe cases the whole financial systems which may have further consequences to real economy (DB, 2005). Therefore excess volatility of financial markets is also important with regard to financial stability.

As we said the volatility reflects uncertainty about future asset price development. This can be in turn influenced by many factors, either by the factors specific to the asset (such as firm specific factors) or by common market factors. The already mentioned report of the Bank for international settlements (BIS, 2006) that tried to identify different determinants of low volatility on the financial markets in past years specifies a large number of factors that impact volatility. We review some of the factors presented in the report below.

Firstly it is the *real factors* that may affect the level of volatility (such as volatility of GDP growth, changes in real interest rates or expected inflation) reasoning that volatility tends to be countercyclical, which is reinforced by higher uncertainty accompanying periods of recessions. *Firm level characteristics* such as high leverage and uncertainty about profitability work in direction to increase stock price volatility. The developments in financial markets also contribute to the level of volatility. The *improved liquidity* is recognized as one of crucial financial factors contributing to lower volatility. Market liquidity is supported by financial innovations (new instruments, improved risk management) and activity of financial institutions (expansion of institutional investors, better informed, more frequent trades or activities of hedge funds). Although the financial factors may have a positive effect on lowering volatility, they may also increase it representing a danger in herding behavior and high leverage, an issue that we already mentioned earlier. Finally volatility may be affected by *monetary policy*. It could happen directly through the impact on short term interest rates and by improving market confidence in a stable and transparent environment. It may also be indirectly through the impact of monetary policy on inflation, real interest rates and the stability of GDP growth.

2.2.2 GARCH MODEL- A MOTIVATION

It has been documented that the volatility is not constant in time and it tends to appear in clusters. Among other stylized facts for many financial series is the fat-tailed (leptokurtic) distribution, which means that the extreme values in the series (higher losses or gains in returns) are more common (especially in periods of high volatility) than for the density of normal distribution[25]. The leverage describes the asymmetry of volatility, which tends to be higher for downward movements in asset prices then for the upward ones.

There are several approaches to volatility modeling. It can be estimated e.g. using historical volatility or exponential weighted moving average methods; derived from an option pricing formula as the implied volatility or estimated using the stochastic volatility models and other methods (Brooks, 2002). The prevalent method of modeling volatility, especially in the application to finance is the family of ARCH models (*autoregressive conditional heteroskedasticity),* which was introduced by Robert Engle in 1982. Few years later, in 1986 a generalized form of ARCH was developed by Bollersev and is known as *general autoregressive conditional heteroskedasticity*, GARCH model (Engle, 2003). It is one of the most common extensions of ARCH model and we will apply it in our empirical analysis. The ARCH and GARCH models conveniently capture some important features of financial time

[25] In statistical terms kurtosis measures whether a distribution is more peaked than the normal distribution. The leptokurtic distribution is a one with higher kurtosis.

series characteristics[26]. The idea of the models is to make more realistic models and forecasts of volatility by imposing a non-linear[27] structure on the conditional variance, which is time-varying (heteroskedastic).

GARCH models are a convenient tool to handle the modeling of volatility of financial series because the key idea of the approach is to capture the dynamics in volatility. This enables to adjust the forecast in line with this dynamic structure and make it therefore more realistic. "The GARCH forecast variance is a weighted average of three different variance forecasts. One is a constant variance that corresponds to the long run average. The second is the forecast that was made in previous period. The third is the new information that was not available when the previous forecast was made" (Engle, 2003, p.329).

To be able to evaluate and forecast volatility it is important to see how it behaves over time. As we have mentioned, among the observed facts of financial time series is that returns tend to change periods of high and low variance. The fact that the variance in asset returns and other financial variables is changing over time (*heteroskedasticity*) reflects changing perception of risk and different phases of volatility in the market.

Moreover the shocks tend to be persistent and volatility tends to appear in clusters. This means that large changes in returns are usually followed by large changes. Variance that is changing in time based on its pattern in the past is referred to as *conditional heteroskedasticity*. This means that the level of volatility is changing, conditional on the level of volatility in the previous period (e.g. Brooks, 2002).

We try to illustrate this on an example. Imagine that a market experiences an unexpected large negative shock, for example a terrorist attack. The asset prices drop and deviate from their long term path (which we can assume were determined by the fundamentals) and the volatility increases as the market reevaluates the risk, which becomes suddenly higher. The increased market uncertainty may lead to higher risk aversion, larger price movements and persistence of the shock in the market for some time period. The price fluctuations may return

[26] As an example, Enders (2004) presents as some of these features as trends in series, meandering pattern, possible long time persistence of shocks, co-movement with other series, volatility that is typically not constant in time but depends on past realizations and past shocks or that periods of high volatility are followed by high volatility.

[27] By non-linear structure is meant that the variable (in case of GARCH the conditional variance) is a non-linear function of other explanatory variables.

back to some average, long-run level, reflecting the natural adjustment to news that is no more affected by the market nervousness from the shock.

Therefore the dynamic approach to forecasting volatility that captures these facts should be taken to make volatility forecasts more realistic. An investor who evaluates his risk exposure for the following period takes into account some average level of risk (the long-run, unconditional volatility) and when volatility is changing, the changing market conditions should also be reflected in his expectations. The conditional volatility incorporates on top of the long-term average volatility also the past shocks. It is therefore a very useful concept for investor who is evaluating the dynamics of volatility in the short time or over certain holding period, based on the information that he already has about the past.

As an example of GARCH application that is also relevant for the case of the Czech Republic we refer to Fidrmuc and Horváth (2008) who apply the GARCH model to study volatility of exchange rates for several EU NMSs between 1999 and 2006. Authors examine the behavior of exchange rate in relation to the implicit target zones and asymmetry effects in exchange rate volatility in countries that adopted inflation targeting regimes including the Czech Republic. Authors examine the behavior of exchange rate volatility and its dependence on a distance from the implicit exchange rate target. GARCH model is applied to test the conditional volatility behavior. Their results suggest that for all the countries under study, the persistence of shocks in volatility is quite high and that the distance from the implicit target rate does not decrease the conditional volatility, but on the contrary tends to increase it. Moreover authors use threshold ARCH (TARCH) model to check whether the exchange rate volatility behaves asymmetrically. They present arguments for possible asymmetry in volatility of the exchange rates (for example observed different volatility behavior of assets prices in case of their downward and upward movements or possible disproportion in central banks actions during phases of exchange rates appreciation and depreciation). Among their findings is that when the exchange rate appreciates against the target value, with the increasing distance the volatility increases.

Their work demonstrates large possibilities of applications of GARCH modeling of financial variables, including extension to asymmetric behavior.

2.2.3 MULTIVARIATE GARCH - A MOTIVATION

Our aim is to identify common relationships and interactions between the volatilities of the different markets returns. Therefore we are interested in modeling the market returns volatilities as well as their covariances and correlations. We want to estimate the volatility spillovers to evaluate on direct dependence between the volatilities of the two markets for which we apply the multivariate GARCH model. This is because as the theory as well as empirical evidence suggests, there exist volatilities transmissions between different markets. Multivariate GARCH models represent a mean to estimate the time-varying conditional variances as well as the conditional covariances between two variables (for example Brooks, 2002). Some examples of empirical applications of different specifications of multivariate GARCH models are named below.

The application is found among others for example in already mentioned studies of Kearney and Patton (2000) who use different specifications of the BEKK-GARCH[28] model to study the transmissions of volatility simultaneously between three, four and five exchange rates. Karolyi (1995) applies the BEKK-GARCH method to evaluate short-run relationships in returns and volatilities between USA and Canadian stock markets. The authors stress that the convenience of the multivariate GARCH approach is that it enables to study simultaneously the relationship between the market returns and incorporate the dynamics of conditional volatility and the impact of possible contemporaneous volatility transmissions that may be present.

In the already mentioned work of Colavecchio and Funke (2006), authors use the Dynamic conditional correlation (DCC) and constant conditional correlation (CCC) version of the GARCH model to identify possible volatility spillovers and market co-movements. Worthington and Higgs (2004) use a BEKK multivariate GARCH to assess mean and volatility spillovers in Asian markets. Hassan and Malik (2007) use the multivariate GARCH approach to study transmission of volatilities between USA sectors in relation to portfolio optimization.

In relation to the Czech markets the applications of multivariate GARCH techniques are found in works of for example Égert and Kočenda (2007) who test the hypothesis of higher synchronization between different European stock markets on intra day data using GARCH

[28] The specific parameterization was proposed by Engle and Kroner in 1995 and the BEKK stands for Babba, Engle, Kraft, Kroner (Bauwens, et al. 2006, p.83.)

model (DCC-GARCH). Babetskaia-Kukharchuk, et al. (2007) apply the bivariate BEKK-GARCH model on exchange rate pairs of four EU NMS to evaluate the similarity of the currencies behavior to the Euro. Based on the estimated time-varying conditional variance and covariance processes they construct the dynamic correlation coefficient to assess the relation between the volatilities. As we have already quoted: "Higher values of GARCH correlations mean similar behavior of volatility of exchange rates, which can also be interpreted as synchronization of exchange rates´ shocks across countries" (Babetskaia-Kukharchuk, et al., 2007, p.3). In line with their approach we also try to identify the synchronization between the movements in the respective conditional volatilities[29].

2.2.4 GARCH and MULTIVARIATE GARCH MODEL- FORMALIZATION

We now turn to the formalization of the GARCH model. However as we have emphasized earlier, it is not our goal to present an exhausting econometric background behind these estimations. In the formalization and properties of the GARCH model follow Brooks (2002), Enders (2004), Bauwens, et al. (2006), Engle (2001) and Arlt, Arltová (2007).

GARCH MODEL

We assume that the random variable of interest y_t can be specified using the following representation:

$$y_t = \mu_t + \varepsilon_t \qquad \text{(I.2.1)}$$

where the term μ_t is the conditional mean of y_t and the new information formalized by ε_t (the error term). By conditional we mean that variable depends on past realizations up to time *t-1* or more generally on set of relevant information available at time *t-1* that we denote I_{t-1}[30]. We can therefore write the conditional mean of y_t as $\mu_t \equiv E(y_t \mid \mathrm{I}_{t-1})$[31].

For illustration we can assume y_t as the following process:

$$y_t = \Phi y_{t-1} + \varepsilon_t \qquad \text{(I.2.2),}$$

[29] However the economic interpretation of multivariate GARCH has to be done with caution as "volatility co-movements should not be interpreted as a direct causal relationship" (Colavecchio, Funke, 2006, p.23).
[30] Information set I_{t-1} generated by the process $\{y_t\}$ until time t-1, for ex. Bauwens, et al., 2006, p.80.
[31] By the notation E(•) we denote the expected value of the variable.

where $|\Phi| < 1$ so that the process y_t is stationary and the term ε_t is specified as:

$$\varepsilon_t = \nu_t \sqrt{h_t} \qquad \text{(I.2.3)}$$

where $\{\nu_t\}$ is a white noise process[32] with zero mean $E(\nu_t) = 0$ and variance $\text{var}(\nu_t) \equiv \sigma_\nu^2 = 1$. So for the process $\{\varepsilon_t\}$ it holds that it has zero conditional mean and time-varying conditional variance h_t. We formalize this as $E(\varepsilon_t \mid \text{I}_{\text{t-1}}) = 0$ and $\text{var}(\varepsilon_t \mid \text{I}_{\text{t-1}}) = E(\varepsilon_t^2 \mid \text{I}_{\text{t-1}}) = \sigma_t^2 \equiv h_t$.

In the ***GARCH (p,q)*** specification, ***the conditional variance of {ε***

$$h_t = \omega + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{q} \beta_i h_{t-i} \qquad \text{(I.2.4).}$$

The p and q in equation (I.2.4) denote the number of lags of conditional variances h_{t-i} (or GARCH terms (q)) and the squares of the past errors ε_{t-i}^2 (or ARCH terms (p)). If we assume the distribution of ν_t conditional on I_{t-1} to be normal with zero mean and unit variance ($\nu_t \sim \text{N} \mid \text{I}_{\text{t-1}}(0;1)$), then the error ε_t will be also be conditionally normally distributed with $\varepsilon_t \sim \text{N} \mid \text{I}_{\text{t-1}}(0, \text{h}_\text{t})$.

In practice, the most frequently used specification of the model is the GARCH (1, 1) form that specifies the conditional variance only by the constant ω and first lags of past conditional variances and squared error terms, that is one ARCH term ($p=1$) and one GARCH term ($q=1$). For further illustration we use this basic form of the model, **the GARCH (1,1)**:

$$h_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} \qquad \text{(I.2.5).}$$

The conditional variance h_t is restricted by <u>*non-negativity conditions*</u>, which hold if the assumptions on parameters: $\omega > 0$, $\alpha_1 \geq 0$ and $\beta_1 \geq 0$ are fulfilled[33]. The unconditional first two moments of ε_t^2 are the zero mean $E(\varepsilon_t)=E(\nu_t\sqrt{h_t})=0$ and for the GARCH (1,1) case the

[32] The white noise process is defined as a sequence of uncorrelated stochastic variables, identically distributed with zero mean, constant variance and zero autocovariances for all lags (Arlt, Arltová, 2007, p.29).

[33] In case of GARCH (p,q) the non-negativity constraints are $\omega>0$, $\alpha_i \geq 0$ for i=1,….,p and $\beta_i \geq 0$ i=1,…,q.

unconditional variance is given as $var(\varepsilon_t)=E(\varepsilon_t^2)=\omega/(1-(\alpha_1+\beta_1))$[34]. So for the GARCH (1,1) process to be <u>*stationary*,</u> it must hold that $\alpha_1+\beta_1<1$.[35]

The relation of the conditional variance in (I.2.4) or (I.2.5) with our dependent variable y_t is through the equations (I.2.2) and (I.2.3). The conditional variance of the process $\{\varepsilon_t\}$ is also the conditional variance of $\{y_t\}$,

$$\mathrm{var}(y_t \mid \mathrm{I}_{t-1}) = \mathrm{E}((y_t - \mathrm{E}(y_t))^2 \mid \mathrm{I}_{t-1}) = \mathrm{E}((\mathrm{y}_t)^2 \mid \mathrm{I}_{t-1}) = \mathrm{E}((\varepsilon_t)^2 \mid \mathrm{I}_{t-1}) = h_t\,.$$

As Enders (2004) notes, the fact that the conditional variance of error terms follows an ARMA[36] process makes it possible to use the identification of the GARCH order using the autocorrelation of squared residuals. We can express ε_t^2 in terms of an ARMA(1,1) process as:

$$\varepsilon_t^2 = \omega + (\alpha_1 + \beta_1)\varepsilon_{t-1}^2 + e_t - \beta_1 e_{t-1} \qquad \text{(I.2.6).}$$

The last equation follows from putting $e_t = \varepsilon_t^2 - h_t$ and $\varepsilon_t^2 = \omega + \alpha_1\varepsilon_{t-1}^2 + \beta_1(\varepsilon_{t-1}^2 - e_{t-1}) + e_t$ .The same logic would apply for higher order GARCH. It is also visible from equation (I.2.6) that the larger is the sum of the parameters $\alpha_1+\beta_1$, the higher is the responsiveness of ε_t^2 to its lagged values. We can see that if the stationarity condition $\alpha_1+\beta_1<1$ didn't hold the impact of the past explanatory variables on current conditional variance would be explosive.

The equations (I.2.4) and (I.2.5) show the logic behind the volatility forecasts by GARCH model as we emphasized it earlier in the motivation for the use of GARCH. The dynamic pattern of the conditional variance is formulated by adding the past shock or information to the past period's variance forecast and to a portion of a long-run constant variance expressed by $\boldsymbol{\omega}$. Each of the parameters then has an obvious interpretation and shows the responsiveness of the conditional variance; the parameter $\boldsymbol{\alpha}$ determines how strongly the

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[34] The moments describing the process $\{\varepsilon_t\}$ (given by equation (I.2.3)) are therefore the unconditional mean $\mathrm{E}(\varepsilon_t)=\mathrm{E}(v_t\sqrt{h_t})=0$ and the conditional mean $\mathrm{E}(\varepsilon_t|I_{t-1})=\mathrm{E}(v_t\sqrt{h_t}|I_{t-1})= 0$, given the assumption of $\mathrm{E}(v_t)=0$. The unconditional variance of the $\{\varepsilon_t\}$ process is constant and depends on the parameters of h_t. For the GARCH (1,1) case we get $\mathrm{var}(\varepsilon_t)=\mathrm{E}(\varepsilon_t^2)=\omega/(1-\beta_1-\alpha_1)$. The autocorrelation functions of the error terms are all equal to zero: $\mathrm{E}(\varepsilon_t\varepsilon_{t-j})=\mathrm{E}(v_t\sqrt{h_t}v_{t-j}\sqrt{h_{t-j}})=0$ for $j\neq 0$ which follows from h_t, v_{t-j} and h_{t-j} do not depend on value of v_t and $\mathrm{E}(v_t)=0$ (Enders, 2004, p.133).

[35] For the GARCH (p, q) process to be stationary it must hold that $\Sigma\alpha_i + \Sigma\beta_j<1$, i=1,…p, j=1…q

[36] ARMA (p,q) stands for Autoregressive Moving Average of autoregressive terms up to lag p and moving average terms up to lag q.

conditional variance reacts to new information while the parameter $\boldsymbol{\beta}$ shows the effect of past conditional variance on the current one. The conditional variance of this periods´ new information ε_t thus incorporates the information that was new in the last period *t-1*. The higher the past shocks will be, the more effect they will have on the current conditional volatility. This explains the volatility clustering in the financial data, as the effect of the past shocks persists to the current period.

The estimation of GARCH consists of estimating the mean equation (I.2.1) and the estimation of the variance equation (I.2.4) of the error terms (I.2.3) to get the parameter estimates of ω, α_1 and β_1. The GARCH models are estimated by the *maximum likelihood method*. This consists of maximizing the log-likelihood function *(LL)*. For the case when we assume the normal distribution of errors *LL* has the form:

$$LL = -\frac{T}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\ln h_t - \frac{1}{2}\sum_{t=1}^{T}(y_t - \mu_t)^2 / h_t \qquad \text{(I.2.7)},$$

where T is number of observations. Substituting the specific form for h_t and μ_t (for example as in I.2.5 and I.2.2 respectively, $h_t = \omega + \alpha_1\varepsilon_{t-1}^2 + \beta_1 h_{t-1}$ and $\mu_t = \Phi y_{t-1}$) this function *LL* can be maximized with respect to the parameters of these equations (for example Enders, 2004). The values of parameters maximizing the log likelihood function are then the required estimates of the conditional variance equation parameters, such as $\hat{\omega}, \hat{\alpha}_1, \hat{\beta}_1, \hat{\Phi}$.

Other assumptions on the *conditional distribution* of the error term ε_t can also be taken, such as for example the Student t-distribution. When this is the case, the log-likelihood function as specified in (I.2.7) has to be adjusted to account for this change. For details on the forms of LL we refer for example to QMS, (2004, p. 588) as this is beyond the scope of our work. Finally various *diagnostic checks* can be performed to test the appropriate specification of mean and the conditional variance specification. We discuss these later in the methodology part. The residuals of the mean equation should be white noise. To check this, Ljung-Box test can be performed. If the mean equation is well specified, the null hypothesis of no correlation in the residuals is not rejected. The squared residuals should not be correlated. The ARCH-LM test can be used to identify whether there are any remaining ARCH effects present.

We tried to present briefly the GARCH model, which we will use to model volatility behavior on the individual markets. Different extensions to the basic GARCH have been developed. An example is EGARCH that captures the asymmetric pattern in volatility between negative and positive returns. More profound theory and derivation of the formulas and other features of the model can be found in many econometric books. We mostly profited from Brooks (2002), Enders (2004) and Arlt, Arltová (2007).

MULTIVARIATE GARCH MODEL

The discussion above was so far focused on a case when the variable of interest y_t is just one dimensional. However in practice, it is useful to study interaction of more variables. Below we present the formalization of the multivariate GARCH model in which we follow mainly Bauwens, et al. (2006), Bauwens (2005) and Brooks (2002)[37]. Bauwens, et al. (2006) formulate the general basic specification for the multivariate GARCH for a Nx1 dimensional vector of dependent variables y_t, $y_t=(y_{1t},...y_{Nt})'$ as follows:

$$y_t = \mu_t + \varepsilon_t, \qquad \text{(I.2.8)},$$

$$\varepsilon_t = H_t^{1/2} v_t \qquad \text{(I.2.9)},$$

where v_t is a Nx1 random vector, $v_t \sim iid$, such that $E(v_t)=0, var(v_t)=I_N$ [38],

$$H_t = H_t^{1/2}(H_t^{1/2})' = var(y_t | I_{t-1}) \qquad \text{(I.2.10)},^{39}$$

$$\mu_t = E(y_t | I_{t-1}) \qquad \text{(I.2.11)}.$$

$H_t^{1/2}$ is a NxN matrix such that H_t is a conditional variance matrix of y_t. "μ_t and H_t can depend on unknown parameters θ, but are otherwise know (parametric model), hence sometimes we write explicitly $\mu_t(\theta)$ and $H_t(\theta)$", (Bauwens, 2005, p.16) [40].

The issue of multivariate GARCH models is in specifying the H_t matrix to deduce the conditional variances, covariances and correlations of several variables and their evolution in

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[37] Other literature dedicated to multivariate GARCH modeling includes for example Engle and Sheppard (2001) or Silvennoinen and Terasvirta (2008).
[38] I_N denotes the NxN identity matrix.
[39] This follows from $var(y_t| I_{t-1})= var_{t-1}(y_t)= var_{t-1}(\varepsilon_t)= H_t^{1/2}var_{t-1}(v_t)(H_t^{1/2})'= H_t$. (Bauwens, et al. 2006, p.81)
[40] As Bauwens, et al. (2006) note in most cases θ can be divided into set of parameters for μ_t and a set for H_t.

time. As we said this is especially valuable in cases when we are interested in the volatility of several assets at the same time and their mutual relationships and interactions on the market. Examples of applications include dynamic hedging strategies, volatility co-movements and spillovers or the dynamics of the covariances and correlations among assets. Bauwens, et al. (2006) present a survey on the many specifications of the multivariate GARCH models concluding that the choice of the particular specification depends on its application. In general the practical issue of these models is to estimate of large number of parameters and to fulfill the model restrictions.

For our purposes we use the so called BEKK specification of a multivariate GARCH model introduced by Engle and Kroner in 1995 to which we refer to as *BEKK-GARCH* and which expresses the conditional variance covariance matrix H_t (following Bauwens, et al., 2006) as:

$$H_t = \Omega'\Omega + \sum_{k=1}^{K} A_k' \varepsilon_{t-1} \varepsilon_{t-1}' A_k + \sum_{k=1}^{K} B_k' H_{t-1} B_k \qquad \text{(I.2.12).}$$

We refer to the specification (I.2.12) as *BEKK(1,1,K)*, where “the summation limit K denotes the generality of the process”, (Bauwens, et al, 2006, p.83). For simplicity we assume that lags *p, q* of past squared innovations and past conditional variances on right hand side are both equal to 1, *p=q=1* which we denote, neglecting the K parameter, as BEKK(1,1) or BEKK-GARCH(1,1))[41]. For the model description further on we assume K=1. We assume the case of two variables (N=2) that we use in our empirical exercise. In this case the model is referred to as *bivariate*.

The parameter matrices are $\Omega = [\omega_{ij}]$ $i, j = 1,2$ is a (2x2) upper triangular matrix , $A = [a_{ij}]$ and $B = [b_{ij}]$ $i, j = 1,2$ are (2x2) matrices of the coefficients, $H_{t-1} = [h_{ij,t-1}]$ $i, j = 1,2$ is a (2x2) conditional variance covariance matrix lagged one period and ε_{t-1} is a (2 x 1) vector of lagged error terms of the mean equation, so we can write the bivariate BEKK (1,1,1) as:

[41] For higher lags *p* and *q* of the equation has analogous form, p=q=1 is often presented for simplicity. For $K=1$, the model has $N(5N+1)/2$ parameters and Bauwens, et al. (2006) mention that sufficient conditions to identify BEKK, with K=1 are that $A_{k,11}$, $B_{k,11}$ and diagonal elements of Ω are positive.

$$\begin{pmatrix} h_{11t} & h_{12t} \\ h_{12t} & h_{22t} \end{pmatrix} = \begin{pmatrix} \omega_{11} & 0 \\ \omega_{21} & \omega_{22} \end{pmatrix} \begin{pmatrix} \omega_{11} & \omega_{21} \\ 0 & \omega_{22} \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}' \begin{pmatrix} \varepsilon_{1t-1}^2 & \varepsilon_{1t-1}\varepsilon_{2It-1} \\ \varepsilon_{2t-1}\varepsilon_{1t-1} & \varepsilon_{2t-1}^2 \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} + + \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}' \begin{pmatrix} h_{11t-1} & h_{12t-1} \\ h_{12t-1} & h_{22t-1} \end{pmatrix} \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \quad \text{(I.2.13).}$$

The matrix H_t is symmetric and must be positive definite. The advantage of the BEKK specification is that: “The positive definiteness of the covariance matrix is ensured due to the quadratic nature of the terms on the equation’s right hand side” (Brooks, 2002, pg. 651). For the BEKK model to be covariance stationary the eigenvalues of $A \otimes A + B \otimes B$ must be smaller than one in modulus[42]. Based on (I.2.12) and (I.2.13) for case of N=2 we can expand the conditional variances and covariance of the matrix H_t from BEKK (1,1,1) as:

$$h_{11t} = \omega_{11}^2 + a_{11}^2\varepsilon_{1t-1}^2 + 2a_{11}a_{21}\varepsilon_{1t-1}\varepsilon_{2t-1} + a_{21}^2\varepsilon_{2t-1}^2 + b_{11}^2 h_{11t-1} + 2b_{11}b_{21}h_{12t-1} + b_{21}^2 h_{22t-1} \quad \text{(I.2.14),}$$

$$h_{22t} = \left(\omega_{12}^2 + \omega_{22}^2\right) + a_{12}^2\varepsilon_{1t-1}^2 + 2a_{12}a_{22}\varepsilon_{1t-1}\varepsilon_{2t-1} + a_{22}^2\varepsilon_{2t-1}^2 + b_{12}^2 h_{11t-1} + + 2b_{12}b_{22}h_{21t-1} + b_{22}^2 h_{22t-1} \quad \text{(I.2.15),}$$

$$h_{12,t} = \left(\omega_{11}\omega_{12}\right) + a_{11}a_{12}\varepsilon_{1t-1}^2 + (a_{11}a_{22} + a_{12}a_{21})\varepsilon_{1t-1}\varepsilon_{2t-1} + a_{21}a_{22}\varepsilon_{2t-1}^2 + + b_{11}b_{12}h_{11t-1} + (b_{11}b_{22} + b_{12}b_{21})h_{12t-1} + b_{21}b_{22}h_{22t-1} \quad \text{(I.2.16).}$$

where $h_{11,t}$, $h_{22,t}$ denote respectively the conditional variances, so that $var(\varepsilon_{1t}|I_{t-1})=h_{11,t}$ and $var(\varepsilon_{2t}|I_{t-1})= h_{22,t}$ and $h_{12,t}$ denotes the conditional covariance $cov(\varepsilon_{1t}\varepsilon_{2t}|I_{t-1})= h_{12,t}$. Because $H_t =(y_t| I_{t-1})$ the elements $h_{ii,t}$, $h_{ij,t}$ are also the conditional variances and covariance of y_t.

As we can see from (I.2.14)-(I.2.16), the interpretation of the parameters as impact of the lagged explanatory variables on the current conditional variances and covariance is not straightforward (they appear in forms of cross-products and functions). We can see that in the considered case *K=p=q=1* and case with only two variables, *N=2*, the number of parameters to be estimated equals eleven. This reflects one of the disadvantages of the multivariate GARCH

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[42] where $\otimes$ is a matrix Kronecker product, we refer to Silvennoinen and Terasvirta (2008).

models, specifically the large number of parameters to be estimated.

Diagonal BEKK-GARCH

When we accept the restriction that matrices A and B from specification (I.2.12) are diagonal we get the so called restricted or *diagonal BEKK-GARCH* model. The number of parameters to be estimated in this case reduces to seven. Such a model is much easier for computation; however the information on the cross impacts is also restricted. The mutual relationship between the two series remains in the form of cross products of past standard errors in the covariance equation. As Bauwens, et al. (2006) note, the diagonal form of BEKK is then not very appropriate to studying volatility transmissions. We are aware of this short coming of this form of BEKK, however, sometimes it is necessary to accept this restriction for example because of its availability in the statistical packages that we are using.

The parameters of the multivariate GARCH models, such as the BEKK-GARCH(1,1) can again be estimated by maximum likelihood methods. Under the normality assumption in the multivariate case the log-likelihood function we get:

$$LL(\theta) = -\frac{TN}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln|H_t| + (y_t - \mu_t)' H_t^{-1}(y_t - \mu_t)) \qquad \text{(I.2.17)}$$

where N is number of variables, T is number of observations and θ denotes all the parameters that we are estimating.

CONDITIONAL CORRELATIONS

From the estimated time-varying conditional variances and covariances processes from equations (I.2.14)- (I.2.16), we can calculate the conditional[43] correlation coefficient:

$$\rho_{12t} = \frac{h_{12t}}{\sqrt{h_{11t}}\sqrt{h_{22t}}} \qquad \text{(I.2.18),}$$

[43] In our work we use the term conditional for this correlation coefficient in the sense that it is derived using the conditional variance and covariance processes from the bivariate GARCH model. Therefore in the empirical application we refer to the correlations in this sense.

where ρ_{12t} denotes the time-varying conditional correlation coefficient between variables 1 and 2. In this case $var(\varepsilon_{1t}|I_{t-1})=h_{11,t}$, $cov(\varepsilon_{1t}\varepsilon_{2t}|I_{t-1})= h_{12,t}$. As such this correlation coefficient gives the strength of the relationship between the fluctuations (as conditional errors $\varepsilon_{1t}|I_{t-1}$).

This correlation measure can therefore be used to investigate the strength of the mutual dynamic relationship between the fluctuations (shocks) in two variables (such as exchange rates). It takes into account the fact that there exist a relationship between these variables and that their conditional variances and covariances are dynamic.

This approach (a diagonal bivariate BEKK-GARCH model with the estimation of the time-varying correlation coefficient) is used for example by Babetskaia- Kukharchuk, et al. (2007) in their evaluation of the similarities of exchange rate movements of four EU NMS countries. We also adopt this approach in our empirical exercise. Studying the conditional correlation coefficient can therefore help to identify possible similarities in volatilities of the asset returns. We now turn to the empirical part, in which we first describe the empirical methodology used and then in three chapters devoted to the individual markets our empirical findings.

II. EMPIRICAL PART

We introduce this part by presenting our methodology used in the empirical estimations. Then we turn to the empirical results, which we present in three chapters, each devoted to the individual market. We first present the results for the foreign exchange market, secondly for the equities market and finally for the bonds market. We start each chapter devoted to the individual market with the market description, focusing on the recent market developments in the Czech Republic. Then we summarize some existing findings of related research on integration of the given market with the Euro area. The empirical estimation of conditional volatilities and their mutual relationships between the individual markets constitutes the main contribution of this empirical part. We conclude the main findings at the end of each chapter. We report detailed estimation results in appendix, included at the end of our thesis.

CHAPTER II.1: EMPIRICAL METHODOLOGY

In our empirical exercise of conditional volatility estimation we follow several steps that we describe below. For the formalizations of the various tests mentioned below we refer to econometric and time series analysis textbooks, for example Enders (2004) or Brooks (2002). In application of these tests we follow common practice for time series analysis.

- ***data***

We work with daily data downloaded from Reuters Wealth Manager web site. Our sample period starts with January 1999 and ranges until February or March 2008, according to the dataset. As we need comparable set of data in terms of same observations on the same dates for the bivariate GARCH model, we adjusted our data sets so that they are equal as to the dates and number of observations. For the *foreign exchange market* we use the daily closing spot prices of exchange rates in terms of USD, the CZK/USD and EUR/USD rates. For the *equities markets* we use the daily closing bid prices on the market aggregate indices in national currencies[44]. For the Czech Republic, we use the PX index in CZK. We use the Dow Jones Stoxx 600 broad index for the European region countries (we use abbreviation DJ for Dow Jones) in EUR. This index also includes countries that do not participate in the monetary union and even countries outside the EU, however it enables to evaluate the volatility transmission from the entire European region (total of 18 countries), including the influence of important equities markets, such as United Kingdom[45]. For the ***bonds market*** we use the yields on 10-year government bonds. We use the closing values of the yields reported by Reuters[46]. For the Euro area bond markets we approximate the development by a German for the Czech bond market by the Czech government bond with 10-years maturity.

- ***software***

We use the EViews 5 for most of our calculations. We also use JMulTi for the multivariate GARCH estimation and the related model diagnostics. We therefore describe our estimation steps in line with the procedures applied in these software.

- ***returns***

The first step in our analysis is to transform our data on spot prices into returns. In line with common practice we use the continuously compounded returns defined as:

$$r_{i,t} = (\ln S_{i,t} - \ln S_{i,t-1}) * 100 \qquad \text{(II.1)}$$

$r_{i,t}$ is the percentage return of the asset between time t and $t\text{-}1$, ln the natural logarithm,

$S_{i,t}$ is the spot price at time t and $i \in \{CZ, EU\}$[47].

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[44] The use of daily data in local currency is also adopted for example in Karolyi (1995).
[45] These 18 countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. www.stoxx.com. [cit.2008-5-5]. Some other studies on financial integration with Euro area (for example Babetskii, Komárková, Komárek, 2007) use the narrower Dow Jones Eurostoxx index, which covers the companies from across 12 Euro zone countries and is a subset of the broader Dow Jones Stoxx 600.
[46] The market convention is the ISMA yield to maturity for both CZ and German bond government yield. "Reuters 'native' yield to maturity is calculated using the issuer defined day-count convention and the market specific compounding rule…ISMA yield to maturity is calculated according to ISMA conventions: annual compounding. We employ the native day count for this convention." Reuters Wealth Manager. [cit. 2008-1-22]
[47] EU as a subscript here stands for European countries considered not the European Union.

For the case of bonds we already get the data in form of yields on a given bond, we therefore do not transform those data.

- ***stationarity***

Our next step is to check the stationarity of our time series. Stationarity is an important feature to be verified, because using non-stationary time series can for example lead to spurious regressions or outlasting and boosting of shocks (for example Brooks, 2002). We therefore use several techniques to test for the stationarity of our data, namely the Augmented Dickey-Fuller (*ADF*) test, the Phillips-Perron (*PP*) test and the Kwiatkowski, Phillips, Schmidt & Shin (*KPSS*) tests. The first two tests have their null hypothesis that the series has a unit root. Rejecting the null for *ADF* and *PP* at the given level of significance means, that the series is stationary. If we cannot reject unit root in levels, we difference the data and perform the same test on their differences. If then the unit root can be rejected, the series are stationary in first differences. The *KPSS* test has as a null hypothesis stationarity of the series, therefore failing to reject the test means we can consider the series stationary.

To confirm stationarity of our series, we should reject the unit root by the *ADF* and *PP* test and fail to reject stationarity by *KPSS* test at a given level of significance. This robustness check is proposed for example in Brooks, (2002, p.382). We report the results of all the stationarity tests in appendix.

- ***descriptive statistics***

As basic characteristics of each series we describe the data using descriptive statistics. We present the *mean value* (expressing the average value), *standard deviation* (expresses dispersion of the values from the expected value), *skewness* (which describes the asymmetry of the data from the mean), *kurtosis* and *maximum* and *minimum* values. As we already noted earlier, financial time series tend to be leptokurtic that means they have excess kurtosis (compared to normally distributed series). In practice this means that there is a higher probability of more extreme values and of more values close to the mean value compared to normally distributed variable. We also use the *Jarque-Bera (JB)* test to check whether the data can be approximated by normal distribution. The low *p-value*s[48] of the test suggest that the series is significantly different from a normal distribution.

- ***equation for returns and ARIMA modeling***

In our empirical exercise we try to evaluate the behavior of the conditional volatility of the time series of different market returns, we therefore first need to specify the returns. In general we could specify current returns for the period t as a random term for the current period and as a function of relevant past information set I_{t-1} including the lagged values of the returns, past errors and any relevant explanatory variables X observable at time t. According to efficient market hypothesis (*EMH*) all new relevant information is immediately reflected in the asset prices and therefore the market returns should be unpredictable.

We build on the assumption of randomness of returns on the daily basis and we include in our return equation only a constant term and a random component. Weak form of EMH assumes that the prices reflect only the relevant historical information and so their past values can be used in attempting to make the returns' forecasts. However it is not our aim to forecast the return series and we do not assume any explanatory variables except for a constant in the return equation. For simplicity we do not introduce any dummy variables either, although it would be possible to extend the equation for day-of the week effect or holiday effect.[49]

The constant in our return equation is included to represent the possible unconditional long-term drift. We can capture the possible existing inefficiencies of the market (meaning as dependencies on the past values, which we observe in practice) as a feature of the random component. We specify the random disturbances in terms of stationary ARMA process to capture possible autocorrelations[50] between these terms. We do this to extract the innovations term for the current period. Then we try to identify whether we can extract based on the past information the pattern of the current conditional variance of these innovations.

For illustration, if we would specify our model of the PX returns as an ARMA(1,1)-GARCH(1,1), we could formalize this estimation as:

[48] The *p-value* represents the lowest level of significance at which we can reject the null hypothesis, or the probability that we reject the null hypothesis when we should not.
[49] Such approach is adopted for example in Karolyi (1995, p.13, 14).
[50] Autocorrelation means that the variable X_t is correlated with its own value lagged k periods, X_{t-k}.

$$r_{CZ,t} = c_{CZ} + u_t \qquad \text{(II.2.1)}$$

$$u_t = \rho_1 u_{t-1} + \varepsilon_t + \delta_1 \varepsilon_{t-1} \qquad \text{(II.2.2)}$$

$$\varepsilon_t = \sqrt{h}_t \nu_t \text{, where } \nu_t \sim iid\ (0;1) \qquad \text{(II.2.3)}$$

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \qquad \text{(II.2.4),}$$

where $r_{cz,t}$ is a stationary series of PX returns, u_t is the disturbance term, which follows an ARMA(1,1) process specified as (II.2.2) and ε_t is a new innovation in the disturbance arrived in period *t*, which we specify as (II.2.3) and has a conditional variance h_t (II.2.4).

We choose the appropriate ARMA structure based on criteria of parsimony and goodness of fit of the model (see below). We first estimate the model using the ordinary least squares (OLS). If the remaining white noise errors from our specification show significant ARCH effects, we estimate the return equation jointly with a time-varying conditional variance process of the error terms using a GARCH model.

ARIMA (*Autoregressive Integrated Moving Average*) modeling consist of finding an order of integration *I(d)* of the series (differencing *d* times the variable of interest) and capturing possible structure and autocorrelations in variable using *AR* (autoregressive) and *MA* (Moving Average) terms. An *ARMA (p,q)* structure process for a random variable u_t can be in general formalized as:

$$u_t = \rho_1 u_{t-1} + \rho_2 u_{t-2} + ... + \rho_p u_{t-p} + \varepsilon_t + \delta_1 \varepsilon_{t-1} + \delta_1 \varepsilon_{t-2} + ... + \delta_q \varepsilon_{t-q} \qquad \text{(II.3)}$$

where ε_t is an innovation in u_t and *p*, *q* denote numbers of lags u_t and ε_t respectively.

We find the appropriate structure for our time series using the so called *Box-Jenkins methodology*[51], which is a series of steps used to fit the ARIMA structure to series. The three stages are identification, estimation and diagnostic checking. The *identification* phase consists of identifying the patterns in the series with the help of graphs and autocorrelation and partial autocorrelation functions. We first identify whether the series should be differenced (the order of integration *I*) and then, based on the autocorrelation and partial autocorrelation functions, we look for the appropriate degree of *p* and *q* to be used in the model specification of the

[51] "…Box-Jenkins (1976) strategy for appropriate model selection." (Enders, 2004, p.76).

disturbances. We then *estimate* the selected ARIMA structure on our data series. The best model should be *parsimonious* in AR and MA terms and should fit the data well (*goodness of fit)* according to the information criteria. Finally the *diagnostic checks* should be performed to verify that the residuals from the estimation are white noise (should not have any regular pattern).

- ***goodness of fit***

As a criterion for a goodness of fit we use the Schwarz (*SC*) and Akaike (*AIC*) information criteria. As a rule of thumb, these should be minimized to provide the best fit of the model. The idea of these criteria is that the more explanatory variables we use the more "penalized" we get by not selecting a more parsimonious model.

- ***residuals checks***

To check whether the *residuals* of our model *are white nois*e, we use the *Ljung-Box Q-statistics.* Under the null hypothesis there is no autocorrelation in residuals up to lag *k*, so we use this to test for the randomness of the data. If the *Q-statistics* is significant, we can reject no autocorrelation hypothesis at given significance level.

To test for *ARCH effects in residuals,* we also use the *Q-statistics* for the standardized squared residuals. The significance of *Q-statistics* indicates existence of the ARCH effects (significant autocorrelation of squared innovations). To check for the presence of ARCH effects we also use the ARCH-LM test, which performs regression of the squared residuals on their own lags.

- ***GARCH estimation and maximum likelihood method***

In case we identify significant ARCH effects, we model the time series simultaneously with a conditional variance equation of the error terms specified by a *GARCH* process as described previously in the theoretical part (see equation I.2.4). In most of the cases the GARCH (1,1) specification is sufficient to capture the ARCH effects. We repeat analogous procedures of model estimation, (parsimony and goodness of fit criteria) and we also repeat all the residuals checks. We only present the results for the selected models. From the estimated conditional variance equation we derive the conditional standard deviation as volatility in each market. Finally, to see how well our selected model performs, wee also try to estimate it on a different data samples.

We also perform the GARCH estimation under different conditional error distributional assumptions[52]. As we often cannot accept the normality of the residuals we try to estimate the GARCH model apart from the Normal distribution also with assumptions on different conditional distribution of the errors that try to capture the fat tails (Student's t-distribution or GED (generalized error distribution)). Similar approach is also used in other applied studies (for ex. Orlowski and Lommatzsch (2005) use GED in case of the bond market conditional variance; on the other hand other studies, for ex. Kearney and Patton (2002) assume normal error distribution.

After specifying these distributional assumptions the GARCH model is estimated using a *maximum likelihood method*, which is based on finding the parameters of the model that maximize the *log-likelihood function* (*LL*). This function can have different forms, based on the conditional error distribution assumption. We already specified the form of *LL* under normal distribution in equation (I.2.7)[53]. For other distributional assumptions the specification of *LL* is different and also includes additional parameters of the distribution to be estimated. For details on the specification of *LL* under the different distributions we refer for example to QMS (2004) or Herwartz and Kascha (2005) as it is beyond the scope of our work.

- ***<u>multivariate estimation</u>***

We use JMulTi for the *unrestricted bivariate GARCH*, which estimates the BEKK-

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[52] We try to identify possible improvements of residuals fit by using different distributional assumptions by comparing the quantile plots. These compare the standardized residuals (ε_t/σ_t) from our estimation with a theoretical quantile of the distribution. We present these quantile plots in the appendix.
For the assumption of normality for example EViews allows to compute *quasi-maximum likelihood* (*QML*) covariances and standard errors, which, in case the mean and variance are correctly specified, will lead to consistent ARCH parameter estimates (QMS, 2004, p.591). We use this option in case we estimate the model assuming the normal distribution. As Brooks advises, this procedure should be used when the non-normality is suspected (Brooks, 2002, p.461). We prefer to present results under different assumptions tested. As Herwartz, Kascha (2005) note, using incorrectly the non-normal distribution assumption may lead to inconsistent estimates, whereas the conditional normal can lead to consistent (although less efficient) estimates, when estimated using QML. This discussion on conditional error distribution is again beyond the scope of our work, we only wanted to briefly outline that this is also one of the issues in GARCH estimation. In our empirical exercise we try to use the different assumptions to discover possible significant differences in the conditional variance estimation.
[53] The iterative method to evaluate the likelihood function used by EViews as well as JMulTi is the BHHH algorithm. BHHH named after Berndt, Hall, Hall and Hausman, see for example Brooks,(2002).

GARCH (1,1) model[54]. As a model diagnostics, we again perform the residuals checks, i.e. Portmanteau tests for autocorrelation and normality and the multivariate ARCH-LM test that are available in the econometric package. As a robustness check we also estimate the model on a different data sample in each case. For a comparison of our results we also try to estimate the *restricted diagonal BEKK-GARCH* model (this time in EViews[55]), which assumes that the coefficient matrices A, B are diagonal (I.2.12). We have discussed the theory of these models in previous part.

The output of the software in both cases consists of the parameter estimates of the matrices Ω, A, B in equation (I.2.12). These parameters subsequently enter the conditional variance and covariance equations in forms of products that determine the impact of the various GARCH terms on current conditional variances (see equations (I.2.14- I.2.16)). We present the output in form of the matrix parameter estimates in appendix. We also calculate the functions of these terms as they form the conditional variance and covariance matrix, which we present in the text. We do this in order to be able to discuss the spillover effects between the market volatilities and the co-movements. For the co-movements we also calculate the conditional correlation coefficient from the estimated conditional variance and covariance processes (see I.2.18).

- ***<u>nature of the volatility relationships</u>***

We use the term <u>*volatility spillovers*</u> as the transmission of volatility between the two different markets (This could also be described as *cross-market volatility spillovers).* That means that the volatility spillovers refer to situations in which volatility can be transmitted from one market to the other (either directly or indirectly)[56]. Referring to equations (I.2.14- I.2.16): *direct volatility spillover* to volatility of market 1 (meaning impact on the conditional variance of market 1, $h_{11,t}$) from market 2 can be approximated by the direct effect of past conditional volatility in the market 2 in the last period ($h_{22,t-1}$) or as the effect of spillovers of lagged shocks from the market 2 (past squared innovations $\varepsilon^2_{2,t-1}$) that were new to the market

[54] The software estimates the BEKK-GARCH(1,1) using quasi maximum likelihood (*QML*) estimator with assumption of normal distribution of errors.
[55] The restricted version of the bivariate BEKK estimated in EViews has the form: $Ht = \Omega^*\Omega' + BH_{t-1}B' + A\varepsilon_{t-1}\varepsilon_{t-1}' A'$, Ω = (2x2) low triangular, A and B are (2x2) diagonal assuming normal distribution.
[56] In our case it is also between two periods as results from the model specification.

2 in the past period and were not yet reflected in the market's 2 expected variance. There may be also *indirect impact* of the market 2 on volatility of market 1, for example in terms past conditional covariance between the two markets ($h_{12,t-1}$) or in terms of cross-product of past innovations in the two markets ($\varepsilon_{1,t-1}\varepsilon_{2,t-1}$). As we can see the impact of one market on the other is not straightforward and in practice can realize itself through different channels.

Additionally, for our purpose we refer in the empirical analysis to *volatility co-movements* in case of contemporaneous relationship of the fluctuations in two markets. We approximate on this relationship by the correlation between the fluctuations in two markets, as calculated from the conditional covariances and variances estimated using the bivariate GARCH model[57]. Therefore when referring to volatility co-movements we use the computed conditional correlation coefficient (I.2.18). As we already emphasized earlier these correlations can be understood as synchronization of shocks.

For the dependence between the conditional volatilities *within one market* we speak of own direct *volatility persistence* (in terms of influence of own past conditional variance on the current one) or in terms of transmission of past shocks to own market (in terms of own past squared innovations) into current conditional volatility.

[57] Volatility co-movements could also be expressed as impact on conditional variance of one market from current shocks from other markets (which we however do not include in our specification). This is used for example in Balasubramanyan (2004, p.11).

EMPIRICAL RESULTS

We now turn to the discussion of our empirical results in the context of the individual markets, the foreign exchange market, the equities market and the government bonds market. We devote one chapter to each of these markets, further accompanied with detailed estimation results in appendix.

We repeat at this place that in our work we try to answer the following questions: What is the pattern of volatility dynamics of the Czech financial markets and the Euro area financial markets? Is there synchronization between the Czech and Euro area financial markets and are there significant relationships between these markets through their conditional volatilities? What form do the relationships take? Our hypothesis, which we test for each of the three markets, is formulated as: ***There are significant relationships between the markets of the Czech Republic and the Euro area through their volatility.***

CHAPTER II.2: FOREIGN EXCHANGE MARKET

In this section we focus on the foreign exchange market (further in the text referred to as FX market) for the Czech crown (CZK) and its connection with the Euro (EUR) foreign exchange market. We first discuss the market developments, then we review some existing findings from recent literature and finally we analyze the conditional volatilities, their dynamics and transmissions between the two markets. In line with questions we formulated earlier we first model and discuss patterns of the volatilities individually using a GARCH model. Then we move to the estimation of the bivariate BEKK-GARCH model to investigate jointly the conditional volatilities of the exchange rate returns and the possible relationship between them. Finally, we look at the evolution in time of the conditional correlation between the currency pairs´ fluctuations.

The Czech foreign exchange market is the market of the Czech currency, while the Euro area is a market where the Euro currency is traded. We analyze the spot exchange rate market; that is our data sets contain daily closing spot exchange rates for the period January

1999 to February 2008. We work with their percentage log-returns as defined in equation (II.1). We analyze the development of the two currencies and their volatilities from the point of view of the USD as an approximation for the world currency (the exchange rate pairs CZK/USD in relation to EUR/USD)[58]. This methodology of estimating the alignment of two currencies vis-à-vis third currency is identical with that used in other studies, for example Babetskaia-Kukharchuk, et al. (2007).

MARKET DEVELOPMENTS

Our goal is to investigate the relationship between the Czech crown and Euro currencies. First we present their recent development. The Czech currency is operating under a managed floating[59] since May 1997. The relationship of CZK to Euro is of a key importance. The Euro area still represents the main foreign trade partner of the Czech Republic, despite an appreciation trend of CZK against Euro that is visible since 2004. To illustrate this fact: in 2007 the share of Czech exports and imports to and from EU-12 group in total amounted to 56.6 % and 50.9% respectively[60], in 2004 these shares were 61.8% and 54.1%, in 1999 they reached 64% and 58,3% of exports and imports respectively. The importance of Euro in relation to the CZK currency can also be expressed in terms of foreign exchange market turnover. For example in April 2007 the daily turnovers on spot FX market represented 66.7% for Euro, 28.7% for USD and 4.6% for other currencies[61].

As we can see on the left hand panel of figure FX1, the Czech crown was appreciating against Euro since 1999. The exchange rate bubble, which we can observe as strong appreciation since the end of 2001 until mid 2002, burst in mid 2002 and subsequent depreciation lasted until beginning of 2004. Since then the CZK is appreciating against Euro.

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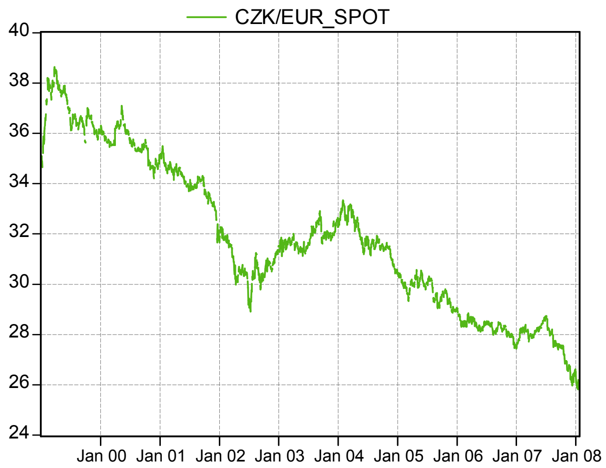
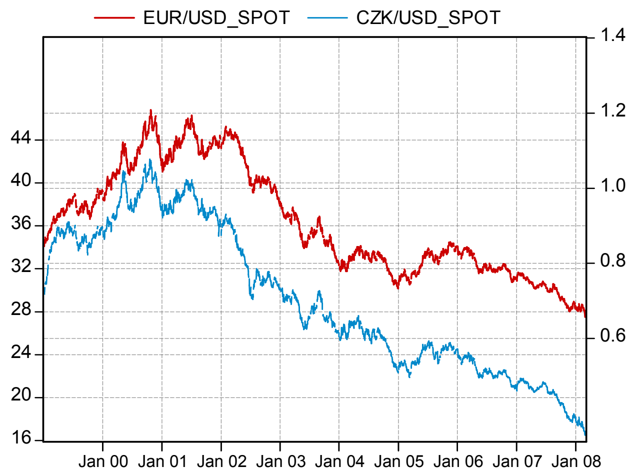
[58] The data set contains the daily closing bid spot prices of nominal cross exchange rates pairs CZK/USD and EUR/USD. The volatility of the market is approximated by the conditional variance of returns of the respective exchange rate pairs.
[59] The exchange rate is floating with the option of the central bank authority to intervene when necessary.
[60] Source: Czech Statistical Office, Foreign trade database, www.czso.cz, [cit.2008-4-8].
[61] The nominal turnover of spot FX market transaction for April 2007 in USD billions - Czech crown against: i) EUR:11,074.5; ii) USD: 4,770.5; iii) Other currencies: 763.5. Total: 16,608.5. Source: CNB, www.cnb.cz, [cit.2008-4-8]

Figure FX1: Nominal exchange rates development, CZK/EUR, EUR/USD and CZK/USD

a) CZK/EUR



b) EUR/ USD and CZK/USD



Note: Nominal exchange rates daily closing spot prices. The right panel shows on the left hand axis the CZK/USD nominal exchange rate, and on the right hand axis the EUR/USD. Data Reuters.

The visual inspection of the development of the two currencies that we study with respect to the "world" currency shows some similarities (right hand panel of the figure FX1). We can observe that depreciating and appreciating tendencies of CZK and EUR vis-à-vis the USD were analogical. Until the end of 2000, both currencies were depreciating against USD. The dollar's strength culminated in October 2000 when it was valued 42 CZK and over 1.2 Euros. The period since the end of 2001 shows diverging development of the two currencies; while the Czech crown started its appreciating trend already in mid 2001, Euro went through a period of depreciation at the break of the years 2001 and 2002. However since 2002 we can see that both currencies appreciated strongly against USD and their movement was very similar with few small and one larger correction in 2005. To demonstrate this with numbers: over the period from January 2002 until January 2008, Czech crown appreciated from its values reaching 37 CZK per USD in January 2002 to about 17.3 CZK in January 2008. Euro developed in a similar way with the USD, when it went up from its value of more than 1.1 Euro per USD in late January 2002 it to 0.7 per USD in January 2008.

The importance of the exchange rate development for a small open economy is indisputable because of its influence on real and financial sector of the economy. As such it is considered as one of the crucial macroeconomic variables of the country. Its development has implications on financial stability, external balance, monetary policy or competitiveness of the national economy. Exchange rates can act as external shock absorbers or on the contrary they can transmit external shocks into the economy. Komárková and Komárek (2007) identify four areas in terms of impact of the exchange rate on financial stability. These are exchange rate volatility, alignment of exchange rates with economic fundamentals, dependence of the exchange rate on the market/region sentiment and interaction of the FX market with the other financial market segments (Komárková, Komárek, 2007, p. 316).

Similar development of two currencies with respect to the third one can indicate similarities in the underlying factors affecting the currencies (CNB, 2007, p.30) and the "convergence in exchange rate fluctuations implies that the underlying shocks become more symmetric" (Babetskaia- Kukharchuk, at al., 2007, p.6). This is important with regard to Czech Republic's participation in the European monetary union. Therefore the study of exchange rate pairs and their volatilities can bring useful insights to possible risks related to financial stability as well as to the Euro adoption readiness. As such the topic has been subject to many studies, some of which we briefly present below.

REVIEW OF RESEARCH

Komárková and Komárek (2007) pursued research on integration of foreign exchange markets of selected new EU member countries (EU-4).[62] Authors conducted different methodological approaches to analyze the selected currency pairs against USD and their relationship to EUR/USD between 1995- 2006. The analysis using standard and rolling correlation coefficients suggests that the correlation between CZK/USD and EUR/USD has increased during the studied period and reached highest levels from the countries under inspection (value of 0.912). The beta convergence analysis using different methods of measurement suggests high and during the considered period increased speed of integration of CZK exchange rate. Their results confirm significant estimates of the beta coefficient, close to the ideal value of -1 (-0.94 for the period 1995- 2006). Another measure used in their work is the sigma convergence that assesses the degree of integration among markets. Using this approach authors find that Czech foreign exchange market has reached the highest level of convergence among the four countries. This is understood from the consistent decrease of the

[62] Czech Republic, Hungary, Poland and Slovakia

sigma deviation since 2002 and its lowest levels for the Czech Republic. (The theory requires the standard deviation of integrated markets to be zero, in which case full convergence of returns would be achieved.)

CNB (2007) reports (in the analysis on economic alignment of Czech Republic with Euro zone) for example that the volatility of the Czech- Euro exchange rate was relatively low in terms of historical and also in terms of the expected implied volatility. Such development (of a low volatility in a floating exchange rate regime) is considered as favorable for participation in a monetary union (CNB, 2007, p.30-32).

We already mentioned the work of Fidrmuc and Horváth (2008) who use the GARCH models and analyze the behavior of exchange rate and its volatility in relation to the implicit target zones. Among others, authors find that the volatility of Czech-Euro exchange rate between 1999 and 2004 exhibits significant volatility persistence and also significant (although of lower values) persistence of shocks. Authors also identify certain asymmetric effects in the conditional volatility behavior such as significant positive impact of exchange rate appreciation against the implicit target on conditional volatility of the exchange rate.

The correlation among currency fluctuations of four EU NMSs (Czech Republic, Hungary, Poland, Slovakia) and their similarities with development of Euro against USD is analyzed by the already mentioned study by Babetskaia-Kukharchuk, et al. (2007). Authors use the dynamic correlation coefficient constructed from estimated bivariate BEKK-GARCH model on data between 1994 and 2005. They find that the behavior of CZK and EUR exchange rates against USD is similar, as they find strong correlation between fluctuations of CZK and Euro especially since 2000 (which may be affected by the finalization of EU accession treaty (Babetskaia- Kukharchuk, et al. 2007, p.3). They also argue that for the individual countries their results are in line with the exchange rate regimes and degree of trade integration with Euro area. We adopt similar approach as theirs in construction of the correlation coefficient and we extend the analysis until 2008.

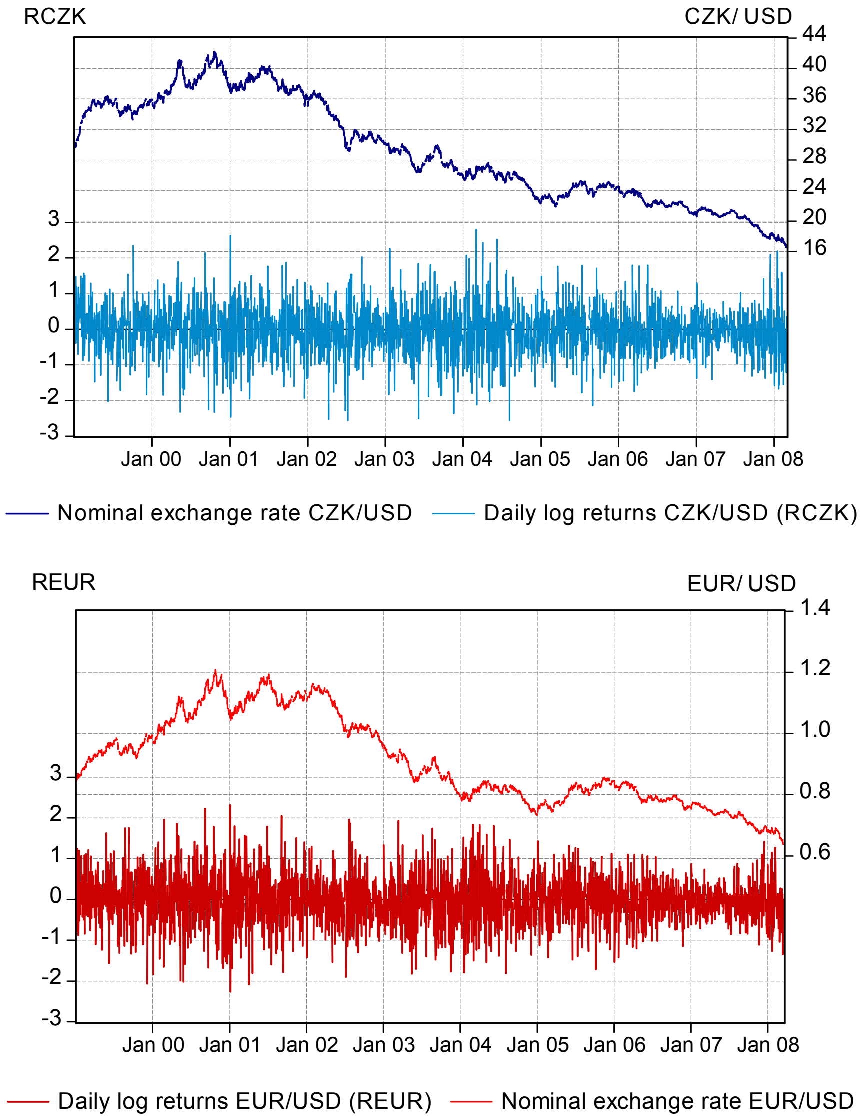
INITIAL ANALYSIS

We are interested in behavior of returns of the currency pairs as defined by equation (II.1) and their volatility. (In tables and figures we denote RCZK and REUR returns of CZK/USD and EUR/USD respectively). We present their developments in figure FX2.

Figure FX2: Nominal exchange rates CZK/USD and EUR/USD and respective daily returns

a) CZK/ USD and RCZK

b) EUR/ USD and REUR



The left hand axis of each panel shows the percentage returns, the right hand axis the nominal exchange rate values.
Own calculations. Data Reuters.

We can observe the volatility clustering in the returns series, with periods of high and low volatility. For the Czech crown the first glance at the daily returns at figure FX2 a) shows that highest volatility occurred in the beginning of 2001 and beginning of 2004[63]. It seems that volatility has decreased after 2004 with probably the most stable period in second half of 2006 and first half of 2007. The second half of 2007 seems to be more volatile, which may perhaps be the market reaction to the US sub-prime mortgage market unfavorable development and general increased market uncertainty regarding future developments of US economy.

[63] The Czech Republic officially joined the European Union on May 1st 2004.

When we look at the EUR/USD development we get quite a similar picture as for the CZK/USD case especially since mid 2006. It seems that the EUR/USD exchange rate was more volatile at the break of 2000 and 2001. The higher volatility at the beginning of 2004 however seems to be less pronounced than in the Czech case. It could be maybe that the EU enlargement had a smaller impact on the perception of Euro that in the individual case of Czech Republic.

We would expect that the Czech crown would be more volatile in general as it is not as stable and strong economy compared to the economies of Euro area (and Euro currency). Its higher risk perception should be reflected in higher returns. Moreover the negative returns of CZK/USD tend to be higher in absolute values and also more frequent (in comparison to EUR/USD returns). This is observable when looking at the bottom parts of the plots of figure FX2, especially when comparing the extremely negative values of the CZK/USD returns.

The brief inspection of the pattern of the behavior of the foreign exchange markets is valuable to provide an overall picture, although it cannot serve as a basis for conclusions. It suggests that periods when the volatility development was significantly changing were the break of 2000-2001 and mid 2003- 2004 and since second half of 2007. We might also suspect that the exchange rate fluctuations behaved similarly since mid 2006 and thus we can expect the conditional correlation to be high or increasing over this period. To move further, we estimate volatilities using GARCH framework.

We first performed different *stationarity tests* for the returns series. Both ADF and PP tests reject unit roots at one percent significance level. The KPSS test does not reject stationarity at one percent level[64]. We can conclude that the series are stationary at one percent level. We present the detailed results in the appendix to this chapter.

We present the *descriptive statistics* for exchange rate return series summarized for the entire period and also for the two sub-periods; before and after May 2004. We do this so as to establish, whether the period after the EU enlargement had any fundamental impact on these characteristics. The statistics for the whole period show that the daily mean percentage return is very close to zero for both exchange rates. The standard deviation is higher for the CZK/USD returns, which confirms the previously observed higher volatility for the Czech FX market

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[64] For both series ADF and PP reject unit root at 1%, KPSS fails to reject stationary at 1% but not at 5%. Our results are satisfactory for stationarity. The fact that KPSS and ADF test give different results (at 5% level) signifies fractional integration, which is beyond the scope of our thesis.

from the graphical inspection.

Table FX1: Returns of CZK/USD and EUR/USD - Descriptive statistics

		Mean	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	No. of obs.
Full sample 1.4.1999-28.2.2008	RCZK	-0.024	2.803	-2.561	0.681	-0.086	4.048	112.438 (0.000)	2392
	REUR	-0.011	2.310	-2.263	0.608	0.016	3.698	48.632 (0.000)	2392
Subsample I 1.4.1999-30.4.2004	RCZK	-0.006	2.803	-2.556	0.723	-0.160	3.895	52.072 (0.000)	1385
	REUR	-0.001	2.310	-2.263	0.674	0.011	3.423	10.332 (0.006)	1385
Subsample II 5.3.2004-28.2.2008	RCZK	-0.049	2.528	-2.561	0.617	0.036	4.176	58.200 (0.000)	1007
	REUR	-0.024	1.799	-1.813	0.504	-0.031	3.585	14.506 (0.001)	1007

Own calculations in EViews. Data Reuters.

For the CZK/USD returns the skewness was negative in the whole period and in the first period (signifies that returns are asymmetrically distributed around the mean with larger negative values) and it was positive in the period after 2004. Both return series have kurtosis higher than three, which means the distribution of returns can be characterized as fat tailed and extreme values are more frequent in the data compared to the normal distribution (as observed in many financial series). This effect is stronger for the CZK/USD returns. When looking at the two sub-periods, we can note that the standard deviation has decreased for both return series and that the kurtosis has increased between the periods. Finally, the Jarque-Bera test rejects the null hypothesis that the returns of CZK/USD and EUR/USD can be approximated by normal distribution at one percent level of significance in all cases.

MODELING VOLATILITY

As discussed in the methodology part, we assume that exchange rates behave randomly and therefore the behavior of FX returns is actually unpredictable. We work with daily returns $r_{i,t}$ as defined by equation (II.1), which we specify in the returns equation as:

$$r_{i,t} = c_i + u_{i,t}\ , \qquad \text{(II.4)}$$

where $i \in \{CZ, EU\}$, c_i is a constant. The random term u_{it} may capture possible inefficiencies of the market (which we specify with a stationary ARMA process with random innovations of the period *t,* which we denote as ε_t.). The use of a return equation with only a constant as explanatory variable is also applied by Fidrmuc and Horváth (2008). As they say the constant expresses average rate of appreciation and depreciation.

The linear OLS estimates from our specifications[65] point to the presence of ARCH effects as indicates the significant *Q*-statistics for the squared residuals. We also test for the presence of ARCH effects in the residuals of the specified model using the ARCH-LM test, which reports significant results. We therefore turn to evaluating the model together with a GARCH specification of the conditional variance equation of the news entering the returns at period t, $\varepsilon_{i,t}$. We start our estimation with a GARCH (1,1) specification of the conditional variance process. Because we also found significant departure of the residuals from normality; we try to estimate the GARCH model under different assumption on the conditional error distribution (Normal and Student's t). We summarize the final specification and the main coefficient estimates in table FX2. We report detailed results for both assumptions in appendix (table AFX1)).

Our results show a similar pattern for the two series, except that for EUR/USD returns, the GARCH(1,1) specification also finds a significant AR(1) term in the mean equation[66]. Both returns show a significant appreciation trend (significant negative mean constant). The estimated coefficients of the conditional variance equation are significant; the ARCH and GARCH terms at one percent significance level, the variance constant terms are close to zero and significant at 10% level in both cases under normality assumption.

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[65] We try to fit the stationary returns to an appropriate ARMA structure, based on the information criteria (AIC) and (SC). For CZK/USD returns we find some plausible alternatives minimizing AIC and SC, however that would have weak economic interpretation. The AR(1) model produces "worse" results in terms of AIC, SC and coefficient significance, so we decide to use for the returns of the CZK/USD exchange rate the model only with a constant. This estimate shows significant coefficient c_{cz} and a nearly zero R-squared, which corresponds to unpredictability of the exchange rate development. The identification of an appropriate ARMA process for the EUR/USD returns shows significant AR(1) process. The residuals from these specification estimated by OLS are not correlated for neither the returns CZK/USD, EUR/USD as shows the *Q*- statistics.

[66] For the returns on CZK/USD the residuals from this estimation are white noise and they do not show any remaining ARCH effects, suggesting that the GARCH(1,1) specification is sufficient to capture the pattern in the conditional variance. The residuals estimated with GARCH variance still show some fat tails when we assume normal distribution. When we assume the Student t-distribution, the t-distribution degree of freedom parameter is estimated as (7.8) and significant; the quantile plot also suggests that this distribution corrects for some of the fat tails. Otherwise the conclusion from this estimation is similar under both assumptions.

For the EUR/USD returns, the AR(1)-GARCH(1,1) specification leaves some remaining ARCH effects in residuals (at five percent significant it is for two lags). This suggests that GARCH(1,1) may not be sufficient to explain all of the relationships of the conditional volatility on the past. We therefore tried to specify the model of higher order GARCH (2,1) which removed the ARCH effect from the residuals. We found that adding another lag of the past squared innovations removed the ARCH effect from the residuals, however one of the ARCH parameters turned out negative and non-significant). We prefer to select the more parsimonious GARCH (1,1) representation. We keep in mind that the squared residuals remain correlated for few lags. For the case of the EUR/USD returns, the assumption of normality shows some departure at the positive values, otherwise the estimation conclusions are more or less similar, with higher significance levels for the t-distribution.

Table FX2: Results of GARCH estimation for CZK/USD and EUR/USD returns. 1999 -2008.

formalization of the chosen specification

CZK/USD log returns: *rCZK*	EUR/USD log returns: *rEUR*
$r_{CZK,\ t} = c_{CZK} + \varepsilon_{CZK,\ t}$	$r_{EUR,\ t} = c_{EUR} + u_{EUR,\ t}$ where $u_{EUR,\ t} = \rho_1 u_{EUR,\ t-1} + \varepsilon_{EUR,t}$
$r_{CZK,\ t}$ … daily log returns of CZK/USD exchange rate at time *t*, defined in eq. (II.1) c_{CZ} … constant term of return equation	$r_{EUR,\ t}$ …daily log returns of CZK/USD exchange rate at time *t*, defined in eq. (II.1) $c_{EUR,\ t}$ …constant term of return equation $u_{EUR,\ t}$ …disturbances following AR(1)
where error term $\varepsilon_{CZK,\ t} \sim N\vert I_{t-1}\ (0;h_{CZK,t})$ and the conditional variance $h_{CZK,\ t}$ follows a GARCH(1,1): $h_{CZK,\ t} = \omega_{CZK} + \alpha_{CZK}\varepsilon^2_{CZK,t-1} + \beta_{CZK} h_{CZK,t-1}$	and error term for period *t*, $\varepsilon_{EUR,\ t} \sim N\vert I_{t-1}\ (0;h_{EUR,t})$ with GARCH(1,1) conditional variance. $h_{EUR,\ t} = \omega_{EUR} + \alpha_{EUR}\varepsilon^2_{EUR,t-1} + \beta_{EUR} h_{EUR,t-1}$

Main results. January 1999- February 2008

	Return equation		Conditional variance equation		
	c_i	**ρ_i**	**ω_i**	**α_i**	**β_i**
i	*Mean constant*	*AR(1) term*	*Variance constant*	*ARCH term*	*GARCH term*
rCZK	**-0.0276 ****	**n/a**	**0.0027 ***	**0.0255 *****	**0.9689 *****
	(-2.061)		*(1.958)*	*(4.422)*	*(127.809)*
rEUR	**-0.0188 ***	**-0.0443****	**0.001 ***	**0.0267 *****	**0.9706 *****
	(-1.708)	*(-2.223)*	*(1.673)*	*(5.101)*	*(165.566)*

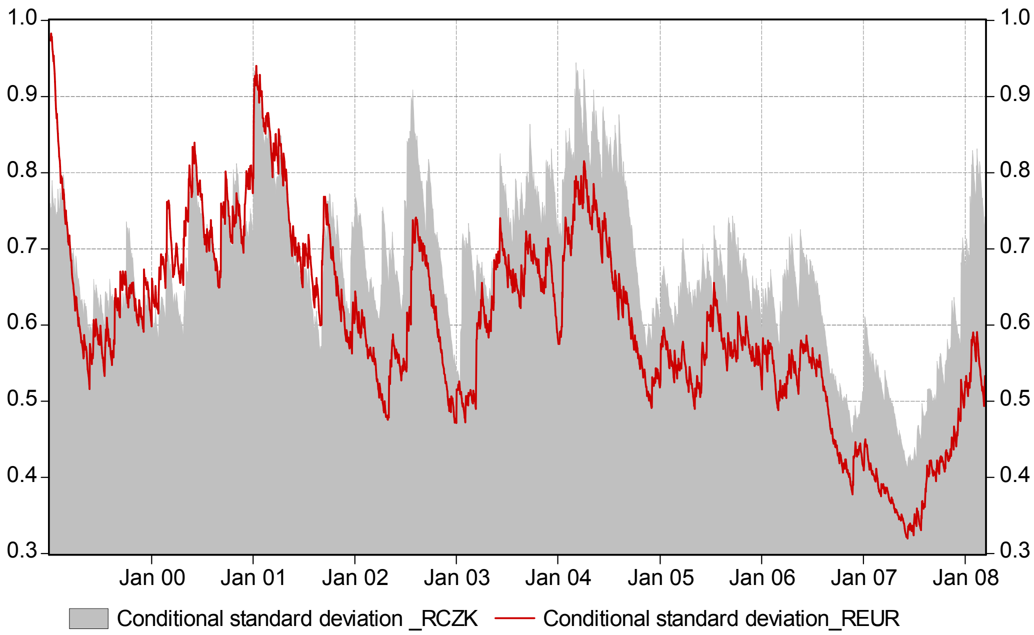
***, **, * denotes 1%, 5%, 10% level of significance. Numbers in brackets are the z-statistics. Sample: 5.1.1999- 28.2.2008. Observations: 2392. The GARCH model restrictions are also satisfied, all variance eq. coef. are positive (non-negativity restrictions for variance). The sum of the coefficients is lower than one (condition for stationarity). However the Wald test does not reject their equality for EUR/USD returns at 10%. Also calculated with t-distribution in appendix. Detailed results in appendix table AFX1. Own calculation using EViews. Data Reuters.

For both returns of CZK/USD and EUR/USD the dominant effect has the past conditional variance as estimated by the GARCH (1) coefficient (β) close to 0.97 in both cases, while the dependence on the last period news on volatility is significant however relatively small (α close to 0.025). The sum of coefficients that is very close to one suggests that the persistence of the conditional variance on the past is strong in both cases.

To check our results we estimate the same model specification for the individual returns for the two periods separated by the accession of the Czech Republic to the EU in May 2004 (see table AFX2 in appendix for details). The results for the CZK/USD returns under the reduced samples confirm significant constant appreciation term only for the second period. Significant persistence on own volatility (GARCH term) is confirmed in both samples, the effects of past news (ARCH terms) are slightly higher than for the full sample with lower significance for the first period. For the sample 2004-2008 the model residuals are autocorrelated so this specification does not perform well as in the case of full sample. For the EUR/USD returns for sample 2004-2008 the coefficient estimates confirm significant volatility persistence in both reduced samples, AR(1) term of the return equation is only significant in the period 2004-2008. However the selected specification leaves strong ARCH effects autocorrelation in residuals pointing to poor performance of the model for the reduced samples.

We extract the dynamic conditional volatility as estimated by the conditional variance equation for the two return series for the period 1999- 2008. As we are interested in its mutual development, we present the two jointly in figure FX3. The graph shows that the daily returns of the CZK exhibit higher volatility than returns of the EUR/USD returns. This is an expected result as we already mentioned that Euro is more stable and stronger currency then the CZK.

Figure FX3: Conditional standard deviation of FX market returns (CZK/USD and EUR/USD)



Own calculations in EViews. Data Reuters.

Firstly we can observe that the estimated conditional volatility is not constant. We identify several "peaks" for the Czech FX market volatility (grey area); the break of the years 2000 and 2001, the middle of 2002 and during the first half of the year 2004 and finally break of the years 2007 and 2008. As already suggested by the estimated variance equation, the persistence in volatility is quite high. From the end of 2004 the volatility stabilized at a level slightly below the level of the first half 2000 ranging between 0.6 and 0.7 as measured by the conditional standard deviation. The volatility has significantly decreased since the 2nd half of

2006, as we already emphasized earlier. Finally we can observe the increase in volatility since the second half of the 2007. For returns on EUR/USD exchange rate we can see that the periods of high volatility roughly correspond to the CZK/USD one, with generally lower absolute values. The sharp decrease of volatility in mid 2006 with following rise in mid 2007 is also visible for EUR/USD case, again of lower absolute values. After the rise at the end of 2007, the volatility of EUR/USD as expressed by the conditional standard deviation reached approximately the levels observable between 2005 and 2006.

So far our analysis suggests that the dynamic evolution of volatility at the individual market seems to be quite similar. We have observed periods of higher volatility measured by the conditional standard deviation at around the same periods. Since approximately half 2005 we observe that the volatility of the FX markets returns shows similar patterns in behavior when related to the USD. To verify nature of the relationship and possible volatility transmissions between the two markets, we estimate the bivariate GARCH model.

VOLATILITY TRANSMISSIONS

We first estimate the unrestricted bivariate BEKK-GARCH model. We estimate the model on the full sample (January 1999 - February 2008) and to verify its results also on the reduced sample (which we select as the period from EU enlargement in May 2004 until February 2008). We report on the detailed results in appendix, tables AFX3 and AFX4.

For illustration on the volatility interaction we calculated the coefficients of the conditional variance and covariances equations from the estimated parameter matrices. The numbers in bold are functions of estimated coefficients, which were significant at 5% level, others are products of non-significant estimates[67]. The table FX3 shows impact of the terms in variance and covariance equations on current period conditional variances and current period conditional covariance. (For example coefficients for the effect of past conditional variance in market 2: $h_{22\ t-1}$ on the current conditional variance in market 1: $h_{11,t}$ is calculated as 0.0044 and significant at 5% level). The subscript 1 stands for CZK/USD, the subscript 2 for EUR/USD.

[67] We did not test joint significance of the coefficients in the unrestricted model due to computational issues. The results therefore have to be interpreted with caution. We approximate on the significance of the product of the two coefficients, only when each of them was significant at 5% level (according to t-values exact, which we compare with the value 1.960 of the quantile of normal distribution).

Table FX3: Coefficients of the conditional variance and covariance equations for FX market.1999-2008

	constant term	$\varepsilon_1\varepsilon_{1,\,t-1}$	$\varepsilon_1\varepsilon_{2,\,t-1}$	$\varepsilon_2\varepsilon_{2,\,t-1}$	$h_{11,\,t-1}$	$h_{12,\,t-1}$	$h_{22,\,t-1}$
$h_{11,t}$	**0.0109**	**0.0744**	-0.0803	0.0217	**0.8467**	**0.1223**	**0.0044**
$h_{22,\,t}$	**0.0012**	**0.0003**	0.0041	**0.0134**	**0.0002**	**-0.0284**	**1.0064**
$h_{12,t}$	**0.0026**	0.0049	0.0289	-0.0171	**-0.0130**	**0.9221**	**0.0667**

The numbers in bold are functions of estimated coefficients significant at 5% level, others are products of non-significant estimates. We approximate on the significance of the product of the two coefficients, only when each of them was significant at 5% level. Details table AFX3 appendix. Own calculations in JMulTI. Data Reuters.

We find significant own volatility persistence within each market (as significant impact of own past news and own past conditional variances on the current conditional variances). This result thus confirms our findings from the univariate estimation and was also confirmed for the reduced period[68]. The size of the impact again weighs more the past conditional variance while a small weight is assigned to the last period's news. We can see that the sensitivity of current conditional variance on past shocks is higher for the CZK/USD returns compared to EUR/USD.

We find that the effect of EUR/USD returns´ volatility in form of past conditional variance is very strong within the market itself, has a significant impact on the conditional covariance between the two studied markets and also directly affects the CZK/USD current conditional volatility. The impact of the direct volatility spillover is however of very low value (0.004). The indirect impact on CZK/USD volatility in form of persistence of past conditional covariance is significant and higher than the direct one (0.122). Moreover these spillover effects are no more significant on the reduced sample.

In the other direction we can see that the EUR/USD volatility also absorbs some volatility from the CZK/USD returns in form of past conditional variance, however this effect is nearly zero (0.0002) and significant only for the full sample. Also significant, but of very low importance is volatility spillover in form of past shocks from CZK/USD. The indirect volatility spillover effect in terms of past conditional covariance is higher and negative, however still of low value (-0.028).

Finally the conditional covariance between the two market returns is to highest extent affected by its own values from the previous period and also positively by the EUR/USD past conditional variance. The impact of past CZK/USD returns´ conditional volatility is found to

[68] The constant terms are significant for the full sample, for the reduced one only the diagonal ones.

be negative, however of quite a low importance (-0.013). This suggests that the higher conditional volatility of Czech market in the past period tends to directly decrease the volatility co-movements (understood as the correlation between the exchange rate fluctuations). Oppositely higher past conditional variance of EUR/USD affects these co-movements in a positive way. This may be considered as sign of asymmetry in the effects of each markets of their impact on volatility co-movements, however especially for the CZK/USD effect, its size is not very strong [69].

The model diagnostics still shows some remaining autocorrelations in residuals and also significant ARCH effects at higher lags[70]. The model performance is therefore rather limited and the spillover effects are not confirmed on the reduced sample period.

From the estimated variance-covariance series we calculated the conditional correlation coefficient as specified in (I.2.18), which we present in figure FX4.

Several features of the relationship between volatilities of CZK/USD and EUR/USD returns emerge from it. Firstly, the conditional correlation between the fluctuations in the two currencies vis-à-vis the USD is very high reaching the values around 0.85 (the perfect correlation of the two currencies in case of a monetary union would be equal to one). Secondly, we can see the evolution of this relationship. For the period from 1999 until end of 2000 we can see some large fluctuations in the correlations and their subsequent stabilization at a high level, reaching values over 0.85 and 0.9 in 2001. The period of highly volatile correlation is observed during the year 2002. This may be because of the appreciation period of CZK against Euro in that time. The values of correlation were again high and persistent since the first half of 2003 until 2007. We can also see certain decrease in the value of the conditional correlation coefficient to the values between 0.80 and 0.85 in 2007.

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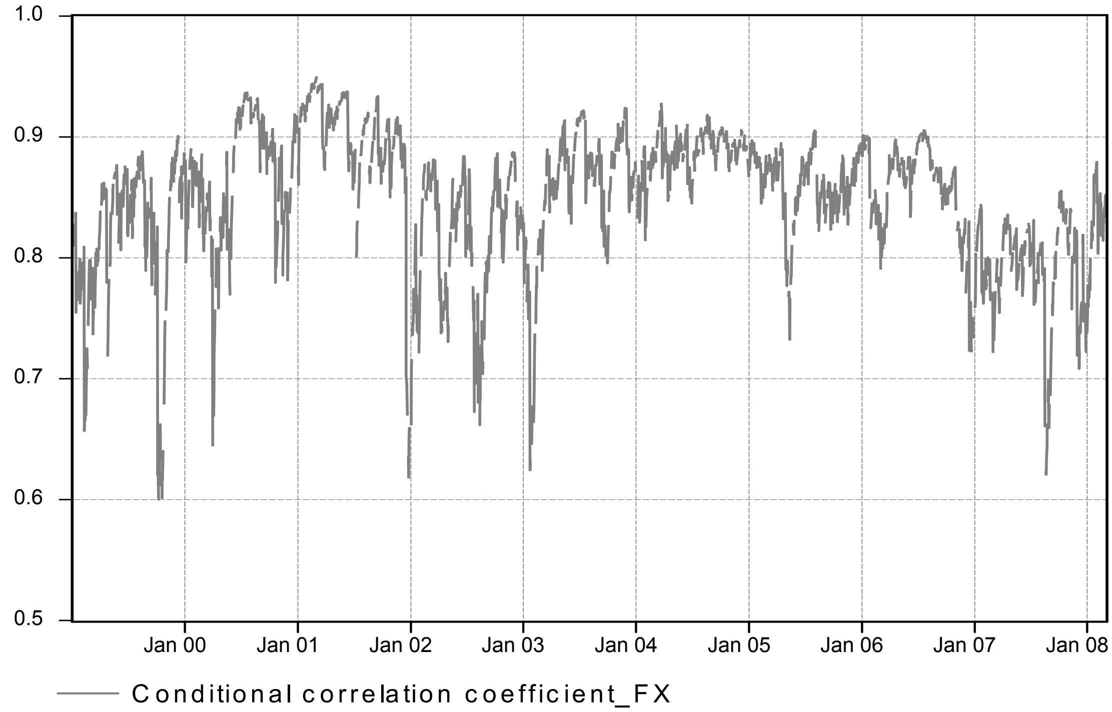
[69] For comparison we also try to estimate the *restricted diagonal BEKK-GARCH* model. Under this specification, the constant terms in the variance are significant; suggesting that some long term average volatility impacts all the conditional variance and covariance equations. The own volatility persistence within each market is significant with the high weight being assigned to the past own conditional volatility and the lower weight to the last period shocks. The model also estimates significant and negative mean for the Czech market, which supports the result from the univariate estimation (see table AFX7 for details).

[70] The stationarity condition of the model is satisfied, the residuals from this joint estimation show some significant autocorrelation at first lag and the squared residuals show remaining correlation for higher lags. The multivariate ARCH-LM test is performed at lag 16 not significant for the full sample; for the reduced sample however it is significant on five percent level.

Figure FX4: Conditional correlation coefficient FX market returns (CZK/USD, EUR/USD) fluctuations



Calculated from the unrestricted BEKK-GARCH. Own calculations using JMulTi, EViews. Data Reuters.

CONCLUSIONS FOREIGN EXCHANGE MARKETS

We found that conditional volatilities of CZK/USD and EUR/USD are dynamic and can be captured by a GARCH process. We also found significant and strong own volatility persistence in each market, which manifest itself mainly through the persistence of current conditional volatilities on the past ones. The most recent period from mid 2007 shows increase in volatility for both currency pairs.

Moreover we identified signs of volatility spillovers between the EUR/USD and CZK/USD in both directions in forms of dependence on past conditional variance, however this impact was low and the result was not confirmed when considering only the period after EU enlargement. Spillovers of past shocks were also found from the CZK/USD to EUR/USD but again of very low importance and significant only for the full period 1999-2008. Our results should however be seen rather as indicative as the model diagnostics points to drawbacks of the model performance.

We derived the time-varying conditional correlation coefficient of exchange rate fluctuations from the estimated bivariate GARCH conditional variances and covariances. This correlation points to a strong relationship in terms of volatility co-movements of CZK/USD and EUR/USD returns. The conditional correlation is high, over 0.8, however it has been lower since 2007 until present.

As suggested previous research, the foreign exchange market of the Czech Republic exhibits high degree of integration with the Euro market. Our additional perspective on the markets connections through volatility transmissions is supportive for these findings. Our results are in accordance with the findings of previous studies, such as Babetskaia-Kukharchuk, et al. (2007) who have also found convergence in exchange rates fluctuations.

We conclude that the relationships between the volatilities of Czech and Euro area foreign exchange markets are identified mainly as important volatility co-movements. Some indications of direct volatility spillovers are also found when considering the period 1999-2008 however of low values.

CHAPTER II.3: EQUITIES MARKET

In this section we focus on the development of the equities markets in the Czech Republic and in the European region. We want to answer questions on the similarities in the behavior of these markets by evaluating the pattern of the volatility dynamics. Is there synchronization between these equities markets and are there significant relationships between them through their conditional volatilities over the period from 1999 until present? What form do these relationships take? Our hypothesis is: ***There are significant relationships between the Czech and European equity markets through their volatility.***

We introduce this empirical part with a brief description of the Czech stock market development. Then we follow with a review of recent research findings on its integration with other European markets. Based on the methodology described earlier, we model and analyze the volatility development on the two markets and their mutual relationship within a GARCH framework.

MARKET DEVELOPMENTS

The Czech stock market can be characterized as an emerging market with a relatively low number of stocks listed on the regulated stock exchange market and relatively low liquidity in comparison with countries with mature developed stock markets. Currently there are only thirty-three listed shares on the main and official free market of the Prague stock exchange (PSE)[71] and the market capitalization is rather low on an international scale. Small equities markets are likely to respond more to relatively larger changes in capital movements. Therefore greater volatility is also one of their features.

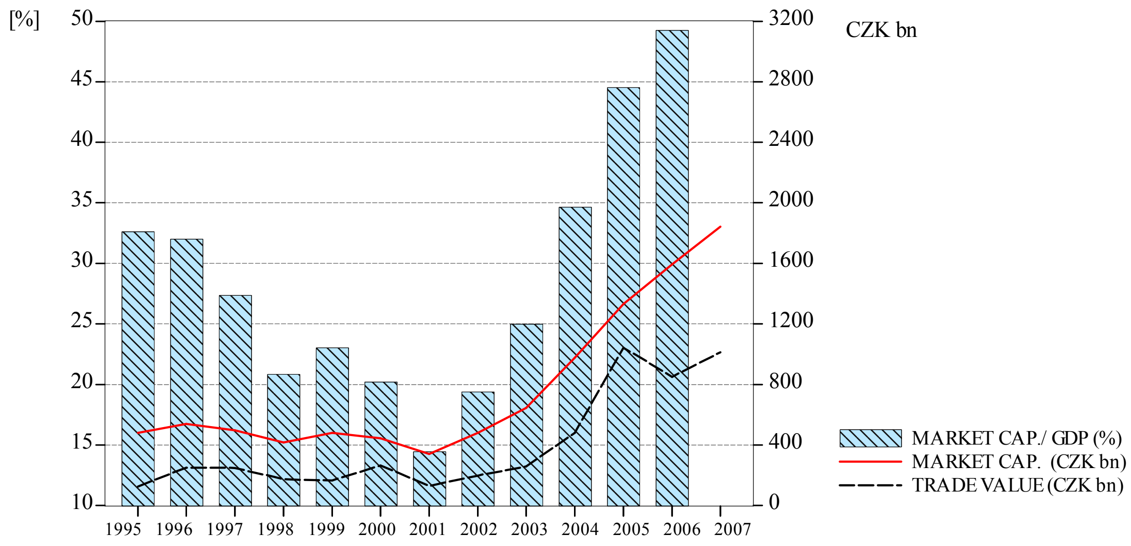
For illustration the Eurostat reports that Czech stock market capitalization amounted to EUR 69.2 billion as of the end of December 2007 compared to the stock market capitalization of Germany reaching EUR 1,440 billion. The total market capitalization for the EU-25 at the end of 2007 amounted to EUR 11,000.5 billion, which makes the Czech share about 0.6% of

[71] PSE regulated market listed 33 shares, 127 bonds, 47 warrants and certificates and 6 futures listed on a special market as of May 9, 2008. Source: www.pse.cz, [cit.2008-5-9].

the total[72]. However the PSE has recorded significant growth in terms of market capitalization since 2001.

Modern history of the Czech stock market in its beginnings (the PSE was established in 1992 and trading officially started in April 1993) shows a rather poor record. Problems were on both supply and demand sides as well as in the generally inappropriate regulatory framework. One of the problems was the initial "flood" of the PSE by the illiquid stock issues from the Czech coupon privatization in 1993 (955) and in 1995 (674) out of which 1,300 were later in 1997 de-listed for their low liquidity[73]. Other factors that could have contributed to the slow development of the stock market in the Czech Republic were for example the traditional approach of local firms to external debt financing or limited know-how of domestic private investors.

Figure E1: Prague Stock Exchange Indicators, 1995- 2007.



Data: PSE, CZSO (for GDP), own calculations

In the past few years some important changes pointing to the positive development of the Czech stock market and its growing importance could be observed. From among these events we would name especially the full membership of PSE in the Federation of European Securities Exchanges (FESE) that followed the entry of the CR to EU and being "designated

[72] In comparison with other CEECs, Hungary and Slovakia have lower market capitalization in absolute values (31.4 and 4.7 billion EUR respectively) while Poland has the highest out of the CEE-4 countries with EUR 518.9 billion. Source: Eurostat, http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,1&_dad=portal&_schema=PORTAL, [cit.2008-3-28].
[73] Data and information source: PSE: www.pse.cz, [cit.2008-3-28].

offshore securities market" by the US SEC in 2004.

The first foreign stock issue in 2002 and the first IPO in mid-2004 also represent important steps in the market development[74]. Moreover in 2006 and 2007 the PSE has extended its trading activities to trading with derivative instruments and also launched the Energy exchange. The official market index that we use for our empirical analysis is the PX index that took over the historical data of the PX50 and uses as a base the PSE blue-chip securities[75]. The PX index base is variable and as of May 2008 consisted of 13 issues.

The above mentioned market growth was significant not only in terms of market capitalization but also in terms of traded volumes between 2001 and 2007, with a drop in 2006. The number of issues was however declining since 1999. Komárková and Komárek (2008, p.92) offer as explanatory factors of the increased interest in investment on local stock market the activities of pension funds and investment funds, real and nominal convergence to the EU as well as the adoption of some common rules that facilitate the investments within the EU markets. (As an example we can name the full membership of new EU member states in FESE after joining the EU).

Table E1: Selected PSE indicators, 1999-2007

	1999	2000	2001	2002	2003	2004	2005	2006	2007
Market Capitalization (CZK bn)	479.65	442.89	340.25	478.04	644.48	975.77	1 330.81	1592.0	1841.68
Market Capitalization/GDP (%)	23.05	20.23	14.47	19.40	25.01	34.67	44.54	49.26	n/a
Total trade value (CZK bn)	163.46	264.15	128.80	197.40	257.44	479.66	1 041.17	848.90	1013.02
Total trade volume (mil. pcs)	772.66	822.91	546.54	804.11	830.77	1 179.11	1 764.88	1072.1	983.92
Number of issues	195	151	102	79	65	55	39	32	32

Market capitalization and number of issues as of Dec. 31. Data: PSE, CZSO for the GDP (in current prices). Own calculations

REVIEW OF RESEARCH

Several studies investigate the stock markets integration and volatility transmission of the CEECs among each other and with the developed countries. We summarize some of the

[74] First foreign issue Erste Bank in 2002 and first IPO was Zentiva.

[75] The currently used PX official market index replaced in March 2006 the previous PX50, computed since 1994. The second PSE price index with a broader base is called PX-GLOB. For details on PX calculations, we refer to PSE. www.pse.cz.

recent ones that focus on the Czech Republic.

Babetskii, Komárek and Komárková (2007) focus on financial integration and stress its importance for a smooth transmission of monetary policy as especially important for future Euro adoption. They investigate convergence of stock markets of four EU NMS (Czech Republic, Hungary, Poland and Slovakia) with Eurozone on national and sector levels. Their results for the speed of convergence suggest existing beta convergence; for the case of the Czech Republic it significantly increased in the period 2001-2006 compared to the period 1995-2000[76], but without significant impact of EU accession on the speed of convergence. Regarding the degree of achieved integration (the sigma convergence) their findings show that level of convergence was increasing until 2004 and since 2005 it started diverging slightly from the Euro area markets; authors explain this by the fact that national indexes grew faster after the EU enlargement than the selected Euro area stock index.

In a study that we mentioned earlier in the text, Komárková and Komárek (2008) further provide some complementary analysis. Their results of news based measures analysis show that the Czech stock market was to large extent influenced by the Euro-wide news.[77] Moreover authors present significant positive relationship between the return on the Czech stock index and its Euro area counterpart using the asymmetric TGARCH and EGARCH volatility models.

In a recent paper Égert and Kočenda (2007) study the intraday co-movements and their dynamic correlations between three CEECs´ stock markets (Czech Republic, Hungary and Poland) and three mature European markets (France, Germany and UK)[78]. Firstly their results show that correlations between the different stock exchanges are indeed time varying. However their findings show that although positive correlation exists between the three CEECs´ stock returns and the Western European benchmark (French index), this correlation is very low (0.01-0.03). It is somewhat higher (0.02-0.05) between the three CEECs markets but much lower compared to correlations between French and German markets (between 0.5 and 0.9). Authors conclude that volatility is mainly driven by local factors and that the stock market

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[76]Value of beta convergence for the Czech Republic has increased from -0.71 to -0.91. The closer the level of beta is to -1 the higher is the speed of convergence. Results of the analysis of correlation show return correlation with Euro area at 0.42 in 1995-2006.

[77] As measured by the changes in national index dependent on changes in benchmark index.

[78] Authors study data for following national stock markkets: Budapest´s BUX, Warsaw´s WIG-20, Frankfurt´s DAX-30, Paris´ CAC-40 and London UKX. The authors analyze high frequency data for the period between mid 2003 and early 2006 using a multivariate DCC-GARCH model.

integration in terms of co-movements remains low so far and as such offers plausible possibilities for international portfolio diversification.

In their previous study Égert and Kočenda (2005) authors use similar high frequency data for period between mid-2003 and early 2005 and a wide range of methods to analyze possible contagion effects that happen on intraday basis between the stock returns and return volatilities of the three selected CEECs (CR, Hungary, Poland) and West European stock markets (Germany, France, UK)[79]. They find mutual spillovers effects between the volatilities and some contagion effects between the returns. Among others their results suggest that the volatility of PX50 is positively influenced by the rise in volatility on the mature European markets as well as by positive changes in other CEECs markets volatility. Authors conclude that there is no robust stable long-run relation between the studied index pairs.

Finally we present results of Baltzer, et al. (2008), who study the equities market integration of EU new member states between 1994 and 2006. The authors suggest that integration between the stock markets of NMSs and EU is quite low with increasing importance of EU shocks especially since EU enlargement in 2004[80]. Moreover their results show that on average (for all NMSs) the part of variance explained by Euro shocks has significantly increased after 2004, although larger part (almost double) was explained by US shocks.

Overall, the different results suggest that integration of the Czech stock market with other European countries is rather low, with perhaps some indications of increasing trends after the EU accession. Our analysis does not try to repeat the existing findings although some of models (such as GARCH) were already presented in recent studies (Komárková, Komárek, 2008). We extend the data set for the recent data until March 2008, which enables us to include the turbulent market developments of the last year. Our main contribution is in evaluating the conditional correlation between the fluctuations of Czech and European market returns. Based on existing studies and differences between the markets we would expect these correlations to be rather low.

[79] Authors apply cointegration methods, causality and vector autoregression (VAR) analysis to ensure robustness of their results. Their other findings include that the PX50 index is positively influenced by the BUX as well as by the DAX and CAC returns. Interesting evidence is also found that volatility spillovers exist also in the direction from small markets to dominant ones.

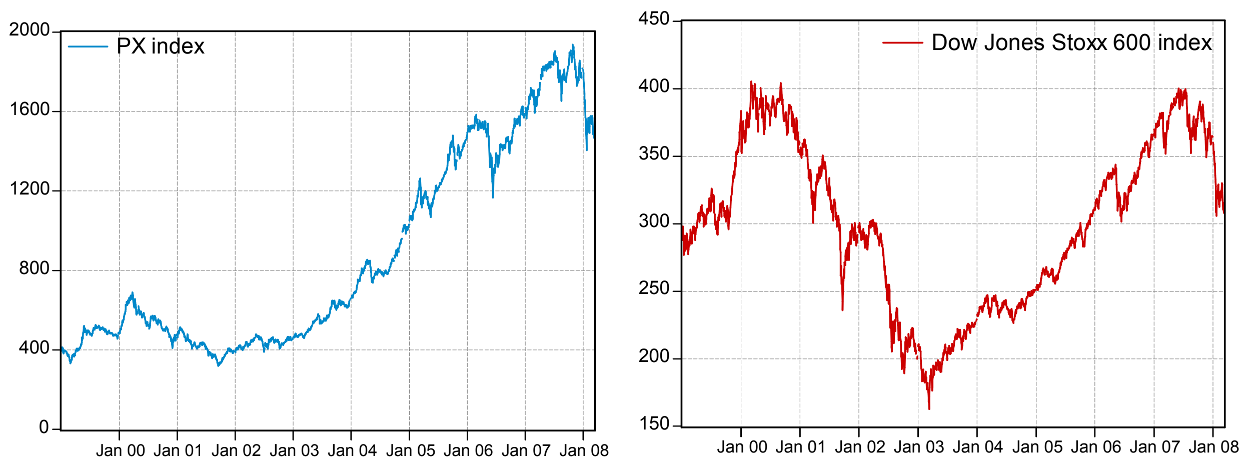
[80] Their method consists of evaluating stock returns as and dependence of their variance on common Euro area and world components and computing variance ratio that show what portion of country's variance is determined by euro area wide shocks and which by global shocks (Baltzer, et al., 2008, p. 10). If the integration has increased, the common shocks should become more important and the variance ratio should increase.

INITIAL ANALYSIS

We start our analysis with modeling the conditional volatility of individual returns and then we move to studying their mutual relationships. As an approximation of the European equities markets we use the Dow Jones Stoxx 600 broad index (we also refer to it as DJ Stoxx). This index incorporates in total 600 constituents of companies of small, medium and large capitalization of 18 countries in the European region (list of these countries mentioned in methodology section)[81].

We can see on the figure E2 that the PX index was rising between the second half of 2001 until the first half of 2006 and then again between mid-2006 and mid-2007. Other important moments in its development include correction in May 2006 and the first drop in mid 2007 that was followed by unstable development in the following months. Finally, a sharp drop in the market is visible since the beginning of 2008. These periods more or less follow developments on world markets, such as in mid-2007, which were in line with a drop following the general negative developments in the US and the US mortgage market problems.

Figure E2: Development of PX index and Dow Jones Stoxx 600 index. 1999- 2008.



Note: Left panel shows the PX index value (in CZK), right panel the DJ value (in EUR). Data Reuters.

The development of the Dow Jones Stoxx 600 index differed substantially from the one of PX until 2003. Since then the overall pattern seems to be similar with corrections in mid-2006 and the turbulent period since mid 2007. We again work with returns of the index

[81] Source: www.stoxx.com, [cit. 2008-5-5]. It is based on 600 largest companies from the Dow Jones TMI index for European region. For details on the index we refer to www.stoxx.com.

values as defined in the methodology section in equation (II.1). (In tables and graphs we refer to "rPX" and "rDJ" as returns of PX and Dow Jones Stoxx 600 respectively.) Prior to the volatility modeling, some data checks and testing was necessary; this is briefly discussed below and selected results are presented in the appendix.

Both returns series are *stationary* as show the different tests we performed[82]; we present the detailed results in appendix. We present the *descriptive statistics* for returns for the whole period 1999-2008 as well as for the sub-period following the EU enlargement in May 2004. We can see in table E2 that neither of the series follows normal distribution but rather a fat-tailed one. The kurtosis exceeds 3 (the value of kurtosis of a normal distribution), skewness is negative and Jarque-Bera statistics clearly rejects the normality null hypothesis in all the cases. The PX returns exceed in their mean for both samples the returns on DJ Stoxx. The standard deviation of PX returns also exceeds that of the European ones. For both series for the standard deviation was lower for the sub-sample from 2004. This shows the general low volatility of markets especially between 2003 and 2006 (BIS, 2006).

Table E2: Returns on stock indices PX and Dow Jones Stoxx 600 - Descriptive statistics.

		Mean	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	No. of obs.
Sample 1.04.1999 3.07.2008	rDJ	0.003	5.641	-7.027	1.177	-0.267	6.167	987.05 (0.000)	2296
	rPX	0.057	8.084	-6.125	1.273	-0.162	5.580	646.67 (0.000)	2296
Sub-sample 5.03.2004-3.07.2008	rDJ	0.026	5.112	-5.898	0.878	-0.547	7.536	875.49 (0.000)	965
	rPX	0.061	8.084	-6.125	1.203	-0.289	8.569	1260.25 (0.000)	965

rPX stands for returns on PX, rDJ for returns on Dow Jones Stoxx 600. Own calculations in EViews. Data Reuters.

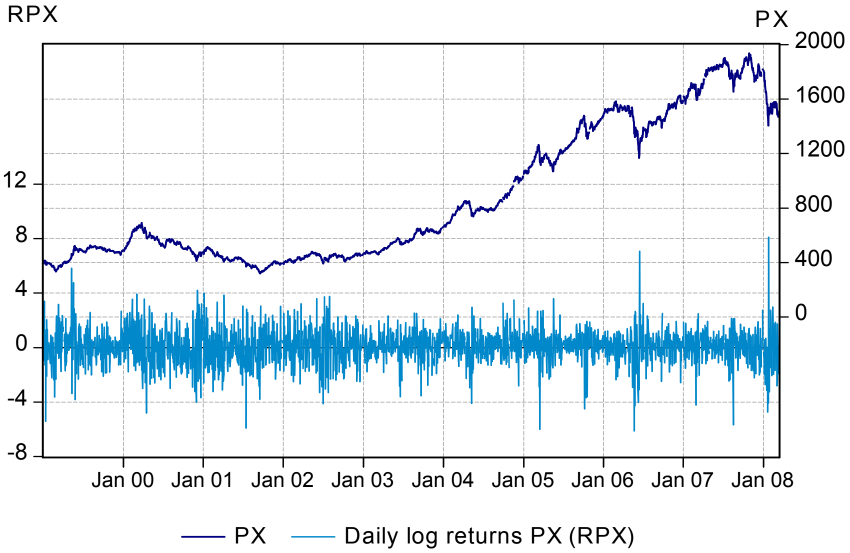
The figure E3 below illustrates the development of both indices with a plot of their returns in the bottom part. For the PX index we can observe that the volatility is higher at the periods when the index dropped and was especially high between 2000 and mid-2001 when the index was declining and again around mid-2002. We can observe relatively tranquil market behavior between 2003 and mid 2006. The drop in index in mid 2006 and mid 2007 was again accompanied by higher volatility in the returns especially in negative values. For the DJ Stoxx index the returns exhibit high volatility especially between mid 2002 and 2003 (the period of

[82] The ADF and PP unit root tests reject unit root at 1% significance level. KPSS results fail to reject stationarity at 1% level.

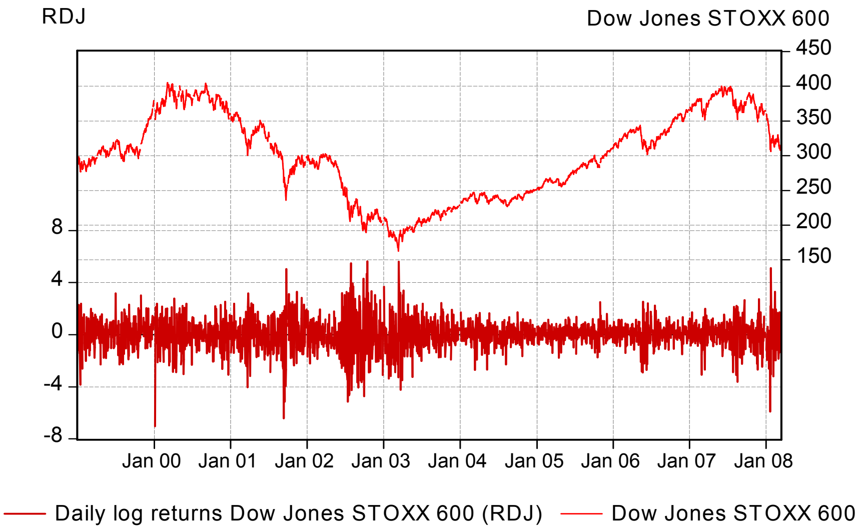
the accounting scandals) followed by a tranquil period until mid 2006 and increased volatility of returns again since mid 2007. In absolute terms the PX returns are higher, which reflects the above mentioned fact that higher reward is required for investing at riskier markets.

Figure E3: PX and Dow Jones Stoxx 600 and respective daily returns. 1999-2008

a) PX and rPX



b) Dow Jones Stoxx 600 and rDJ



The left hand axis of each panel shows the daily percentage returns, the index value (PX in CZK, DJ STOXX in EUR) Own calculations. Data Reuters.

MODELING VOLATILITY

We gain assume that stock markets are efficient and that the returns of the stock market indices behave randomly. Similarly to the FX market we include in the return equation a constant term *c*, (capturing possible long-term drift) and a random disturbance term u_t .

$$r_{it} = c_i + u_{it} \quad \text{(II.5)},$$

where subscript *i* stands for the two markets, $i \in \{CZ, EU\}$[83]. The term u_t can capture the possible market inefficiencies in terms of autocorrelations, which we specify by stationary ARMA process. (To capture the possible autocorrelations in residuals from regression (II.5) we can for example try to impose an AR(1) process on the disturbances, if it seems to be adequate:

$$u_t = \rho_1 u_{t-1} + \varepsilon_t \quad \text{(II.6)}$$

where the error term ε_t captures the new innovations contained in the returns for the period *t*.

We first tried to model the returns series using various ARMA specifications and estimate them with OLS based on the Box Jenkins methodology. However the results showed significant autocorrelation in the squared residuals for different specifications. The presence of ARCH effects was also suggested by the ARCH-LM test. Another common feature of the two returns series is their significant departure of the residuals from normality. We therefore turn to estimate the returns jointly with the conditional variance equation of the innovations ε_t specified by GARCH model[84].

The estimation using the GARCH (1,1) specification indeed proved to be more appropriate for the selected mean equation then the estimation only by OLS and the order *p=q=1* shows to be sufficient enough to capture the ARCH effects in the residuals. The coefficients of the variance equation were significant and the autocorrelation for the selected specifications was removed from the residuals. The kurtosis has decreased compared to the OLS estimate so we can say that the GARCH variance corrected for some of the fat tails. We also estimated our model using various assumptions on the conditional distribution of the error terms (Normal and the Students´ t-distribution). Overall our results lead to similar conclusions for both options in terms of estimated coefficient size and significance[85].

For the PX returns we found the model with an AR(1) term in equation of returns to be

[83] EU subscript denotes here the European region as represented by the DJ Stoxx 600, not the European Union.
[84] For our analysis we neglect the asymmetric effects of negative residuals and fit the simple GARCH model rather then its´ asymmetric versions such as T-GARCH or E-GARCH, which are used in the studies of Baltzer, et al. (2008) or Komárková, Komárek (2008).
[85] The assumption of the t-distribution estimated the df as quite low and significant suggesting the non-normality. For the DJ Stoxx returns the standardized residuals seemed to fit the normal distribution quite well, but the Jarque-Bera still clearly rejected the normality. The quantile plots show that for RPX the t-distribution was able to correct for only some of the fat-tails for the negative values. See figures AE1-AE2 and table AE1 in appendix. The inspection of histogram and the quantile plots after GARCH estimated variance however still suggests that the residuals from the estimated models are not normally distributed.

the most appropriate[86], suggesting that the Czech stock market index returns still exhibit some dependence on the past values in the disturbances. For the European DJ Stoxx 600 returns, the model with only a constant in the return equation seemed to fit the data better. We present the selected specifications (here presented the results with conditional normal distribution) including estimated coefficients in the table E3; we report on the detailed results under the different assumptions including the various diagnostic tests in the appendix.

Table E3: Results of GARCH estimation for equities returns (PX, DJ STOXX 600). 1999 - 2008.

formalization of the chosen specification	
PX log returns: r*PX*	DJ STOXX 600 log returns: r*DJ*
$r_{PX,\,t} = c_{PX} + u_{PX,\,t}$	$r_{DJ,\,t} = c_{DJ} + \varepsilon_{DJ,\,t}$
where $u_{PX,\,t} = \rho_1 u_{PX,\,t-1} + \varepsilon_{PX,t}$ $r_{PX,\,t}$ … daily log returns of PX index at time *t*, defined in eq. (II.1)	$r_{DJ,\,t}$ …daily log returns of DJ STOXX 600 at time *t*, defined in eq. (II.1)
c_{PX} … constant term of returns equation	c_{DJ} …constant term of returns equation
and innovations $\varepsilon_{PX,\,t} \sim N\vert I_{t-1}\ (0;h_{PX,t})$ and the conditional variance $h_{PX,\,t}$ follows GARCH(1,1).	and innovations for period *t*, $\varepsilon_{DJ,\,t} \sim N\vert I_{t-1}\ (0;h_{DJ,,t})$ with GARCH(1,1)conditional variance.
$h_{PX,\,t} = \omega_{PX} + \alpha_{PX}\varepsilon^2_{PX,t-1} + \beta_{PX} h_{PX,t-1}$	$h_{DJ,\,t} = \omega_{DJ} + \alpha_{DJ}\varepsilon^2_{DJ,t-1} + \beta_{DJ} h_{DJ,t-1}$

Main results

	Return equation		*Conditional variance equation*		
i	**c_i** *Mean constant*	**ρ_{1i}** *AR(1) term*	**ω_i** *Variance constant*	**α_i** *ARCH term*	**β_i** *GARCH term*
rPX	**0.1044 ***** *(4.510)*	**0.0560 **** *(2.532)*	**0.0591 ***** *(4.172)*	**0.1171 ***** *(6.301)*	**0.8487 ***** *(41.430)*
rDJ	**0.0416 *** *(1.761)*	n/a	**0.0191 ***** *(3.166)*	**0.1060 ***** *(5.366)*	**0.8827 ***** *(48.152)*

Sample: 6.1.1999- 7.3. 2008. Obs: 2295. ***, **, * denotes 1%, 5%, 10% level of significance. Numbers in brackets are the z-statistics. Also calculated with assumption of Student's distribution of errors, details in appendix, table AE1. The residuals from the selected estimations are white noise and no more ARCH effects were found. The non-negativity constraints of GARCH model were satisfied as well as the stationarity condition: $\alpha+\beta<1$. The Wald test however did not reject at 10% the null hypothesis of equality for the returns of the DJ Stoxx index. Own calculations in EViews. Data Reuters.

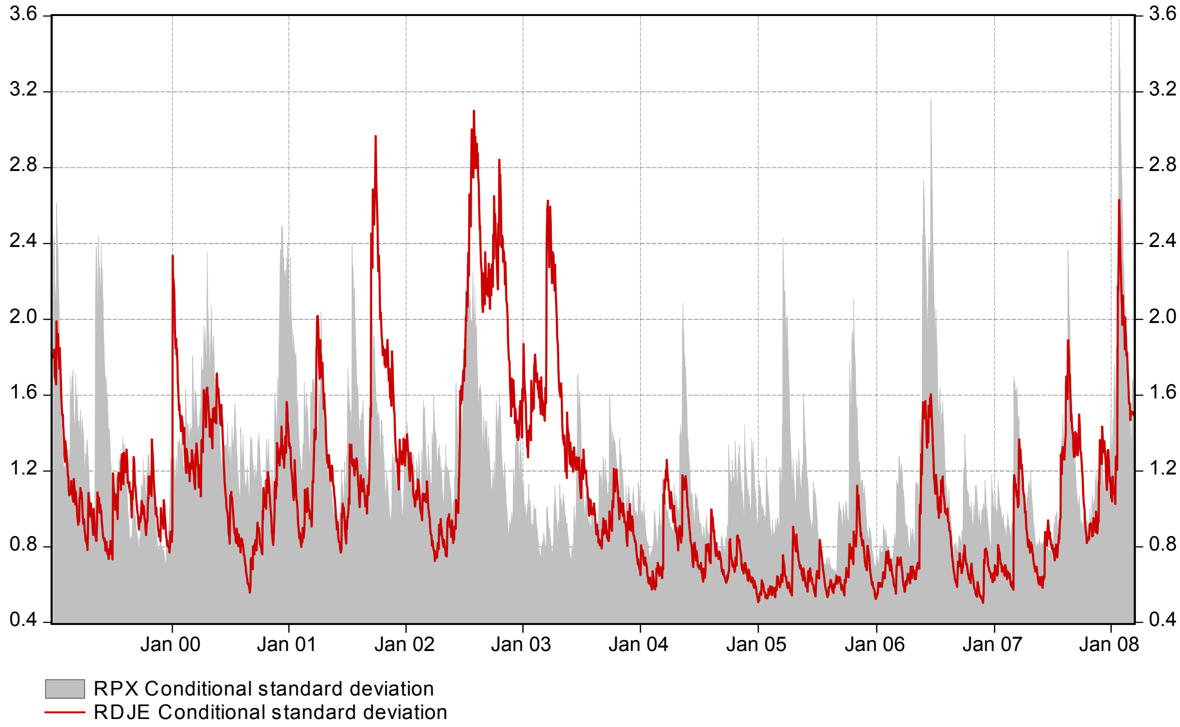
Conclusion from our results is that the conditional variance in both markets is persistent

[86] For the PX returns, the model with a constant in returns and a GARCH conditional variance left remaining autocorrelation in residuals for high number of lags. When we fitted the returns in a model that included AR(1) term, the residuals where already white noise and the information criteria was still below other specifications tested. For the DJ STOXX the model with only a constant in the returns equation had lowest SC and all the residuals tests performed were white noise.

and depends significantly on the past conditional variance (which has a dominant impact, β around 0.85). The effect of past squared innovations on current conditional variance is also significant but of lower values (around 0.1 in both cases). The pattern of the conditional variance is therefore quite similar for both markets; in case of the Czech market the long-term constant variance is higher than for the European DJ Stoxx. The sum of the coefficients $\alpha+\beta$ in the variance equations is very close to one, which reflects high persistence of the volatility on both markets[87].

We derived the conditional variance series for the two markets. According to our results, the volatility of the PX returns representing the Czech stock market (as expressed by the conditional standard deviation) was exceeding the one of the European returns. The most visible exception from this "typical" pattern is the period between mid-2002 and mid-2003.

Figure E4: Conditional standard deviation of equities market returns (rPX and rDJ).



Own calculations in EViews. Data Reuters.

[87] To check the robustness of the results we tested the same model on a sample from May 2004 until March 2008. In the case of the Czech market the AR(1) term in the return equation was no more significant compared to the whole sample, but otherwise the model diagnostic checks confirmed the validity of the selected specification. For the variance equations, all coefficients were significant for both series. For the DJ Stoxx 600 returns the model specification also proved to fit the data quite well; however some remaining ARCH effects in residuals were significant for higher lags. Detailed results are again reported in appendix (Table AE2).

Higher conditional volatility of PX returns corresponds to the already mentioned higher risk perception of the emerging markets. The higher volatility of the European equities market (as approximated by the Dow Jones Stoxx 600 index) around 2002-2003 corresponds to the period following accounting scandals (such as World Com etc.) and the beginning of Iraq war (March 2003). The figure E4 perhaps suggests that these events had higher impact on the volatility of the Euro market then of the PSE. On the other hand low market volatility was observed for the European case between 2004 and mid-2007 and was not accompanied by the similar development of the Czech stock market. Despite the difference in absolute values of the conditional volatilities, we can observe several periods with common pattern in development (high conditional volatility in both markets at the same time). The period since second half of 2007 shows very similar pattern in conditional volatility development.

From the point of view of the Czech stock market, the similarities can be caused either by the volatility being affected by the volatility from the European region or both markets´ volatilities being affected by common, world market news and shocks. Such sensitivities of the returns´ variances to the Euro area or world-wide shocks are tested in Baltzer, et al., (2008) for the period until September 2006. The authors find that on average most of the variance is explained by global factors even though importance of the Euro area factor is increasing. Considering the generally (and worldwide) unstable development on financial markets since mid 2007, the argument for the world influence seems to be quite plausible.

VOLATILITY TRANSMISSIONS

We again try to investigate the relationships between the volatilities of European and Czech stock markets using the bivariate BEKK-GARCH model. First, we estimate the unrestricted model for the complete period 1999-2008 and subsequently for the period following the Czech Republic's accession to the EU in May 2004. Our results from the bivariate unrestricted model are reported in appendix (tables AE3, AE4).

Based on the estimated parameter matrices A, B and Ω from specification (I.2.12) we again calculate their functions as they appear in the conditional variance and covariance equations, as specified by (I.2.14)- (I.2.16). Following table E4 presents in bold the functions of the parameter estimates, which were significant at 5% level and the functions of the insignificant ones in grey[88]. Subscripts 1 and 2 stand for returns of PX, DJ Stoxx 600 respectively.

Table E4: Coefficients of the conditional variance and covariance equations for EQUITIES markets.

	constant term	$\varepsilon_1\varepsilon_{1,\,t-1}$	$\varepsilon_1\varepsilon_{2,\,t-1}$	$\varepsilon_2\,\varepsilon_{2,\,t-1}$	$h_{11,\,t-1}$	$h_{12,\,t-1}$	$h_{22,\,t-1}$
$h_{11,t}$	**0.0723**	**0.1024**	-0.0300	0.0022	**0.8587**	0.0230	0.0002
$h_{22,\,t}$	**0.0186**	**0.0048**	**0.0326**	**0.0549**	**0.0007**	**-0.0493**	**0.9347**
$h_{12,t}$	**0.0249**	**0.0223**	0.0717	-0.0110	**-0.0236**	0.8956	0.0120

Numbers in bold are functions of estimated coefficients significant at 5% level, numbers in grey are products of non-significant estimates. We approximate on the significance of the product of the two coefficients, only when each of them was significant at 5% level. See appendix table AE3. Sample Jan. 1999- March 2008. Own calculations in JMulTI. Data Reuters.

The results suggest that persistence of own conditional volatility is significant and reaches high values for both markets. Our findings show that the Czech market derives more of the current conditional variance from the past shocks then does the European region approximated by the Dow Jones Stoxx 600 (higher impact of past shocks on current conditional volatility of PX (0.102) compared to the European market (0.055)). On the other hand the European market seems to derive more of its volatility persistence from its own past expected variance than does the Czech one (0.935 against 0.859). The constant level of conditional variance is also higher in the Czech case which is in accordance with general intuition.

The impact of direct volatility spillovers from European market into the Czech one turned out insignificant in terms of direct volatility spillovers as well as indirectly in terms of insignificant covariance terms. In the other direction for the full sample the results suggest that the larger European market receives some volatility also from the small Czech market in terms of past shocks as well as past expected variance. Both of these impacts are however of very low value (calculated as 0.0048 and 0.0007 respectively).

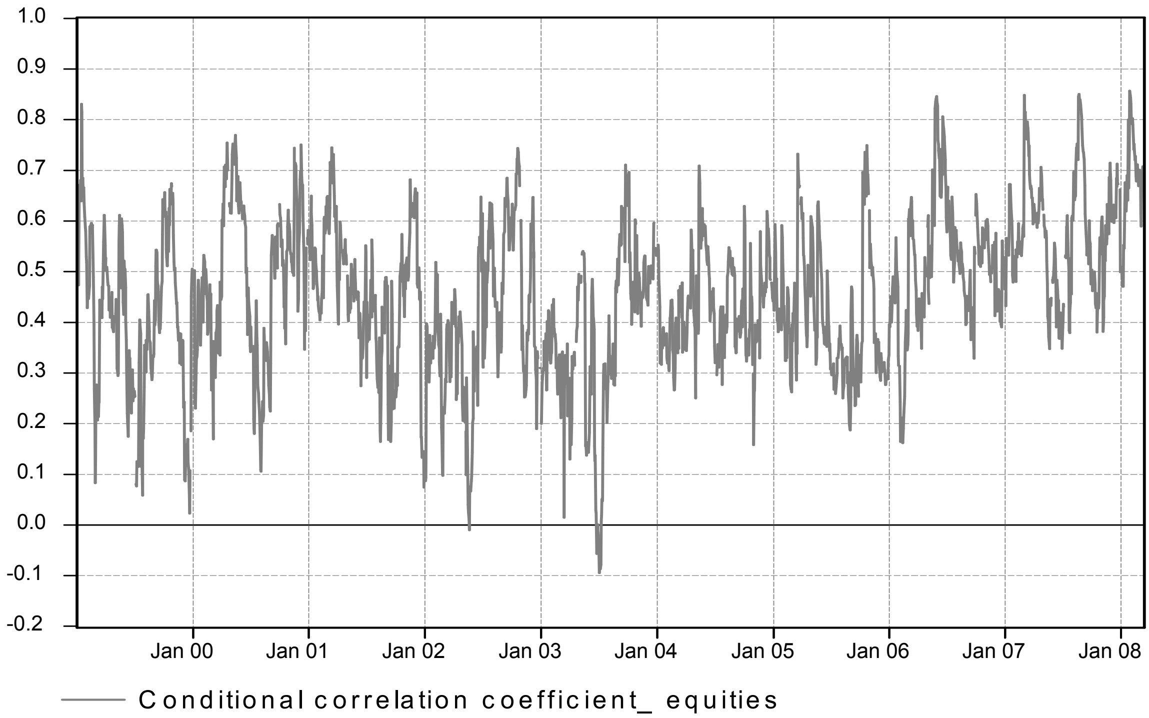
The results for the conditional covariance suggest positive impact of past shocks from the Czech market, which tend to increase the conditional covariance however of rather low importance (0.02). On the other hand we also identify significant effect of past conditional variance of the Czech market, which is negative and of little size of the impact (-0.02).

[88] We did not test joint significance of the coefficients in the unrestricted model due to computational issues. The results therefore have to be interpreted with caution. We approximate on the significance of the product of the two coefficients, only when each of them was significant at 5% level (according to t-values exact, which we compare with the value 1.960 of the quantile of normal distribution).

The diagnostic tests of the model however suggest that there is significant remaining autocorrelation in the residuals as well as significant remaining ARCH effects for both full and reduced samples. Therefore the reporting ability of this model is poor. Moreover our results for the significance of coefficient estimates do not hold when we estimate the model on a period May 2004- March 2008[89]. The stationarity condition is satisfied in both samples. Although we have identified signs of volatility spillovers the results should only be interpreted as indicative. We make this conclusion based on poor model performance in terms of diagnostic tests and insignificance for the reduced sample[90].

We again derive the conditional correlation coefficient between the fluctuations in the PX and DJ Stoxx returns, as defined in (I.2.18), which we use to approximate for the volatility co-movements between the Czech and European equities markets.

Figure E5: Conditional correlation coefficient for equities market returns (rPX, rDJ) fluctuations



Calculated from unrestricted BEKK-GARCH. Own calculation using JMulTi, EViews. Data Reuters.

[89] In this case the estimates are no more significant for all the off-diagonal elements of matrices A, B and Ω.
[90] We also try to test the *diagonal restricted version of the BEKK-GARCH* (assumes diagonality of matrices A , B). The results support our previous findings from the unrestricted estimation that significant own conditional volatility persistence exist within each of the markets, which also confirms our results from the univariate GARCH estimation. Comparing the two markets based on results from this estimation: the European one has higher persistence on the past conditional volatility then the Czech one while the effect of last periods innovations is stronger in the Czech case (size of a_{11} is above a_{22} and b_{11} bellow b_{22}). For details see table AE5 in appendix.

Firstly we can see in figure E5 above that the conditional correlation is very volatile ranging between 0.2 and 0.8 between 2006 and beginning of 2008. The simple linear correlation coefficients between equities market returns as estimated for example in Komárková, Komárek, (2008) fluctuated between 0.3 and 0.4 between 1995 and 2005 using weekly data. In this respect we find similar results but with the visible strong fluctuations. Secondly the changes in the conditional correlation seem to be slightly lower, especially around 2004.

We can also observe slightly increasing tendency in the conditional correlation between the fluctuations in the equities market returns, especially since approximately the half of 2005 however no clear pattern is visible due to the high volatility. Moreover because of the previously emphasized insignificant results of the conditional covariances and the entire model, we need to remind that this conditional correlation can only be seen as indicative.

CONCLUSIONS EQUITIES MARKETS

Our conclusions from the above presented empirical analysis on the volatility of the equities market of the Czech Republic and the European region are summarized below.

We tried to identify the pattern of the volatilities dynamics on each of the markets as estimated by the conditional standard deviations. We found that these are time-varying and can be estimated using a GARCH model. The results also suggested some similar patterns in terms of the direction of the volatilities dynamics for the Czech and European stock market conditional volatilities, especially since mid 2007 when we observe increase of volatility for both indices. The volatility on the Czech equities market is found to be above the European one most of the time, which is in line with general intuition. We found significant strong persistence in own conditional volatility in each of the markets.

Our results for volatility spillovers found some signs of spillovers of volatility from the Czech market to the European one, however of very low importance. In the other direction the spillovers from European market to the Czech one were not significant. The diagnostic of our model suggest that the specification as applied is not adequate, therefore any significant conclusions should not be derived from it.

The calculated conditional correlation coefficient is very volatile and perhaps slightly increasing since approximately mid 2005 suggesting increasing tendencies for similarities of volatilities behavior. The results of this correlation between equities market fluctuations as volatility co-movements can however only are seen as indicative because of poor reporting ability and significance of our model used to derive it.

When we put our findings in perspective with the ones of the existing research, some studies suggested increasing importance of Euro area and the Czech stock market development as a sign of increasing integration between the equities markets. Some of the outcomes of our analysis, indicating increasing correlations between the market fluctuations can be supportive for these findings. We observed some similar pattern of the conditional volatilities in the Czech and European markets in the last turbulent year. We can hypothesize that our inconclusive results on volatility spillovers may also suggest that this development may be given rather by influence of common world factors on both markets volatilities rather by mutual volatility spillovers.

We conclude that based on our estimation we cannot confirm significant volatility spillovers between the Czech and European equities markets. We identify some indications for volatility co-movements in terms of correlations between the fluctuations in equities market returns.

CHAPTER II.4: BOND MARKETS

In this chapter we focus on the development on the bond market in the Czech Republic in relation to the Euro area. Specifically, we concentrate on the long-term government bond market. We want to answer the questions of what is the pattern of volatility dynamics, whether there is synchronization between the Czech and Euro area bond markets and whether there are significant relationships between these markets through their conditional volatilities. Our hypothesis is following: ***There are significant relationships between the government bond markets of the Czech Republic and the Euro area through their volatility.*** We again start with some market characteristics followed by review of research on the related topic and finally we estimate the volatility of 10-year government bond markets.

MARKET CHARACTERISTICS

In general bonds represent debt financial instruments that serve for the issuer as a form of debt financing. Traditionally, the structure of corporate financing in the Czech Republic is mainly by bank credit[91], therefore the position of corporate bonds is not as strong. The largest market share in medium and long term bonds of different maturities is held by the government sector, followed by monetary financial institutions. In the past several years the share of bonds with maturity over 10-years among other debt instruments was rising at the expense of the share of short-term money market debt instruments (from less than 10% in 2002 to almost 40% in 2006). The government sector had the largest share of these long-term bonds. These trends are based on facts presented in table B1 below and table AB1 in appendix.

Table B1: Market size- debt instruments by original maturities in the Czech Republic.

In EUR millions	2002	2003	2004	2005	2006
Money market - Short term	28 953.3	27 958.6	18 540.7	15 268.4	14 306.9
out of which government sector (%)	*6 077.5 (21%)*	*6 357.0 (22.7%)*	*5 433.9 (29.3%)*	*3 249.4 (21.3%)*	*3 258.8 (22.8%)*
Bond market, 1< t < 5	2 155.0	2 376.2	1 455.1	3 006.8	4 467.1
out of which government sector (%)	*2 017.1 (93.6%)*	*2 160.2 (90.9%)*	*1 083.2 (74.4%)*	*2 471.4 (82.2%)*	*3 321.7 (74.4%)*
Bond market, 5 ≤ t <10	6 925.5	8 832.8	10 636.9	10 090.1	11 687.1
out of which government sector (%)	*3 333.5 (48.1%)*	*4 127.7 (46.7%)*	*6 157.5 (58.1%)*	*5 780.1 (57.3%)*	*6 574.4 (56.3%)*
Bond market, t ≥10	3 922.1	5 978.6	8 185.6	14 749.8	19 611.3
out of which government sector (%)	*2 969.8 (75.7%)*	*5 221.6 (87.3%)*	*6 897.0 (84.3%)*	*12 360.6(83.6%)*	*15 820.0 (80.7%)*
Total market	**41 955.9**	**45 146.3**	**38 818.3**	**43 115.1**	**50 072.4**

Source ECB: ECB (2003), ECB (2004), ECB Statistical tables (2005s, 2006s, 2007s, 2008s). Amounts are the nominal values of stocks outstanding at the end-of-period. Percentage in brackets own calculations denoting the share of the government sector on the given maturity segment. The end-of-period exchange rate for the year used EUR/CZK: 30.6 (2002), 32.405 (2003), 30.465 (2004), 29.005 (2005), 27.485(2006). See ECB for more details and detailed breakdown by type of issuer in Table AB1 in appendix.

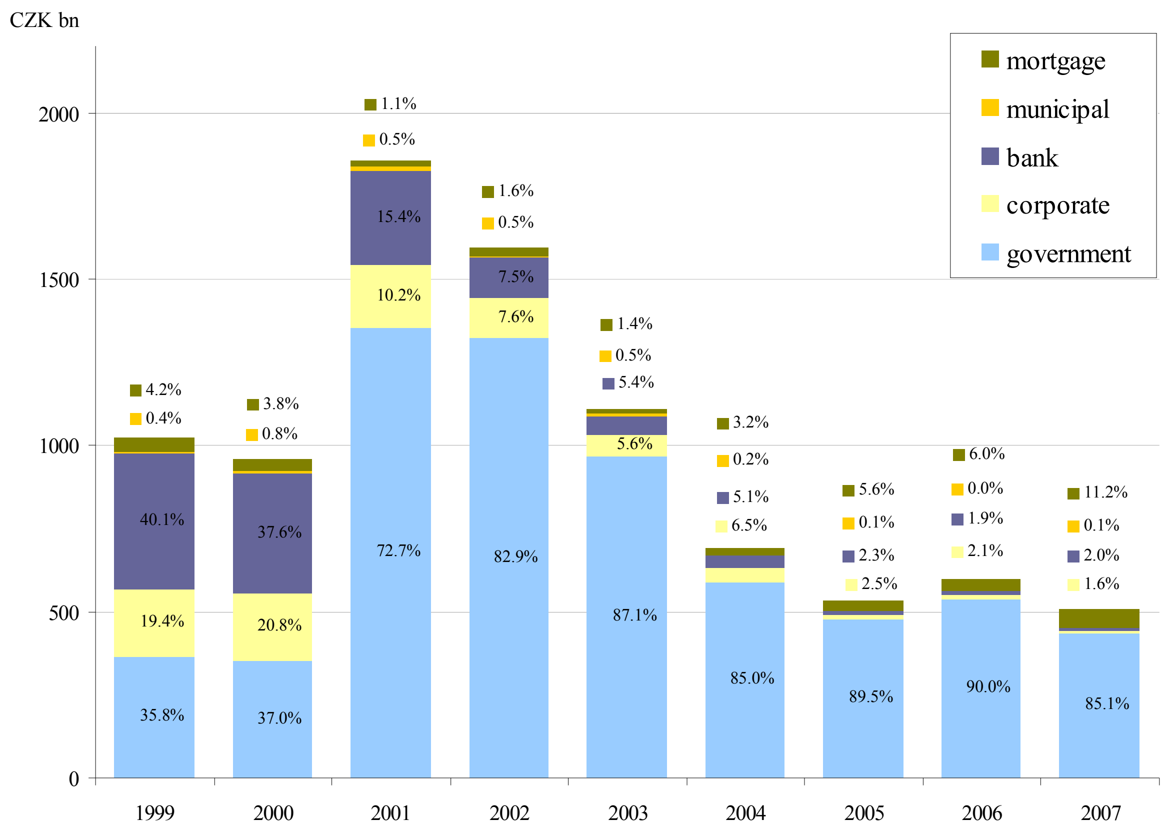
The primary market[92] for long-term debt securities (total for all maturities segments) was also dominated by the government sector (between 60% and 85% in terms of nominal value and between 30% and 50% percent in terms of number of transactions[93]. The issue of Treasury bonds and Treasury bills is in the Czech Republic administered by the Ministry of Finance (MoF) of the Czech Republic that also in advance announces the emission calendar.

[91] Komárková, Komárek (2008, p.69) also mention that Europe still remains a "bank-based system".
[92] Referring to the market segment in which new securities are sold (For example ECB, 2003, p.261).
[93] Source ECB, see table AB2 in appendix.

In comparison to other securities the bond market trade value on the PSE was the highest in 2001 since when it is declining and since 2005 it was below the trade value (for the first time since 1996) of the shares on PSE (see figure AB1 in appendix). This trend also reflects the growth of shares in the PSE as already emphasized earlier in text.

The bonds of the government sector were the most traded bonds on the PSE since 2001[94]. In the figure B1 we show the structure of the bond market and its changes over the selected period 1999- 2007. We can see that the banks´ bonds were dominating with 40% of the market share in 1999 while these had only 2% in 2007. We can also see that the share of corporate bonds declined since 2004 while the mortgage bonds have been gaining on importance since 2003 and in 2007 represented the second largest category of bonds traded on the PSE following the strongest government sector.

Figure B1: Trade value of bonds by type on PSE, 1999-2007.



Percentage values show the share of the bond type on total trade value of bonds for the given year. Mortgage stands for "zástavní listy" in Czech. Own calculations. Data PSE.

[94] We do not consider the RM-system off-exchange trading market, which had negligible share on bonds trade value in the Czech Republic. CNB (CNB, 2006b, p.69), [cit. 2008-20-4] reports the 54 registered issues and total value of trade CZK 0.2 billion (0.0% of total for the year) in this market. We therefore use the PSE data only.

The increasing importance of the government bonds reflects the structure of the government debt in the Czech Republic. More than 95% of the total government debt in 2007 was financed by securities and 77% of the total by the domestic medium and long-term treasury bonds (while in 1999 this share was only 34%) as shows the table B2. The increasing share of T-bonds is in line with the strategy for government debt management. As Komárková, Komárek (2008) note, this one was aimed at decreasing the share of treasury bills and lowering of the share of non- tradable debt in the government debt structure.

Table B2: Structure of the government debt by type of instrument

	1999	2000	2001	2002	2003	2004	2005	2006	2007
In CZK bn									
T-bills	130,1	165,3	186,6	164,1	160,6	125,5	94,2	89,6	82,2
T-bonds	77	104,3	149,6	222,6	319,3	397	487,5	588,9	687,1
As share of total debt (%)	*33,7%*	*36,0%*	*43,4%*	*56,2%*	*64,7%*	*67,0%*	*70,5%*	*73,4%*	*77,0%*
Subtotal for domestic debt	***207,1***	***269,6***	***336,2***	***386,7***	***479,9***	***522,5***	***581,7***	***678,5***	***769,3***
Foreign bond issues	-	-	-	-	-	48,8	78,9	84,1	83,7
Promissory notes	1,1	1,2	1,5	1,6	1,6	0,9	0,8	0,8	0,6
Total securities	**208,2**	**270,8**	**337,7**	**388,3**	**481,5**	**572,2**	**661,4**	**763,4**	**853,6**
As share of total debt (%)	*91,2%*	*93,6%*	*97,9%*	*98,1%*	*97,6%*	*96,5%*	*95,6%*	*95,1%*	*95,7%*
Other	20,2	18,6	7,3	7,7	11,7	20,7	30,5	39,1	38,7
Total debt	**228,4**	**289,4**	**345**	**396**	**493,2**	**592,9**	**691,9**	**802,5**	**892,3**

Note: Provisory notes for IBRD and EBRD membership, Category Others include for ex. direct credits. Values as of end of the year. Own calculations. Source: MoF [95]

Further on we therefore focus on the long-term[96] government bond market to which we refer to as bond market in most of the time. Specifically we select the 10-year government bond segment. Moreover the government bonds are also important as their yields are often used to evaluate the development of market long-term interest rates. Such an example is that the 10-year government bond yields are used to measure the long-term interest rates as one of the convergence criteria for the EU MSs that aim to adopt Euro[97]. Also the government bonds are used as a benchmark in valuations of other financial instruments (for example as a proxy

[95] Source: MoF, [cit. 2008-20-4]. <http://www.mfcr.cz/cps/rde/xchg/mfcr/xsl/central_govern_debt_38491.html> and <http://www.mfcr.cz/cps/rde/xchg/mfcr/xsl/str_vyvoj_sd.html>

[96] Long-term financial instruments are typically in finance referred to the ones with maturity over 1 year.

[97] ECB for ex. defines the long-term interest rates used to evaluate the convergence criteria as the ytm on 10-year government bonds. "*…observed over a period of one year before the examination, a Member State has had an average nominal LTIR that does not exceed by more than 2 percentage points that of, at most, the three best performing Member States in terms of price stability. Interest rates shall be measured on the basis of long-term government bonds or comparable securities, taking into account differences in national definitions.*" ECB, 2003.

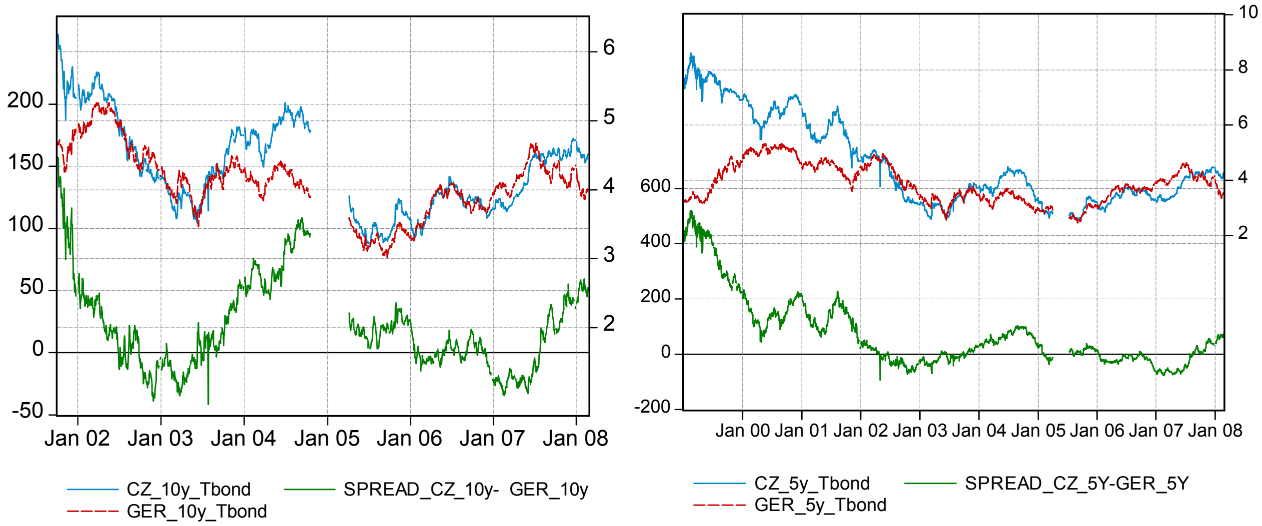
for the capital market risk free rate) or serve as collateral assets (Baele, et al., 2004, p. 34 or Komárková, Komárek, 2008, p.81). We further refer to government bonds as T-bonds or bonds unless specified otherwise.

As we said we use the 10-year government bonds for our study of the long-term bond market. We work with the yields to maturity or "ytm", (further referred to as yields) on the Czech government bonds and the German government bonds that are reported by Reuters[98]. The German government bonds are considered as representative bonds for the Euro area market. Their use as a reference benchmark for Euro area is also applied for example in the study by Komárková, Komárek (2008) or Baltzer, et al. (2008).

The development of the 10-year government bond yield for comparison presented together with the ones of 5-year maturity segment is shown in Figure B2. We can see similar behavior of the two maturities segments over the period 2002-2008. The 10-year Czech and German bond yields were moving in line since mid 2002 till mid 2003 and then the entire period between 2005 and mid 2007. There was a divergence period in 2004 reaching at highest 100 basis points.

Figure B2: Daily yields on 10-year and 5-year Czech and German government bonds.

a) 10-year government bonds *b) 5-year government bonds*



Daily yields (ytm). Data from 04/2005- 07/2005 (for 5-year bonds) and 10/2004- 03/2005 (for 10-year bonds) were removed to have identical samples for both series. Own calculations. Data Reuters.

98 The market convention is the ISMA yield to maturity for both CZ and German bond government yield. "Reuters 'native' yield to maturity is calculated using the issuer defined day-count convention and the market specific compounding rule…ISMA yield to maturity is calculated according to ISMA conventions: annual compounding. We employ the native day count for this convention." Reuters Wealth Manager. [cit. 2008-1-22].

We can observe that the 5-year bond yields were converging between 1999 and 2002 and since 2002 the spread between the yields was oscillating around zero with maximum differences of 100 basis points. For both maturity segments the spread was even negative (lower yields for CZ bonds) in the break of 2002 and 2003 and also in beginning of 2006 and first half 2007.

Nevertheless comparing directly the yields in different countries assumes that also the systematic risks (such as credit or liquidity risks) are the same in the countries (Baltzer, et al., 2008, p. 16). However this does not have to be the case. For instance remaining differences in bond yields may be given by differences in ratings of each government, liquidity or issuance techniques as remind Orlowski and Lommatzsch (2005). In our example the differences in default risks are reflected in Czech government bonds rating as A+ while the German ones as Aaa[99]. The bond yields are affected by different factors including news on different macroeconomic variables including fiscal policies that affect market expectations. For example Baele, et al. (2004) notes that risk premium will be higher if markets evaluate the government fiscal policies as weak ("unsound") (Beale, et al., 2004, p. 38). Moreover the currency risk can influence the differences between the yields in case of German and Czech bonds.

REVIEW OF RESEARCH

The bond market in the EU NMSs[100] has been recently evaluated by Baltzer, et al. (2008). Authors find that the dispersion between the NMSs and Euro area benchmark yields was decreasing between 2001 and mid 2006 for all maturities (from 300 to 50 bps). Authors find this a similar pattern (referring to Baele, et al., 2004) to the one of the current Euro area countries between 1995 and mid 1997[101].

The authors test the reaction of the local bond yields to changes in the benchmark yields (common news) and for the Czech Republic they find that the sensitivity of these changes is moving very close to one (perfect integration would imply identical changes in the yields

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[99] Czech 10-year and 5-year bonds ratings by S&P as A+, German ones by Moodys as Aaa. Source: Reuters.

[100] The countries included in their study on bonds market are Cyprus, Czech Republic, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia.)

[101] In that case, the pattern was that the dispersion between the yields fell from 2.5 percent to 0.5 percent and then got very close to zero and since 1999 remained stable at some minimal differences remaining (perhaps reflecting the differences in systematic risks across the countries), Baele, et al, 2004, charts 9,10.

assuming identical systematic risks[102]), (Baltzer, et al., 2008, p.16). The variance ratio for the Czech Republic is the highest compared to the other countries and ranges on average between 0.40 and 0.76 between the years 2002 and 2005[103]. The bond market of the Czech Republic (together with the Polish one) is identified by the authors as showing a significant degree of integration with Euro area bond market. Authors also refer to other recent findings that Czech bond yields are more sensitive to ECB rather than the CNB news[104]. Moreover they find signs of higher integration of new MSs with Euro area based on different quantitative indicators (such as increasing share of new MSs bonds in international portfolio held by Euro area members.

Komárková and Komárek (2008) focus on the development of the 10-year government bond markets in Czech Republic, Hungary and Poland against the German bond market as a Eurozone benchmark. As authors note the development of ten and five year maturities are very similar and they choose the 10-year bonds because these are less affected by the monetary policy decisions. For the Czech market they find increased correlation with the German 10-year bonds yields following EU accession (0.77 for 2001-2004, 0.88 for 2004-2008 and 0.86 for the full period). They also find that the Czech Republic reaches very high degree of integration based as the sample standard deviation is getting very close to zero in 2006 (together with a slow speed of convergence, which is in line with the achieved level). In the analysis based on the dependence of yield changes on common factors (in their case by the changes in German government bond yields) authors find that for the Czech Republic (and Poland) the changes in yields are increasingly and to large extent determined by the changes in German government bond yields rather than by purely local factors. They conclude that the Czech market is highly integrated with German bond market.

The same set of countries (Czech Republic, Hungary and Poland) is analyzed in terms of bond yields compression in the study by Orlowski and Lommatzsch (2005). Authors argue that increasing convergence in government bond yields is given by adoption of single currency

[102] Expressed as a slope coefficient of a regression of changes in local bond yields on changes in benchmark yields. (Baltzer, et al., 2008. p.16).
[103] Variance ration as "…the proportion of variance in local yield changes that is explained by changes in the German benchmark", (Baltzer, et al, 2008, p.17). The other countries are: Cyprus, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia
[104] Baltzer , et al. 2008, p.18 refer to findings of the study: Lommatzsch, L.-T. and K. Orlowski, 2006, "Bond yield compression in the countries converging to the Euro", William Davidson Institute Working Paper # 799.

(or by the expectations of the adoption) and by harmonization of macroeconomic policies in the converging countries. They analyze the co-movements of the 10-year government bond yields of the selected countries with German one between 2000 and mid-2005 and suggest that compression in bond yields can indicate increasing financial integration of the bond markets of new EU MSs to Euro area[105].

Their main result is that the German yields have a positive impact on the yields of the other countries confirming the co-movements in the bond markets. From among their findings for the Czech Republic we can name the strong and significant dependence on the German bond yields, also significant positive influence of the term spread or positive but weak effect of exchange rate depreciation on the bond yield. The conditional variance estimation for the Czech Republic shows a significant impact of ARCH and GARCH effects on the conditional volatility, with quite a low sum of the estimated coefficients. This as authors note suggests convergence of the volatility to some steady-state (Orlowski, Lommatzsch, 2005, p.20). From the fundamentals analysis for the Czech case they find significant effects of changes in German bond yields and the ECB reference rate as well as lagged inflation and GDP growth rate on the Czech 10-year government bond yields. Overall, they conclude that all the three countries are increasingly integrated with the Euro area markets.

Based on the research findings, the Czech bond markets seem to be highly integrated with the Euro area one, as represented by the German government bonds. In the following empirical exercise we try to offer an additional point of view at the development of these bond markets by studying the relationship through their conditional volatilities. Similarly to other studies we take the German bonds as representatives for the Euro area. We try to find whether there exist some volatility spillovers between the two bond markets and investigate the development of the volatility co-movements as expressed by the correlation between the fluctuations in the bond yields.

[105] They construct a model for nominal bond yields and examine their dependence on German yields and other exogenous variables - the term spread and the exchange rate development and estimate the dynamics of conditional volatility of these yields. Authors use a TGARCH-M model with GED errors to model the conditional mean and variance equations of the bond yields. They also use the central bank reference rate as one of the regressors in the conditional variance (as it may have impact on the volatility). Moreover they analyze yield compression based on fundamental variables that drive the bond yields in these countries including the German bond yields, nominal exchange rate, long-term real interest rate, expected inflation or the output gap.

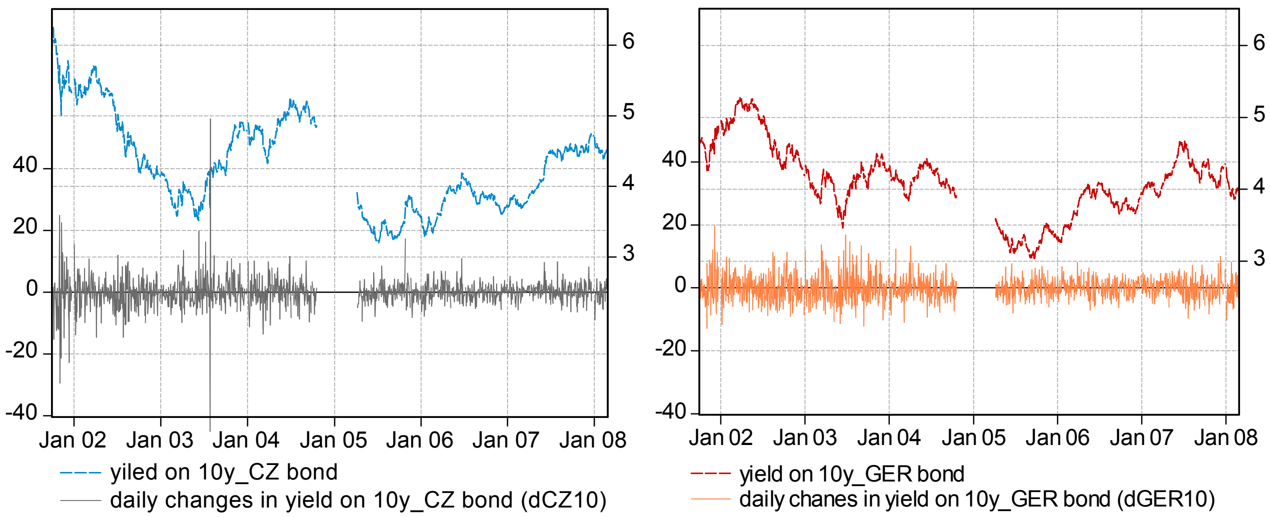
INITIAL ANALYSIS

This time we do not have to calculate the returns as was the case of FX rates and equities as our data are already reported as yields (reported by Reuters as yield to maturity, we use the yields for closing values). In our empirical exercise we focus on the volatility behavior for the period 2005-2008 because of a continuous data sample[106]. The daily yields are *not stationary*, we therefore work with their *first differences* which as shown by the different test are already stationary. (In the tables and graphs we refer to the daily changes in Czech and German bond yields as "dCZ10" and "dGER10" respectively.)

In order to present a more complete picture we present the development of the bond yields since already 2001. The figure B3 plots the yields and their daily changes for the two respective bonds.

Figure B3: 10-year CZ and German government bond yields and respective daily changes.

a) CZ 10-year bond *b) German 10-year bond*



Note: dCZ10 and dGER10 stands for daily changes in 10-year CZ and German government bond yields respectively. The right hand axis shows the reported yield, the left hand axis shows the daily difference in yields in bps. Own calculations. Data Reuters

We can see that none of the yield of the two bonds shows any clear trend over the entire period. The Czech yields were higher than the German ones especially until mid 2002 and

[106] We get the daily data from January 2002 until January 2008, however for the Czech bond yields observations are missing from October 2004 until April 2005 (120 in total) when downloaded form the Reuters Wealth Manager. As for the bivariate GARCH and the conditional correlations we need data sets of identical sample size, we therefore choose to study the most recent common sample available from April 2005 until 2008.

between mid 2003 and mid 2005. Nevertheless the higher yields in CZ case are not a rule, in some cases the CZ ones were below German yields. It seems from the figure that since about mid 2005 the yields were increasing for both bonds, however since mid-2007 we see a diverging pattern in the yields. While the CZ 10-year bond yield remained stable, the one of 10-year German bond started decreasing.

The 10-year Czech bond daily yield changes seem to be more volatile prior to 2004 when we have the data break with some periods of large changes (mid-2002, mid-2003) and some of small changes (beginning of 2003). The daily changes in the German 10-year bond yields seem to be having higher volatility at the end of 2002 and especially in 2003. Between 2004 and mid 2007 these yield differentials appear to be quite stable in a band of +/- 10 basis points. Overall, we can see that the volatility of the differentials seems to be especially low in 2006 and first half of 2007. In the second half of 2007 we notice an increase in daily changes for the yields on both bonds.

We present the <u>*descriptive statistics*</u> for the differenced yields on 10-year Czech and German bonds for the period 2005- 2008 on which we focus in our volatility estimation and also for the full sample 2001-2008.

Table B3:Daily changes in yields on 10-year bonds- Descriptive statistics.

		Mean	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	No. of obs.
Sample 7.4.2005 - 21.2.2008	dCZ10	0.084	17.349	-9.416	2.732	0.418	6.033	299.1 (0.000)	725
	dGER10	0.055	10.051	-10.237	2.910	-0.095	3.217	2.5 (0.2849)	725
Sample full 3.10.2001 - 21.2.2008	dCZ10	-0.052	56.127	-45.026	4.420	0.582	30.948	48609.6 (0.000)	1491
	dGER10	-0.026	19.691	-12.856	3.705	0.409	4.574	195.6 (0.000)	1491

Note: Daily changes in yield dCZ10 and dGER10 in basis points. Observation for 6.4.2005 (the change between the data break) removed. Own calculations in EViews. Data Reuters.

For the sample 2005-2008 (top two lines) we can see that the mean is close to zero for both bonds, it is slightly higher for the Czech one than the German one. The differences in CZ bond yields also have slightly lower volatility in this period than the changes in German yields as measured by the standard deviation. The Czech bonds also have higher kurtosis and positive skewness in the reduced sample and depart from normal distribution, while the German ones are normally distributed with kurtosis close to three and skewness close to zero and the Jarque-Bera test.

The statistics for the full sample give us quite different results- higher volatility, skewness and extremely high kurtosis for the Czech bonds[107]. The German bond yields for the full period exhibit higher standard deviation than in the reduced sample; skewness is positive. Both series for the full sample are leptokurtic; normality is rejected at one percent level of significance by Jarque-Bera test in both cases. The inconsistencies between the latest and the full sample may be perhaps because of large changes undergone in the Czech government bond market. Further on we focus and report our results to the development for the reduced period April 2005- February 2008.

MODELING VOLATILITY

With the stationary series[108], we first specify the mean equation for the yield differences. As argued in the methodology section we again assume that the bond markets are efficient and that the daily changes in yields behave randomly. We do not include any explanatory variables in the equation of the yield changes, except for a constant and we capture possible autocorrelations found in the residuals by an ARMA structure. Our results by OLS estimation and residual diagnostics again suggest that only an ARMA structure is not appropriate for the bond yields[109]. Therefore we estimate the mean equation together with a GARCH specification of the conditional variance of the error terms. We summarize the chosen model specification including the coefficient estimates for both bonds in table B4. We report on the detailed results in appendix in table AB3[110]. In table B4 we can see that the results are

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[107] For the Czech case the kurtosis is very high for the full sample, however the result may be affected by an extreme value in July 2003.

[108] As we said both series of the bond yields are stationary in first differences. We report the results for the ADF, PP and KPSS tests for the sample 2005-2008 in appendix.

[109] When estimated by OLS for the Czech 10-year bonds we choose the ARMA (2,1) structure for the mean equation, for the German 10-year bond the MA(1). In both cases the residuals from the OLS estimation are white noise, but have correlated squared residuals (for the German case starting at higher lags, about 20). The ARCH-LM test also indicates the presence of ARCH effects (for the German case significant at higher lags, cca 20).

[110] For the case of the 10-year Czech government bond, we choose the parsimonious AR(1) specification for the conditional mean equation and the GARCH(1,1) structure that captures sufficiently well the squared residuals´ autocorrelation. We estimate the given specification with assuming normal, GED and t-distribution of errors to capture the possible fat tailed distribution of the daily yield changes. All the estimated coefficients under all assumptions are significant, except the constant in the mean equation. The estimates of the variance coefficients sum up to number below one and are all positive, so non-negativity and stationarity conditions are satisfied. The standardized residuals and the standardized squared residuals tests show no remaining autocorrelations (insignificant both the Q-statistics and the ARCH-LM test).

The estimation with GED and t-distribution error assumption estimate GED parameter (1.3) as well as the parameter v of degrees of freedom of the t-dist. (5.8) as significant. Otherwise the coefficient values and significance are very similar in both cases, GED and the t-distribution report higher significance for ARCH and GARCH terms. GED seems to give the best fit based on quantile plots. It is also used in application by Orlowski, not very similar for the two bonds.

Table B4: Results of GARCH estimation for 10-year government bond market. 2005 - 2008.

formalization of the chosen specification	
CZ 10-year government bond	German 10-year government bond
$dy_{CZ10,\ t} = c_{CZ10} + u_{CZ10,\ t}$	$dy_{GER10,\ t} = c_{GER10} + u_{GER10,\ t}$
where $u_{CZ10,\ t} = \rho_1 u_{CZ10,\ t-1} + \varepsilon_{CZ10,t}$	$u_{GER10,\ t} = \varepsilon_{GER10,t} + \delta_1 \varepsilon_{GER10,\ t-1}$
$dy_{CZ10,\ t}$ … time difference between yields on 10-year Czech government bonds at *t* and *t-1* (dCZ10)	$dy_{GER10,\ t}$ …time difference between yields on 10-year German government bonds at *t* and *t-1*. (dGER10)
c_{CZ10} … constant term of the conditional mean equation	c_{GER10} …constant term of the conditional mean equation.
where error term $\varepsilon_{CZ10} \sim iid \vert I_{t-1}\ (0;\ h_{CZ10,t})$ (assuming GED here) and the conditional variance $h_{CZ10,t}$ follows GARCH(1,1). $h_{CZ10\ t} = \omega_{CZ10} + \alpha_{CZ10}\varepsilon^2_{CZ10,t-1} + \beta_{CZ10} h_{CZ10,t-1}$	with error term $\varepsilon_{GER10} \sim N \vert I_{t-1}\ (0;\ h_{GER10,t})$ and the conditional variance $h_{GER10,t}$ follows GARCH(1,1). $h_{GER10,\ t} = \omega_{GER10} + \alpha_{GER10}\varepsilon^2_{GER10,t-1} + \beta_{GER10} h_{GER10,t-1}$

Main results

	Conditional mean equation			Conditional variance equation		
i	**c_i** *Mean const.*	**ρ_i** *AR(1) term*	**δ_i** *MA(1) term*	**ω_i** *constant variance*	**α_i** *ARCH term*	**β_i** *GARCH term*
dCZ10	**0.0928** *(0.879)*	**0.1879 ***** *(5.230)*	n/a	**3.0969 ***** *(2.594)*	**0.1629 ***** *(2834)*	**0.3941 **** *(2.062)*
dGER10	**0.0921** *(0.761)*	n/a	**0.2028***** *(5.500)*	**0.0839** *(0.643)*	**0.0227 *** *(1.671)*	**0.9681 ***** *(36.191)*

Sample: 7.4.2005- 21.2.2008, 725 observations. *i* stands for Czech or German bond. ***, **, * denote 1%, 5%, 10% level of significance. Numbers in brackets are the z-statistics. The dGER10 under normal error distribution, the dCZ10 under GED, with GED parameter estimated 1.3 ***. Non negativity constraints were satisfied, stationarity condition: $\alpha+\beta<1$ also. The Wald coefficient test however at 10% did not reject the H0 of equality for the German bonds. Details in appendix table AB3. Own calculation using EViews. Data Reuters.

The conditional variance of the Czech bond is mainly derived from the high and strongly significant long-term constant variance term (ω), and a persistence of conditional volatility (β) is quite low (0.39) compared to the German bond (0.97)). There is significant but rather low impact of the last periods´ shocks. The sum of the ARCH and GARCH terms for the Czech bond yields is quite low, suggesting lower persistence of shocks. (Similar finding is

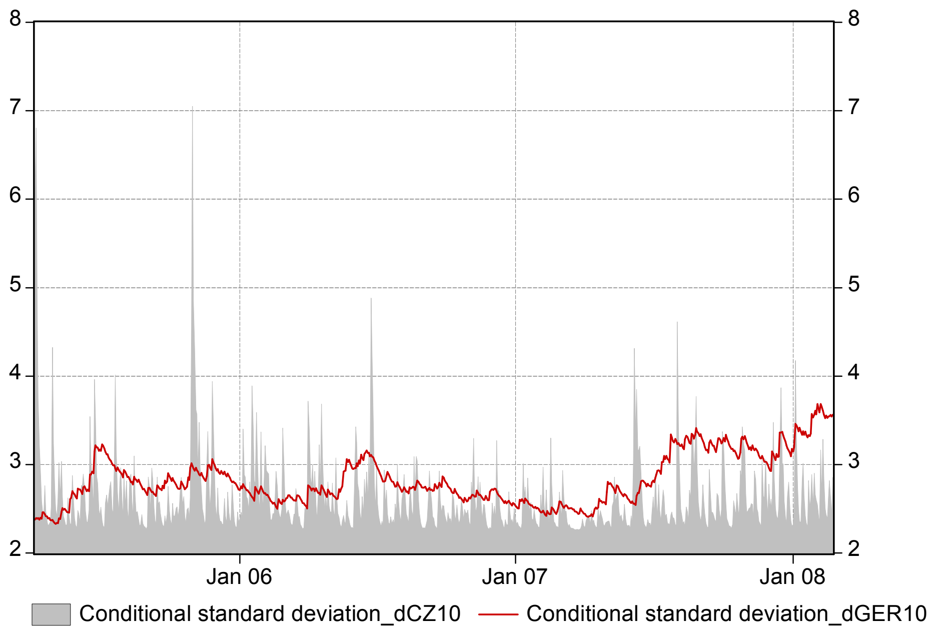
Lommatzsch, 2005 for the bonds market.

For the German bonds we choose the MA(1) structure in the mean equation estimated together with GARCH conditional variance. The GARCH(1,1) specification is sufficient to remove the autocorrelation in residuals. The specification estimates as significant both GARCH and ARCH terms, however the constants are not significant. The residuals from this estimation are normally distributed; we therefore do not estimate the model under different error distributional assumptions.

presented by Orlowski and Lommatzsch (2005) who however construct a different model including exogenous variables for conditional variance and mean equations). The strong effect of the constant may be perhaps reflecting lower market liquidity of the Czech government bond markets.On the other hand the conditional variance of the German bond is mainly derived from the persistence in the past conditional variance (high β (0.97)). The results suggest that on daily basis the conditional volatility is mainly given by the expected conditional volatility derived in past period which may incorporate the relevant expectations on fundamentals. The previous period's shocks affect the current volatility only to limited extent (The impact of the past shocks to current conditional volatility is quite limited as shows the low value of α (0.023)). We do not find significant long-term volatility level for the German bond.

After evaluating the model specification we extract the conditional standard deviation from the estimated conditional variance equation. The different pattern in the two resulting conditional variances is best visible on a graph. We can identify the "constant" volatility level for the 10-year Czech bond yield changes with high random deviations from it. The conditional volatility of the 10-year German bond yield change shows rather random but more stable behavior, increasing since mid 2007 until the end of the sample. Also in both cases the deviations were reaching lower levels in second half of 2006 until first half of 2007.

Figure B4: Conditional standard deviation of 10-year Czech and German government bond yields



Own calculations using EViews. Data Reuters.

Finally we checked our estimation of both univariate GARCH and bivariate BEKK-GARCH models on the full data sample from October 2001 until February 2008 (data set which included the data break). The results for the univariate estimation of the German bond yields for the full sample were confirmed including the residuals checks; only the normality of residuals was rejected. For the differences in 10-year Czech government bond yields and the selected specification the model diagnostic showed strong autocorrelations pointing to poor model fit to the data. This suggests our model is not appropriate. Detailed results are presented in table AB7 in appendix. We therefore cannot confirm our results for the data sample 2001-2008. This may be because of the important break in the data or by the changes in the market structure and development that make the result inconsistent for the full and reduced period[111].

VOLATILITY TRANSMISSIONS

The development of the two conditional volatilities for the two bonds suggests quite a different pattern. We try to find out whether there is a significant volatility spillover or co-movement between the two bonds by estimating the bivariate GARCH model. The results from the unrestricted model estimation for the estimates of the parameter matrices (as specified in the theoretical equation (I.2.12)) show very poor significance at five percent level[112]. Moreover the model performance is also insufficient in terms of the residuals tests due to high autocorrelation in residuals and squared residuals[113]. This suggests that the model is not appropriate for our data and its reporting ability is rather bad. The detailed estimation results are presented in table AB4 in appendix.

At least for illustration we again present the functions of the estimated parameters as they enter the conditional variance and covariance processes. In table B5, the impacts of the various terms are marked as bold if they are function of significant coefficient estimates at 5%

[111] For the case of the Czech bonds the estimated univariate model AR(1)-GARCH(1,1) had all coefficient significant, however there was a strong remaining autocorrelation in squared residuals up to high lags (between lags 1-23 and 34-91), see table AB7 in appendix for details. We tried to include additional ARCH and GARCH terms and estimated the model under different distributional assumptions. Some of the specifications were able to remove the autocorrelation of squared residuals at lower lags (such as the AR(1)-GARCH(4,1)-GED specification, or AR(1)-GARCH(3,1) with t-distributed errors). Nevertheless we did not manage to remove the autocorrelation of the squared residuals, which was significant from lag 34 until lags 50 or 70, depending on a specification.

[112] The only significant estimates at 5% level are the diagonal constant terms and b_{11} and b_{22} parameters. Other estimated coefficients of the parameter matrices turned out non-significant on 5% significance level.

[113] The residuals tests (Portmanteau tests for autocorrelation and ARCH-LM test) show significant autocorrelations; the ARCH effects are present up to high lags. The normality is rejected for the Czech and not for the German bonds. The stationarity condition was satisfied.

level[114]. The values in grey show impacts that are a function of (at least one) insignificant estimates. Subscript 1 stands for 10-year Czech government bonds, subscript 2 for their German counterparts.

Table B5: Coefficients of the conditional variance and covariance equations for 10-year bonds market

	constant term	$\varepsilon_1\varepsilon_{1,\ t-1}$	$\varepsilon_1\varepsilon_{2,\ t-1}$	$\varepsilon_2\varepsilon_{2,\ t-1}$	$h_{11,\ t-1}$	$h_{12,\ t-1}$	$h_{22,\ t-1}$
$h_{11,t}$	**0.7958**	0.0389	0.0322	0.0067	**0.8648**	-0.0939	0.0026
$h_{22,\ t}$	0.2832	0.0017	-0.0155	0.0353	0.0013	0.0684	**0.9032**
$h_{12,t}$	0.4745	-0.0081	0.0337	0.0153	0.0335	0.8820	-0.0480

The numbers in bold are functions of estimated coefficients significant at five percent level, others are products of non-significant estimates. We approximate on the significance of the product of the two coefficients, only when each of them was significant at 5% level. Sample April 2005- February 2008. Own calculations in JMulTI. Data Reuters.

The parameters estimates point to significant persistence of the own conditional volatility in both markets is significant[115]. For conditional variance of the Czech bonds there is also a clear difference in the results compared to the univariate estimation. The former one suggests that own volatility persistence is strongly significant and is estimated around 0.865 while when estimated using univariate model it was much lower (0.035). However due to bad model performance, the reliability of this estimate is rather low.

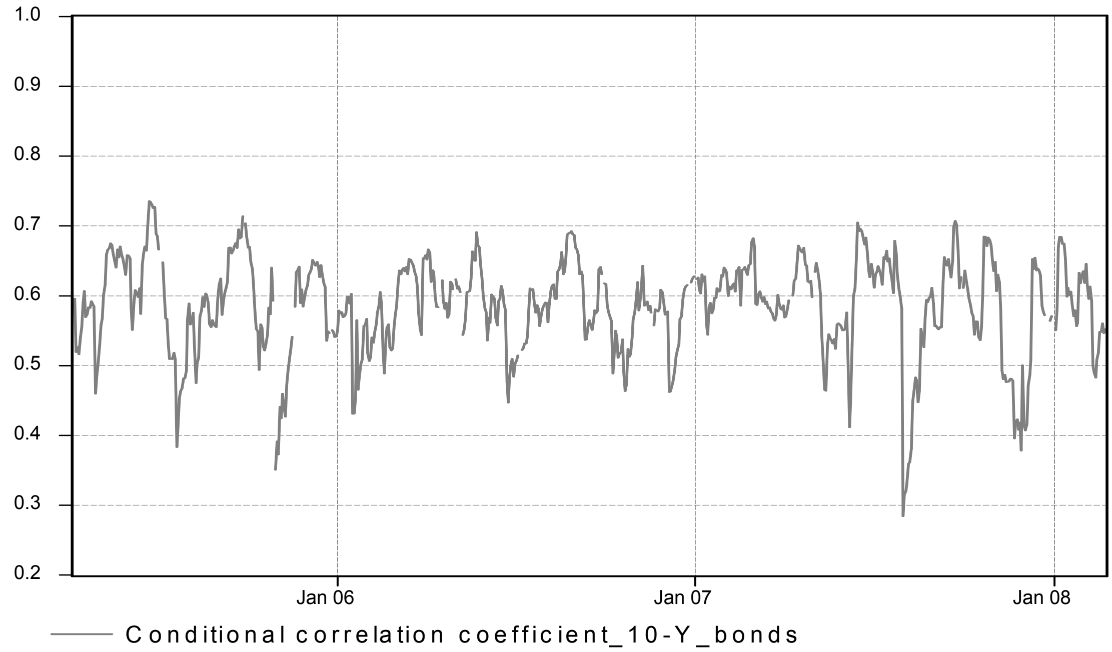
The differences between the results from different model estimations[116] and the poor performance of the unrestricted model lead us to conclude that it is not very appropriate and we cannot draw any significant conclusions from it.

The derived conditional correlation is quite strong, with a mean close to 0.6 and quite stable until mid 2007. Since then we can observe higher volatility of the daily conditional correlations between the fluctuations in the bond yields changes, suggesting increasing

[114] We again remind that we did not test the joint significance of the coefficients in the unrestricted model due to computational issues. The results therefore have to be interpreted with caution. We approximate on the significance of the product of the two coefficients, only when each of them was significant at 5% level.
[115] This results from significant diagonal parameters of matrix B (b_{11}, b_{22}) as specified in (I.2.12).
[116] The estimation of a *diagonal BEKK-GARCH model* shows different results from the previously discussed unrestricted model (We remind that the diagonal version of BEKK-GARCH model imposes restrictions on parameter matrices A and B (see eq. (I.2.12)) to be diagonal.). For the Czech bond the impact of own past conditional volatility on the current one is estimated as lower than by the unrestricted model (0.460 vs. 0.865) and closer to the values estimated in the univariate case. This time most of the parameter matrices coefficients are estimated as significant except one of the diagonal elements of a constant matrix Ω, which is moreover estimated as negative. For completeness we present results of the restricted model in AB6 in appendix.

differences in the pattern of volatility behavior. The conditional correlation coefficient also seems to be more stable, when compared to the results for the other markets (stock and foreign exchange) over the period 2005-2008. As we are evaluating the long-term stable debt instruments, this result is in accordance with general intuition. However we must bear in mind that it is not backed with a well performing model. Perhaps this result may be reflecting other, in our estimation not included relationships between the two markets. As such its interpretation as volatility co-movements may be misleading. We present the conditional correlation coefficient from the unrestricted diagonal model in figure B5.

Figure B5: Conditional correlation coefficient for 10-year bonds (dCZ10. dGER10) fluctuations.



Calculated from the unrestricted BEKK-GARCH. Own calculations in JMulTi, EViews. Data Reuters.

CONCLUSION 10-YEAR GOVERNMENT BOND MARKET

We evaluated empirically the conditional volatility of the daily changes in 10-year government bond yields. Different previous studies suggested high degree of financial integration of the Czech bond market with the Euro area one using various methods. The Czech bond market is affected by its German counterpart as showed previous research on the topic.

The pattern of the bond yields shows that the Czech and German government bonds show similar development in terms of yields with convergence of the spread over the period

2005-2008 (the yield spreads were max. 50 basis points). However the estimated conditional volatility pattern of the two bond yields is quite different. The German bond yields derive most of the conditional volatility from the past volatility forecasts and to lower extent they are affected by the past news. On the other hand the conditional volatility of the Czech bonds shows significant constant long-term level and limited own volatility persistence. The results for the Czech bond market are however not consistent as the model performance is poor for when applied to larger sample 2001-2008.

The joint estimation of volatility transmissions had quite a poor performance. We could not confirm direct cross-volatility spillovers between the markets. Existence of own volatility persistence in the 10-year German government bond yield is a result to which we arrive using different methods. For the Czech bonds however our findings differ for each specification, we therefore conclude that our model is not appropriate.

The conditional correlation between the fluctuations of the 10-year government bond yields reaches quite high values on average moving around 0.6 for the selected period 2005-2008. Based on these findings the volatility behavior would appear as quite similar in the two markets. However the poor model significance does not allow us to make conclusion that this signifies volatility co-movements. Perhaps the strength of the correlation reflects other relationships between the two bonds (that exist according to previous research). Better results could be obtained by accounting for these relationships and our approach therefore does not bring any valuable contribution.

We conclude that the pattern of conditional volatility dynamics in the 10-year government bond market is different for the Czech Republic and for the Euro area represented by the German bonds. The latter ones show conditional volatility persistence, for the former one the inconsistencies in results do not allow us to make reliable conclusions. ***The conditional correlations between the fluctuations in the two markets were identified as quite high. However the poor model reporting ability does not allow concluding that these correlations reflect synchronization of shocks and similar volatilities. Based on our analysis, we conclude we cannot confirm our hypothesis of existing significant volatility relationships between the two markets***.

CONCLUSIONS

Financial markets of different countries can hardly be analyzed in isolation in today's globalized and interconnected world markets. Our work was inspired by the implications of increasing financial market interconnections. As a theoretical background for our empirical analysis of financial market interconnections between the Czech and Euro area we discussed financial integration. We have adopted a broad definition of financial integration as an increased openness and subsequent strengthening of linkages between the financial markets.

Our discussion of some of its implications suggests that financial integration may have rather a stabilizing effect on the markets by increasing market efficiency and better risk sharing or smooth monetary policy transmission. On the other hand greater market openness brings about certain risks related to financial stability. As we have mentioned, the financial integration is for its importance also closely monitored by different authorities.

We based our hypothesis on the assumption that stronger financial integration increases the exposure of the individual markets to common factors. We suggested that this may be accompanied by higher synchronization in the market behavior. We tried to offer an additional perspective of financial markets' synchronization, namely through their volatilities as complementary information to the assessment of linkages between the studied markets. Specifically, we formulated our hypothesis that there are significant relationships between the financial markets of the Czech Republic and the Euro area through their volatility on the foreign exchange, equities and government bond markets.

Volatilities and their transmissions are important for all market participants that are all exposed to financial markets risks. We used the existing research findings on the integration of the Czech and Euro area markets as groundwork for our analysis and we examined the market synchronization in terms of volatility behavior and transmissions.

For our purposes in the empirical part of the work we used the family of GARCH models. As we argued, these are largely applied in finance for their convenience for volatility modeling. Moreover as we discussed, they can be especially useful in their multivariate forms when studying mutual relationships and interdependencies between assets, such as volatility transmissions. As such they have been used in applications some of which we have reviewed.

Our empirical analysis was aimed at answering questions related to synchronization between the Czech and Euro area financial markets. We investigated relationships between these markets through their conditional volatilities and tried to identify their forms.

Firstly, our findings show that reflections of the turbulent behavior in financial markets in the past year are observable in the market volatilities. Since approximately mid-2007 an increase in conditional volatility can be observed in all the markets that were subject of our study.

In terms of volatility transmissions we were not able to confirm the significance of our model when evaluated in each market for the selected period and for different periods as a check for its validity. We therefore emphasize that our conclusions regarding volatility relationships can only be taken as indicative.

With respect to the foreign exchange market we concluded that the relationships between the volatilities of Czech and Euro area foreign exchange markets are identified mainly as important volatility co-movements, which we defined in terms of conditional correlation between the market fluctuations. Some indications of direct volatility spillovers were also found when considering the period 1999- 2008, however of very low values. In line with the existing research findings our results are supportive of increasing integration as well as synchronization of the market behavior.

As some of the previous research suggested, integration of the Czech equities market with the Euro area is rather low with signs of certain progress in terms of integration. We discussed that the Czech equities market has gone through some important positive development in the past years. Based on our empirical analysis we could not however confirm significant spillovers between the Czech and European equities markets volatilities as we could not base our results on a well performing model. We identified some indication for increasing correlations between the fluctuations in the stock market returns. These correlations are however still very volatile without a clear pattern.

Finally we evaluated the development of the bond markets. We discussed some important market characteristics showing growing importance of government bonds on the debt market in the Czech Republic over the past few years. The similar behavior of Czech government bonds yields with the Euro area ones suggests a high degree of integration of the two markets. This is also emphasized in many existing empirical studies. Our empirical analysis of the volatilities pattern however did not manage to contribute to these findings, as it was not supported by a well performing model. We did not find significant volatility spillovers. We also identified indications of stable and quite important conditional correlations. These correlations may however not be reflecting synchronization of shocks and similar volatilities but also other relationships. We concluded we cannot confirm our hypothesis of existing significant volatility relationships between the two markets.

Our empirical analysis of financial markets' interconnections through their volatilities did not allow us in most cases to conclude on significant volatility spillovers and therefore to confirm our hypothesis of significance of these relationships. However we believe that the indications that we have presented bring some additional insights on the financial markets interconnections and their dynamics. The correlations between the fluctuations indicate the strongest degree of interrelatedness between Czech Republic and Euro area in the foreign exchange market.

We did not evaluate the driving forces behind the volatility relationships. This could be a possible extension to our empirical analysis. As we have emphasized the financial markets' interconnections are far from being straightforward. Further research on the driving forces that cause market co-movements can be especially valuable as to profit from the increasing integration and stronger market linkages.

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APPENDIX

AP I. THEORETICAL PART

Box AI: Review of selected financial market integration indicators

We follow Baele, et al. (2004, p.11-20), Baltzer, et al. (2008, p.7-11) and CNB (2007) and their argumentation in the list of financial market integration indicators they use and to which we have referred to in the text. This box is presented for completeness and information only; we did not apply these indicators in our study.

a) ***Price based measures*** include either direct comparison of yields on assets from different regions or measures adjusted for the different characteristics of the assets (such as risk factors). One such direct measure is the *difference between yield on local assets and a chosen benchmark assets*; this spread would be under perfect market integration zero. Formally, we can write $R_{i,t}=Y_{i,t}- Y_{B,t}$, where $R_{i,t}$ is the spread, $Y_{i,t}$, $Y_{B,t}$ denote yields on the *i* country's local asset and a benchmark asset, for example yield to maturity. (For example Baltzer, et al., 2008, p.7)

"*Beta convergence"* (Beta and sigma convergence concepts come from the growth literature, Adam, et al., 2002) is used to measure the *speed of convergence*; the coefficient shows how the spread between the yields on a local and benchmark asset behaves in time. Negative values of beta suggest existing convergence. The value of β gives the speed of convergence, which is faster the closer β is to one in absolute value. Formal expression of the model can be written as:

$$\Delta R_{i,t} = \alpha_i + \beta R_{i,t-1} + \sum_{l=1}^{L} \gamma_l \Delta R_{i,t-1} + \varepsilon_{i,t} ,$$

where $R_{i,t} = Y_{i,t}-Y_{B,t}$ is a spread between country *i´*s yields *Y* on a given asset and a benchmark asset at time *t*, *Δ* is a time difference operator, α_i is a country dummy, *L* is a maximum lagged used, ε_t is the error terms and β is the speed of convergence. (For example, CNB, 2007, p.86).

Beta convergence is in the literature complemented by the "*sigma convergence"* which expresses the *degree of integration* achieved. (In some studies it is referred to as *cross-sectional dispersion in yields*). The convergence increases with decreasing cross-sectional dispersion, under full integration the indicator would equal to zero. The indicator σ can be formalized as:

$$\sigma_t = \sqrt{I^{-1} \sum_{i=1}^{I} (Y_{i,t} - \overline{Y_t})^2}$$

where *I* denotes the number of countries analyzed, $Y_{i,t}$ is yield of an asset (for ex. ytm on a bond), $\overline{Y_t}$ denotes cross-sectional average of yields in all countries at time *t. (*For example Baltzer, et al., 2008, p.8).

ii.) The ***news based measures*** are based on the idea that integrated markets should be to high extent influenced by common factor, while the local factors should have little or no significance. In integrated markets the local shocks should be diversifiable away and so (ceteris paribus) the higher the degree of integration, the greater portion of the price variation is expressed by global factors. Therefore these indicators quantify to what extent price changes are affected by the local or common/ global component. In practice the proxy for the common news can be for example price change in a benchmark asset or innovations in global market returns.

For example a *variance ratio* that explains what portion of the variance of local (country *i*) equities returns is explained by EU-wide news can be formalized as:

$$VR_{i,t}^{EU} = \frac{(\hat{\beta}_{i,t}^{EU})^2 \sigma_{EU,t}^2}{\sigma_{i,t}^2}$$

where $\hat{\beta}_{i,t}^{EU}$ stands for the country *i*'s sensitivity to Euro area shocks, $\sigma_{i,t}^2$ is the variance country *i*'s returns.

iii.) Finally the ***quantity based measures*** depend on the considered market segment and include for example cross border activities or structure of portfolio holdings related to home bias. These indicators can be for example used to describe changes in regulatory framework (such as cross border holdings of euro area banks).

AP II. EMPIRICAL PART

Table AII.1: Summary of data sets

Description	Reuters code	Currency	Data quality	Price/Frequency used	Period
CZK/USD	CZK=	n/a	Realtime	Daily Close	4.1.1999 - 28.2.2008
EUR/USD	USDEUR=R	n/a	Realtime	Daily Close	4.1.1999 - 28.2.2008
PX - PSE index	.PX	CZK	Realtime	Daily Close	4.1.1999 - 7.3.2008
DJ STOXX 600	.STOXX	EUR	Delayed	Daily Close	4.1.1999 - 7.3.2008
10Y CZ T-BOND	CZ10YT=RR	CZK	Delayed	Default yield/ close	3.10.2001-19.10.2004. 6.4.2005- 21.2.2008
10Y GER T-BOND	EU10YT=RR	EUR	Delayed	Default yield/ close	3.10.2001 - 21.2.2008

Data source: Reuters Wealth Manager site

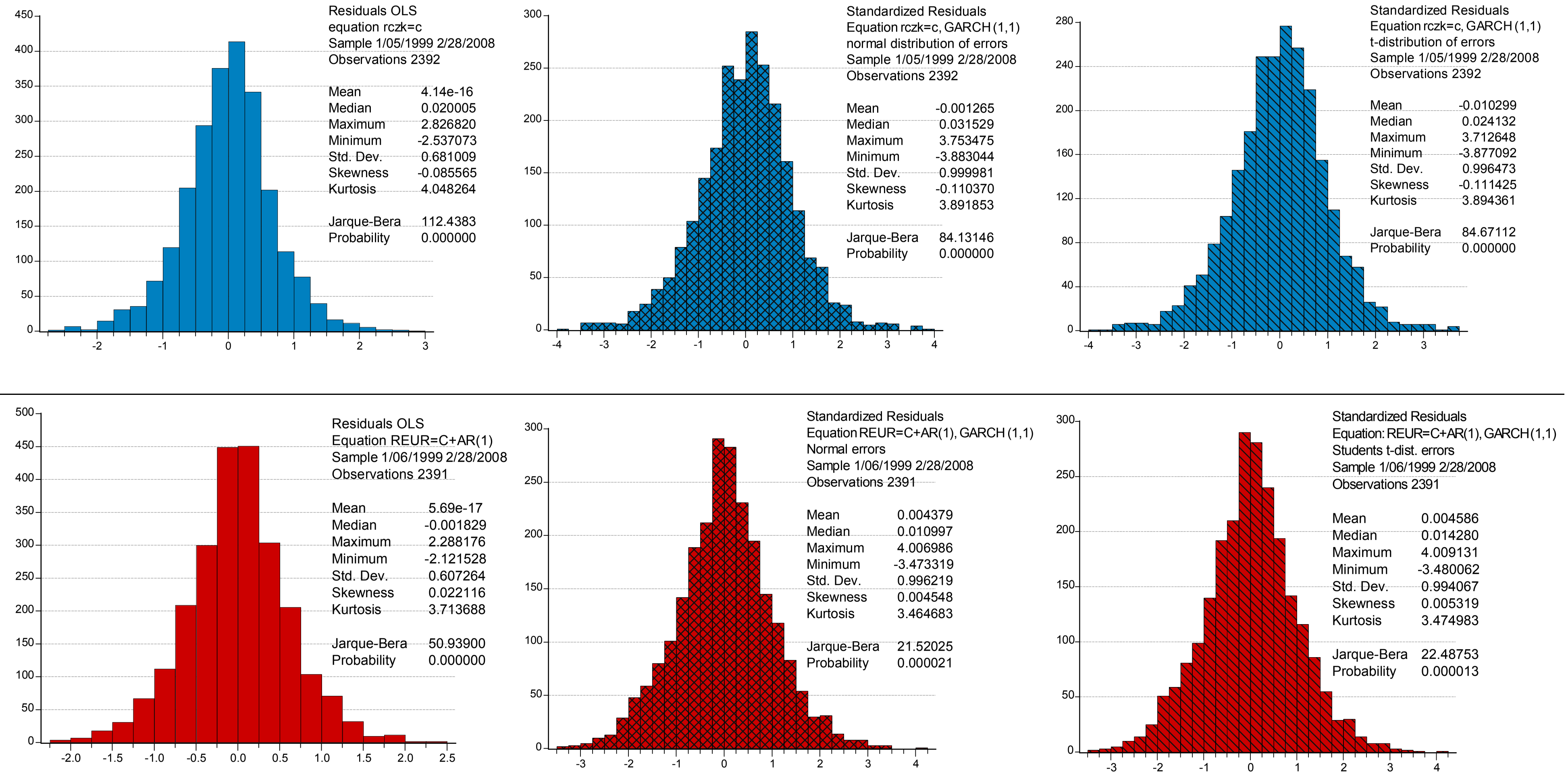
Table AII. 2: Results of stationarity tests

	Test:	**ADF** *H0: unit root*		**PP** *H0: unit root*		**KPSS** *H0: stationarity*	
series:	exogenous var.	Levels	1st differences	Levels	1st differences	Levels	1st differences
returns $\ln(PX_t/PX_{t-1})$	none	-45.521 ***		-45.587 ***			
	constant	-45.597 ***		-45.625 ***		0.167	
	const. & trend	-45.587 ***		-45.615 ***		0.162 **	
PX	none	1.425	-45.452 ***	1.377	-45.453 ***		
	constant	-0.375	-45.506 ***	-0.395	-45.495 ***	5.037 ***	0.196
	const. & trend	-1.530	-45.498 ***	-1.530	-45.487 ***	1.258 ***	0.163 *
returns $\ln(DJ_t/DJ_{t-1})$	none	-48.698 ***		-48.858 ***			
	constant	-48.688 ***		-48.847 ***		0.166	
	const. & trend	-48.678 ***		-48.836 ***		0.158 **	
DJ STOXX (DJ)	none	-0.146	-48.895 ***	-0.108	-49.129 ***		
	constant	-1.351	-48.885 ***	-1.232	-49.118 ***	1.123 ***	0.168
	const. & trend	-1.351	-48.874 ***	-1.231	-49.106 ***	1.128 ***	0.170 **
10y CZ bond	none	0.847	-39.487 ***	0.573	-36.815 ***		
	constant	-0.440	-39.470 ***	-0.657	-36.845 ***	2.517 ***	0.194
	const. & trend	-2.784	-39.425 ***	-3.346 *	-36.833 ***	0.223 ***	0.082
10y GER bond	none	0.361	-24.194 ***	0.293	-24.216 ***		
	constant	1.233	-24.183 ***	-1.200	-24.205 ***	2.576 ***	0.109
	const. & trend	-1.986	-24.156 ***	-2.187	-24.187 ***	0.213 **	0.107
returns $\ln(CZK/USD_t/ CZK/USD_{t-1})$	none	-50.281 ***		-50.287 ***			
	constant	-50.336 ***		-50.330 ***		0.599 **	0.0140
	const. & trend	-50.468 ***		-50.443 ***		0.120 *	0.013
CZK/USD spot	none	-1.166	-49.973 ***	-1.146	-49.979 ***		
	constant	0.394	-49.998 ***	-0.359	-49.999 ***	5.433 ***	0.452 *
	const. & trend	-3.991 ***	-50.078 ***	-3.991***	-50.066 ***	0.494 ***	0.156 **
returns $\ln(EUR/USD_t/ EUR/USD_{t-1})$	none	-51.701 ***		-51.658 ***			
	constant	-51.707 ***		-51.666 ***		0.550 **	0.024
	const. & trend	-51.801 ***		-51.777 ***		0.143 *	0.024
EUR/USD spot	none	-0.670	-51.693 ***	-0.709	-51.645 ***		
	constant	-0.258	-51.692 ***	-0.206	-51.646 ***	4.408 ***	0.474 **
	const. & trend	-2.990	-51.764 ***	-2.982	-51.737 ***	0.616 ***	0.155 **

***, **, * denote 1%, 5% and 10% significance level of rejecting the null hypothesis. Own calculations in EViews. Data Reuters

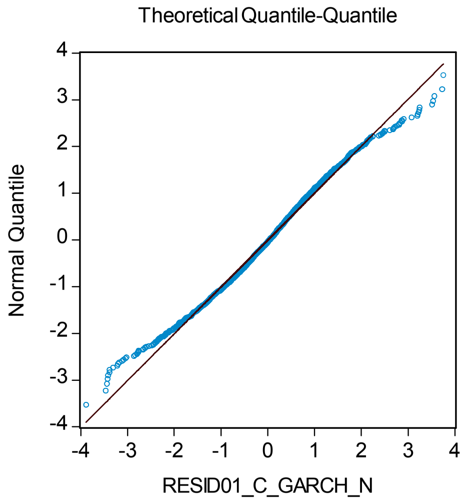
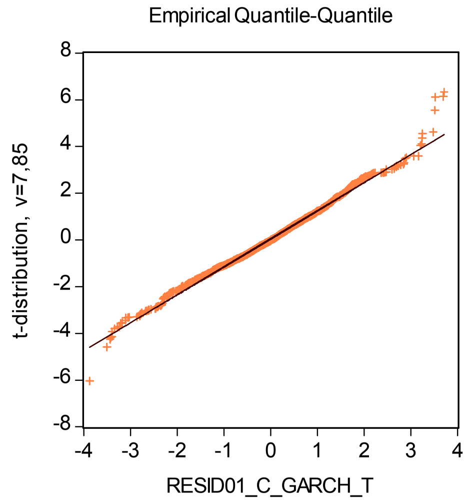
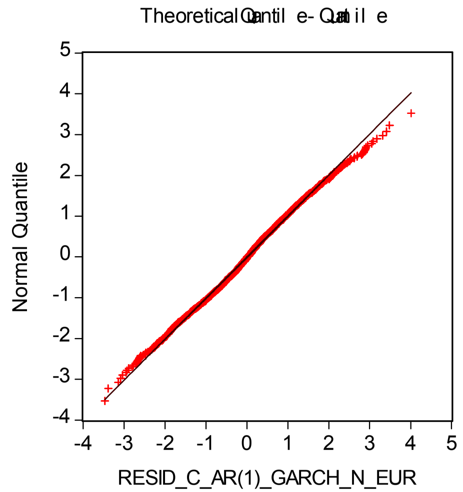
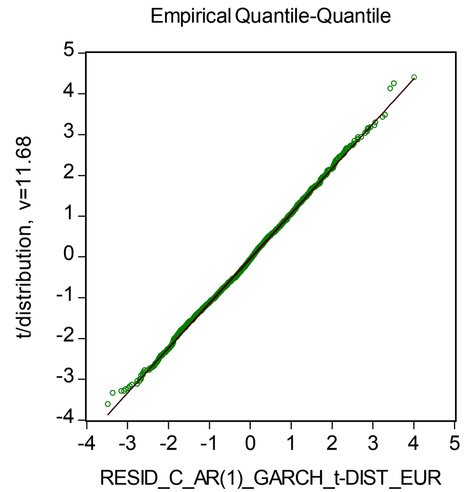
Figure AFX1: FX MARKET. Histograms of standardized residuals: OLS vs. GARCH.

	OLS estimates of returns	GARCH (1,1) estimates assuming Normal distribution of errors	GARCH (1,1) estimates assuming Student t-distribution of errors
RCZK			
REUR			



Own calculations in EViews. Data Reuters.

Figure AFX2: Quantile plots of standardized residuals from estimated GARCH model for FX market.

	Assuming Normal distribution	Assuming Student t-distribution
RCZK		
REUR		

Note: FX market returns of CZK/USD (RCZK) and EUR/USD (REUR).Equations: RCZK=C, REUR=C+AR(1), both with GARCH(1,1) variance. Own calculation using EViews. Data Reuters.

Table AFX1: GARCH model estimates for FX markets returns. Sample 1999 - 2008.

			CZK/ USD returns (RCZK)		**EUR/ USD returns (REUR)**			
	Error distribution assumption		Normal	Student's t	Normal	Student's t	Normal	Student's t
	Variance equation		$h_t= \omega+ \alpha_1\varepsilon_{t-1}^2+ \beta h_{t-1}$		$h_t= \omega+ \alpha_1\varepsilon_{t-1}^2+ \beta h_{t-1}$		$h_t= \omega+ \alpha_1\varepsilon_{t-1}^2+ \alpha_2\varepsilon_{t-2}^2+ \beta h_{t-1}$	
	Return equation		$rczk_t=c+ \varepsilon_t$		$reur_t=c+\rho AR(1)+ \varepsilon_t$		$reur_t=c+ \rho AR(1)+ \varepsilon_t$	
Coefficient estimates	**c**	return constant	**-0.0276 ****	**-0.0216 ***	**-0.0188 ***	**-0.0189 ***	**-0.0168**	**-0.0174**
			(-2.061)	*(-1.699)*	*(-1.708)*	*(-1.774)*	*(-1514)*	*(-1.653)*
	ρ	AR(1) term	n/a	n/a	**-0.0443 ****	**-0.0012 ****	**-0.0408 ****	**-0.0473**
					(-2.223)	*(-2.370)*	*(-2.040)*	*(-2.463)*
	ω	variance constant	**0.0027 ***	**0.0032 ***	**0.001 ***	**0.0012**	**0.0012 ***	**0.0014 ***
			(1.958)	*(1.733)*	*(1.673)*	*(1.594)*	*(1.801)*	*(1.673)*
	α1	ARCH (1) term	**0.0255 *****	**0.0279 *****	**0.0267 *****	**0.0290 *****	**-0.0268**	**-0.0291 ***
			(4.422)	*(4.067)*	*(5.101)*	*(4.649)*	*(-1.566)*	*(-1.728)*
	α2	ARCH (2) term	n/a	n/a	n/a	n/a	**0.0577 *****	**0.0627 *****
							(3.351)	*(3.374)*
	β	GARCH (1) term	**0.9689 *****	**0.9659 *****	**0.9706 *****	**0.9682 *****	**0.9659 *****	**0.9629 *****
			(127,809)	*(109.739)*	*(165.566)*	*(148.714)*	*(149.967)*	*(128.520)*
Equation result	t-dist df		n/a	7.854 ****(5.534)*	n/a	11.68 ****(3.626)*	n/a	11.667 ****(3.652)*
	Schwarz criterion		2.0457	2.0254	1.7897	1.7843	1.7892	1.7836
	Log likelihood (LL)		-2431	-2403	-2121	-2110	-2116	-2105
	Adj. R-squared		-0.00128	-0.00169	0.0017	0.0009	0.0007	0.0004
	Wald test: H_0: $-1+\alpha_1+\alpha_2+\beta_1=0$		-0.0056 * *SE: (0.003)*	-0.0063 *SE: (0.004)*	-0.0027 *SE: (0.002)*	-0.0029 *SE: (0.002)*	-0.003 *SE: (0.002)*	-0.003 *SE: (0.003)*
Residuals test:	Q resid.(k=15)		16.321 (0.361)	16.322 (0.361)	12.025 (0.644)	11.576 (0.640)	11.909 (0.614)	11.969 (0.609)
	Q Sq.resid. (k=15)		22.212 (0.102)	21.273 (0.128)	18.694 (0.177)	18.677 (0.178)	13.063 (0.522)	13.157 (0.514)
	ARCH-LM: Obs*R-sq (k=15)		21.206 (0.130)	20.210 (0.164)	19.391 (0.197)	19.457 (0.194)	13.089 (0.595)	13.238 (0.584)
	Skewness		-0.1104	-0.1114	0.0045	0.0053	0.0034	0.0045
	Kurtosis		3.8919	3.8944	3.4647	3.4750	3.4744	3.486
	Jarque-Bera statistics		84.131 (0.000)	84.671 (0.000)	21.520 (0.000)	22.488 (0.000)	22.425 (0.000)	23.551 (0.000)
	Observations		2392	2392	2391	2391	2391	2391

Note: ***, **, * denotes 1%, 5%, 10% level of significance. Values in brackets are the z-statistics, and by the residuals test the p-values. Wald restriction test for $\sum \alpha+\beta=1$, with significance of rejection the null hypothesis and standard errors in parenthesis. Q stands for Ljung-Box Q statistics lag (k), reported is k=15, in brackets are p-values. ARCH-LM test with p-values in brackets. For the REUR GARCH (1,1) the Q for the squared residuals significant for normal distribution lag for which Q was still significant at * up to k=6 and ARCH-LM test up to k=4 and for t-distrib. Q up to k=7 and ARCH-LM up to k=6. For GARCH (2,1) the remaining ARCH effects are rejected. Own calculations using EViews. Data Reuters.

Table AFX2: GARCH model estimates for FX markets returns. Model estimates for reduced samples

			SAMPLE 1 5.1.1999- 30.4.2004				SAMPLE 2 3.5.2004- 2.28.2008			
			CZK/ USD returns (RCZK)		EUR/ USD returns (REUR)		CZK/ USD returns (RCZK)		EUR/ USD returns (REUR)	
Error distribution assumption			Normal	Student's t	Normal	Student's t	Normal	Student's t	Normal	Student's t
Variance equation GARCH (1.1)			$h_t=\omega+\alpha_1\varepsilon_{t-1}^2+\beta_1 h_{t-1}$		$h_t=\omega+\alpha_1\varepsilon_{t-1}^2+\beta_1 h_{t-1}$		$h_t=\omega+\alpha_1\varepsilon_{t-1}^2+\beta_1 h_{t-1}$		$h_t=\omega+\alpha_1\varepsilon_{t-1}^2+\beta_1 h_{t-1}$	
Return equation			$rczk_t=c+\varepsilon_t$		$reur_t=c+\rho AR(1)$	$reur_t=c+\varepsilon_t$	$rczk_t=c+\varepsilon_t$		$reur_t=c+AR(1)+\varepsilon_t$	
Coefficient estimates	**c**	return constant	-0.0073	0.0029	-0.0045	-0.0050	-0.0471 ***	-0.0456 ***	-0.0289 *	-0.0279 *
			(0.378)	*(0.157)*	*(-0.272)*	*(-0.284)*	*(-2.578)*	*(-2.606)*	*(-1.954)*	*(-0.580)*
	ρ	AR(1) term	n/a	n/a	-0.0676***	n/a	n/a	n/a	-0.009	-0.0192
					(-2.613)				*(-0.292)*	*(-0.580)*
	ω	variance constant	0.0368	0.0259	0.0106 *	0.072	0.0030	0.0039	0.0015	0.0016 *
			(1.283)	*(1.414)*	*(1.818)*	*(1.410)*	*(1.606)*	*(1.645)*	*(1.604)*	*(0.093)*
	α1	ARCH (1) term	0.0337 *	0.0317 **	0.0279 ***	0.0280 ***	0.0323 ***	0.0343 ***	0.0258 ***	0.0266 ***
			(1.929)	*(2.148)*	*(3.106)*	*(2.620)*	*(3.128)*	*(2.920)*	*(2.889)*	*(2.901)*
	β1	GARCH (1) term	0.8960 ***	0.9197 ***	0.9486 ***	0.9656 ***	0.9591 ***	0.9549 ***	0.9673 ***	0.9662 ***
			(13.313)	*(20.594)*	*(54.092)*	*(51.453)*	*(71.324)*	*(68.045)*	*(91.073)*	*(98.887)*
Equation results	t-dist df		n/a	7.785****(4.11)*	n/a	12.120****(2.595*	n/a	8.907 ****(3.034)*	n/a	16.95 *(1.477)*
	Schwarz criterion		2.2004	2.1826	2.0539	2.0484	1.8399	1.8304	1.4454	1.4490
	Log likelihood (LL)		-1509	-1493	-1403	-1400	-913	-904	-710	-709
	Adj. R-squared		-0.00217	-0.0031	0.0019	-0.0029	-0.0030	-0.0040	-0.0037	-0.0044
	Wald test:H_0: $-1+\alpha_1+\beta_1=0$		-0.079	-0.049	-0.023 *	-0.0155	-0.0086	-0.011	-0.0068	-0.007 *
			SE: (0.054)	*SE:(0.035)*	*SE: (0.013)*	*SE: (0.011)*	*SE: (0.006)*	*SE: (0.007)*	*SE: (0.004)*	*SE: (0.004)*
Residuals test:	Q resid.(k=15)		0.482 (0.851)	9.691 (0.839)	10.196 (0.748)	16.083 (0.377)	17.994 (0.263)	18.106 (0.257)	13.279 (0.505)	13.263 (0.506)
	Q Sq.resid. (k=15)		11.017 (0.751)	10.589 (0.781)	13.105 (0.518)	13.402 (0.571)	26.093 (0.037)	26.162 (0.036)	21.423 (0.091)	21.669 (0.086)
	ARCH-LM: (k=15) Obs*R-sq		11.042 (0.749)	19.595 (0.781)	14.075 (0.520)	14.193 (0.511)	26.439 (0.034)	26.468 (0.033)	22.323 (0.100)	22.679 (0.091)
	Skewness		-0.1523	-0.1567	0.0350	0.0283	-0.0207	-0.0220	-0.0556	-0.0560
	Kurtosis		3.8523	3.8649	3.474	3.4565	3.6865	3.7042	3.239	3.2484
	Jarque-Bera statistics		47.247 (0.000)	48.844 (0.000)	13.203(0.001)	12.212 (0.002)	19.849 (0.000)	20.890 (0.000)	2.910 (0.233)	3.116 (0.211)
	Observations		1385	1385	1384	1384	1007	1007	1007	1007

Note: ***. **. * denotes 1%, 5%, 10% level of significance. Values in brackets are the z-statistics, and by the residuals test the p-values. Wald restriction test for $\sum \alpha+\beta=1$, with significance of rejection the null hypothesis and standard errors in parenthesis. Q stands for Ljung-Box Q statistics lag (k), reported is k=15, in brackets are p-values. ARCH-LM test with p-values in brackets. For SAMPLE 1: REUR with t-distributed errors estimated without AR1 term (could not be estimate with AR1), Q at up to * for standard. and stand. squared residual for k=1,2.

For SAMPLE 2: RCZK: Remaining autocorrelation: st. residuals at * for k=2 and stand. squared residuals and lag for which Q was still significant at * k=8-31 (for both distributions). SAMPLE 2: REUR: Remaining autocorrelation for stand. squared residuals, lag for which Q was still significant at * k=6 and between cca k=13-23 for both error distr. Own calculations in EViews. Data Reuters

Table AFX3: FX markets. Unrestricted bivariate BEKK-GARCH (1,1) model estimates for returns CZK/USD and EUR/USD.

FULL SAMPLE: Jan 1999- Feb 2008

Matrix:	Ω		A		B		modulus of eigenvalues
Coefficient:	ω_{11} / 0	ω_{12} / ω_{22}	a_{11} / a_{21}	a_{12} / a_{22}	b_{11} / b_{21}	b_{12} / b_{22}	
coefficient	0.1044**	0.0253**	0.2727**	0.0179	0.9202**	-0.0142**	0.9345
t-values normal	*(8.543)*	*(2.468)*	*(9.440)*	*(0.6594)*	*(77.442)*	*(-1.442)*	0.9593
t-values exact	*(6.839)*	*(3.902)*	*(4.6052)*	*(0.982)*	*(49.013)*	*(-1.984)*	0.9981
							0.9582
coefficient	0	0.0227**	-0.1473	0.1158**	0.0665**	1.0032**	
t-values normal		*(3.443)*	*(-4.631)*	*(3.901)*	*(6.049)*	*(110.336)*	LL
t-values exact		*(2.273)*	*(-1.489)*	*(5.051)*	*(2.812)*	*(137.586)*	-3 117.9

Residuals tests

Multivariate ARCH-LM	test statistics:	164.29	(k=30)	308.41
(k=16)	p-value(chi^2):	0.1185		0.0538
Portmanteau test : k=16	test statistic:	80.79	(k=30)	135.65
H_0 $R_h=(r_1.....r_h)=0)$	p-value:	0.038		0.095

Jarque-Bera test (multivariate)	variable	test stat.	p-val (chi^2)	Skewn	Kurt.
	xi_1	361.581	0.000	-0.1022	4.893
	xi_2	23.289	0.000	-0.00163	3.482

REDUCED SAMPLE: May 2004- Feb 2008

Matrix:	Ω		A		B		modulus of eigenvalues
Coefficient:	ω_{11} / 0	ω_{12} / ω_{22}	a_{11} / a_{21}	a_{12} / a_{22}	b_{11} / b_{21}	b_{12} / b_{22}	
coefficient	0.0420**	-0.0032	0.2581**	0.0258	0.9651**	0.0143	0.9934
t-values normal	*(1.855)*	*(-0.118)*	*(4.820)*	*(0.573)*	*(47.387)*	*(0.786)*	0.9635
t-values exact	*(5.431)*	*(-0.452)*	*(4.193)*	*(0.738)*	*(48.529)*	*(0.757)*	0.9635
							0.9696
coefficient	0	0.0375**	-0.1433	0.100**	0.0249	0.9744**	
t-values normal		*(2.657)*	*(-2.205)*	*(1.874)*	*(1.122)*	*(51.026)*	LL
t-values exact		*(2.089)*	*(-1.720)*	*(2.720)*	*(1.018)*	*(47.168)*	-978.855

Residuals tests

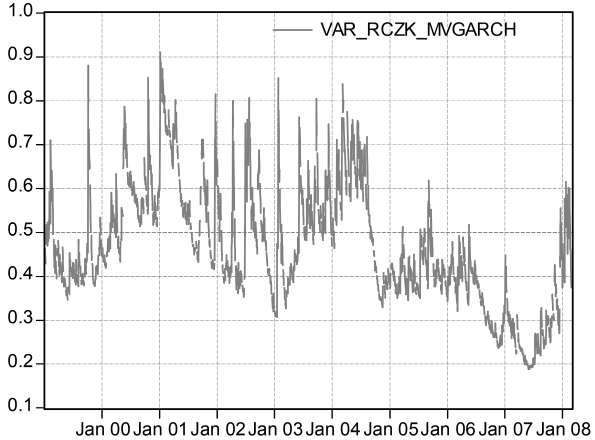
Multivariate ARCH-LM	test statistics	168. 3564
(k=16)	p-value(chi^2):	0.0807
Portmanteau test : k=16	test statistic:	64.4528
H_0 $R_h=(r_1.....r_h)=0)$	p-value:	0.4237

Jarque-Bera test (multivariate)	variable	test stat.	p-val (chi^2)	Skew	Kurt.
	xi_1	43.518	0.000	-0.1494	3.9736
	xi_2	2.571	0.2765	-0.0831	3.1835

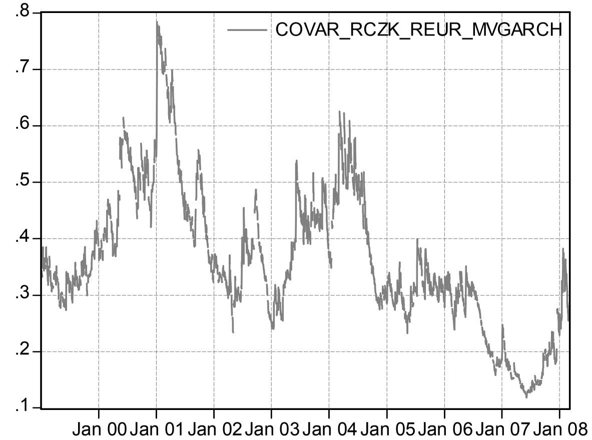
Note: i=1 stands for RCZK, i=2 for REUR. Full sample 2392 observations (4.1.1999- 28.2.2008). Reduced sample 1007 (3.5.2004- 28.2.2008). ** denotes significance at 5% level of significance based on t-values exact, which are compared to value of normal distribution quantile for 5% significance level (1.960), estimates in grey are non significant at 5% level, based on t-values exact. LL denotes log likelihood. "The model is estimated with a quasi maximum likelihood (QML) estimator under normality assumption….exact QML t-ratios which require to evaluate the 1st and 2nd order derivatives of the Gaussian likelihood function analytically" (Herwatrz, Kascha, 2005). Own calculation using JMulTi. Data Reuters.

Table AFX4: FX market. Conditional variance and covariance processes. Returns CZK/USD (RCZK) and EUR/USD (REUR).

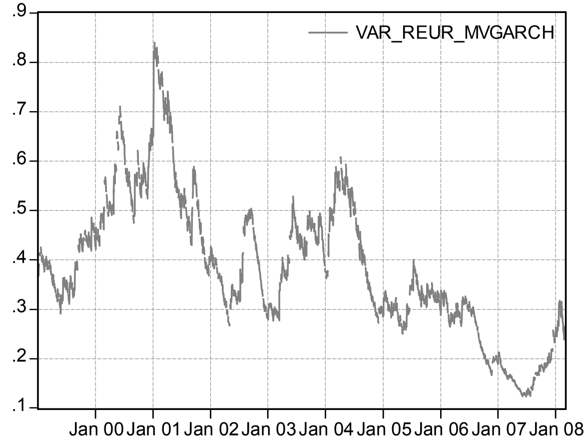
VARIANCE RCZK



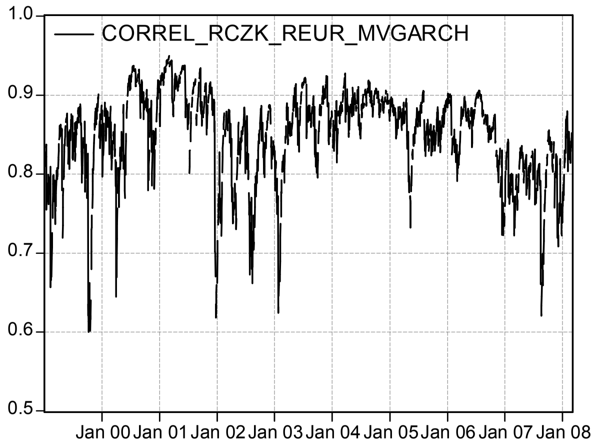
COVARIANCE RCZK_REUR



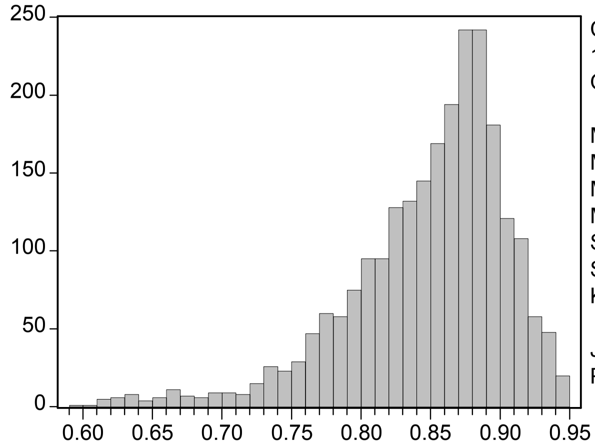
VARIANCE REUR



CORRELATION RCZK_REUR



Descriptive statistics of the conditional correlation coefficient



CORREL_RCZK_REUR_MVGARCH
1/05/1999 2/28/2008
Observations 2392

Mean	0.848248
Median	0.860865
Maximum	0.949515
Minimum	0.599994
Std. Dev.	0.057626
Skewness	-1.232269
Kurtosis	5.054051
Jarque-Bera	1025.876
Probability	0.000000

Results from JMulTi estimation of unrestricted bivariate BEKK-GARCH (1,1) for FX market. Sample 5.1.1999- 28.2.2008. Own calculations in JMulTi and EViews. Data Reuters

Table AFX5: DIAGONAL BIVARIATE BEKK-GARCH(1,1) model estimates for FX market returns: CZK/USD (RCZK) and EUR/USD (REUR).

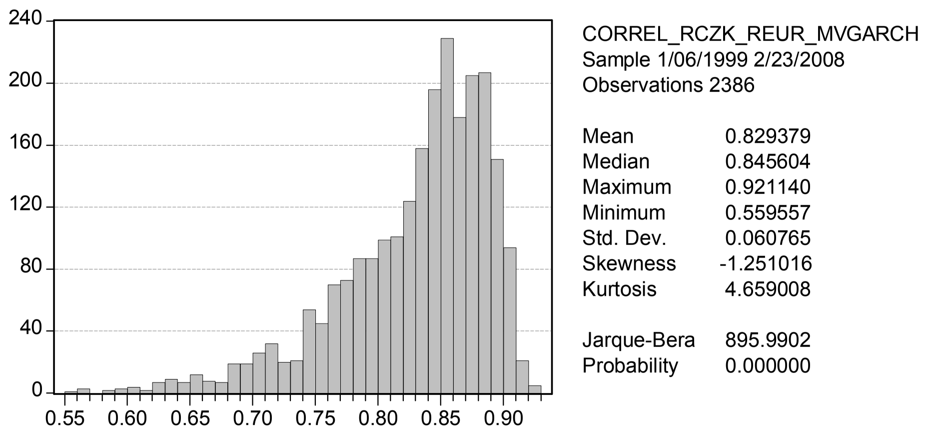
FULL SAMPLE: 1999- 2008

	Conditional variance equation						Return equation
Matrix:	**Ω**		**A**		**B**		
Coefficient:	ω_{11}		a_{11}	a_{12}	b_{11}	b_{12}	
	ω_{21}	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	μ_1
Coefficient	**0.0887*****	**0**	**0.1855*****	**0**	**0.9743*****	**0**	**-0.0298 ***
	(8.7647)		*(8.720)*		*(307.034)*		*(-2.359)*
							μ_2
Coefficient	**0.0492*****	**0.0266*****	**0**	**0.1840*****	**0**	**0.9787*****	**-0.0157**
	(7.976)	*(5.153)*		*(16.704)*		*(400.404)*	*(-1.420)*

Model diagnostics

Log Likelihood:	Schwarz criterion	Likelihood ratio
-3 115.5	2.6408	2 854.9 (p-value =0)

Descriptive statistics of the calculated conditional correlation coefficient



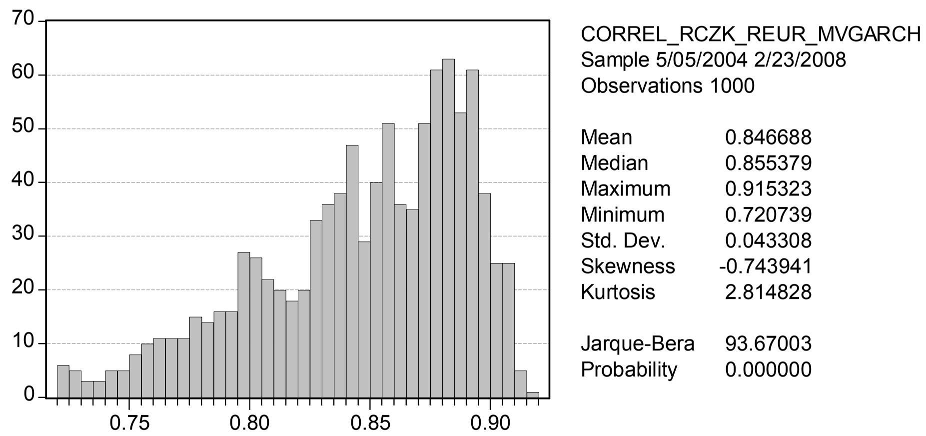
REDUCED SAMPLE: 2004- 2008

	Conditional variance equation						Return equation
Matrix:	**Ω**		**A**		**B**		
Coefficient:	ω_{11}		a_{11}	a_{12}	b_{11}	b_{12}	
	ω_{21}	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	μ_1
Coefficient	**0.0658*****	**0**	**0.1765*****	**0**	**0.9782*****	**0**	**-0.0478 *****
	(4.206)		*(9.459)*		*(187.395)*		*(-2.701)*
							μ_2
Coefficient	**0.0395*****	**0.0247*****	**0**	**0.1666*****	**0**	**0.9814*****	**-0.0245 ***
	(4.055)	*(3.525)*		*(8.308)*		*(223.143)*	*(-1.680)*

Model diagnostics

Log Likelihood:	Schwarz criterion	Likelihood ratio
-958.3	1.9788	1 291.2 (p-value =0)

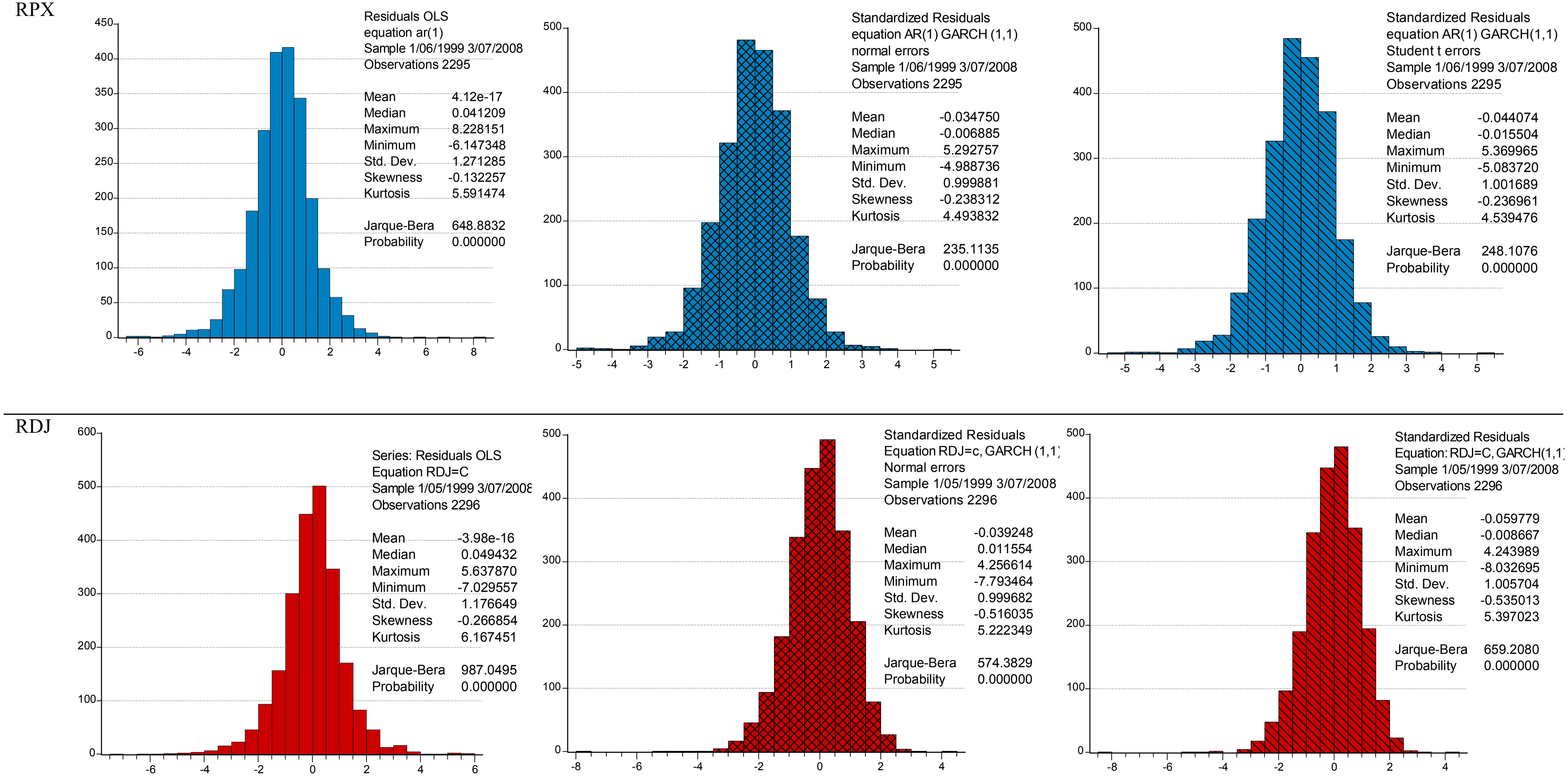
Descriptive statistics of the calculated conditional correlation coefficient



Full sample of 2386 observations (6.1.1999- 23.2.2008), reduced sample 1000 observations (5.5.2004- 23.2.2008). ***, **, * denotes 1%, 5%, 10% significance level. Numbers in brackets are z-statistics. Likelihood ratio of likelihood comparing restricted (univariate) estimations against unrestricted (bivariate) one. Own calculations using EViews. Data Reuters.

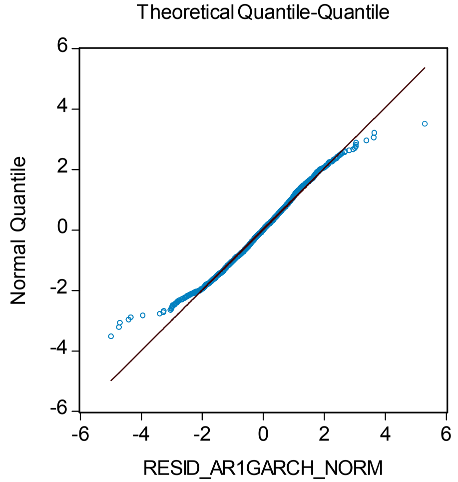
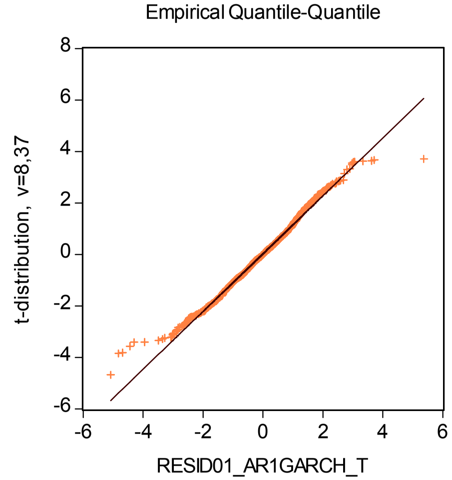
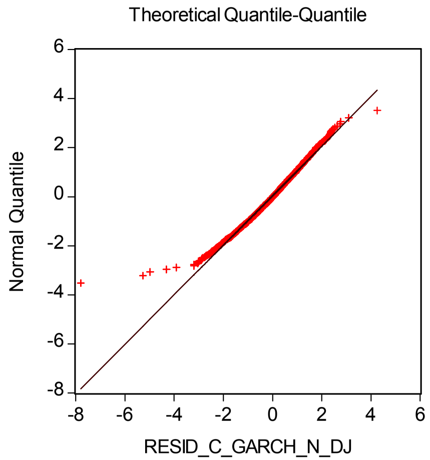
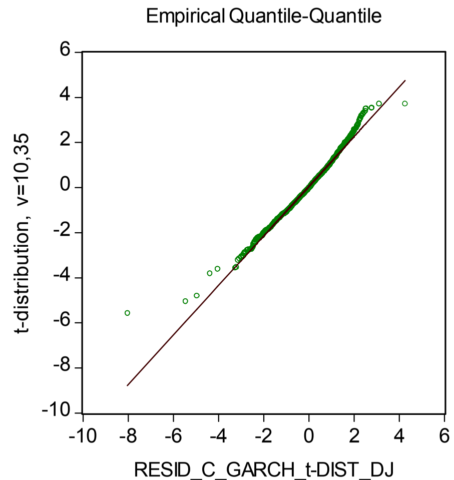
Figure AE1: EQUITIES MARKET. Histograms of standardized residuals: OLS vs. GARCH.

	OLS estimates	GARCH (1,1) estimates assuming Normal distribution	GARCH (1,1) estimates assuming Student t- distribution of errors



Own calculations in EViews. Data Reuters.

Figure AE2: Quantile plots of standardized residuals from estimated equation for EQUITIES market.

	Assuming Normal distribution of errors	Assuming Student t-distribution of errors
rPX		
rDJ		

Note: EQUITIES market returns of PX (rPX) and DJ STOXX 600 (rDJ) Equations: RPX=C+AR(1), RDJ=C, both with GARCH (1,1) variance. Own calculation using EViews. Data Reuters.

Table AE1: GARCH model estimates for EQUITIES market return. Sample January 1999- March 2008.

			PX log returns (RPX)		DJ STOXX 600 log returns (RDJ)	
Error distributional assumption			Normal	Student's t	Normal	Student's t
Variance equation GARCH (1,1)			$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$		$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$	
Return equation			$rpx_t=c+\rho AR(1)+\varepsilon_t$		$rdj_t=c+\varepsilon_t$	
Coefficient estimates	**c**	return constant	**0.1044** ***	**0.1161** ***	**0.0416** *	**0.0610** ***
			(4.510)	*(5.015)*	*(1.761)*	*(3.414)*
	ρ	AR(1) term	**0.0560** **	**0.0464** **	n/a	n/a
			(2.532)	*(2.078)*		
	ω	variance constant	**0.0591** ***	**0.0472** ***	**0.0191** ***	**0.0131** ***
			(4.172)	*(3.431)*	*(3.166)*	*(2.895)*
	α	ARCH (1) term	**0.1177** ***	**0.1147** ***	**0.1060** ***	**0.0946** ***
			(6.301)	*(6.620)*	*(5.366)*	*(7.141)*
	β	GARCH (1) term	**0.8487** ***	**0.8598** ***	**0.8827** ***	**0.898** ***
			(41.430)	*(41.929)*	*(48.152)*	*(65.314)*
Equation result	t-dist df.		n/a	8.37 ***	n/a	10.35 ***
				(6.753)		(7.522)
	Schwarz criterion		3.185	3.1568	2.8795	2.8533
	Log likelihood (LL)		-3636	-3599	-3290	-3256
	Adj. R-squared		-0.0007	-0.0018	-0.0024	-0.0042
	Wald test: H_0: $-1+\alpha+\beta=0$		-0.034 *** *SE: (0.010)*	-0.025 ** *SE: (0.011)*	-0.0113 *SE: (0.007)*	-0.007 *SE: (0.006)*
Residuals test:	Q resid.(k=15)		17.430 (0.234)	18.173 (0.199)	16.697 (0.337)	16.639 (0.341)
	Q Sq.resid. (k=15)		16.949 (0.259)	16.299 (0.296)	12.815 (0.617)	12.099 (0.672)
	ARCH-LM:Obs*R-sq (k=15)		17.270 (0.303)	16.588 (0.344)	12.475 (0.643)	11.838 (0.691)
	Skewness		-0.2383	-0.2370	-0.5160	-0.535
	Kurtosis		4.4938	4.5395	5.2223	5.3970
	Jarque-Bera statistics		235.113 (0.000)	248.108 (0.000)	574.38 (0.000)	659.208 (0.000)
	Observations		2295	2295	2296	2296

Note: ***, **, * denotes 1%, 5%, 10% level of significance. Values in brackets are the z-statistics, and by the residuals test the p-values. Wald restriction test for $\sum \alpha+\beta=1$, with significance of rejection the null hypothesis and standard errors in parenthesis. Q stands for Ljung-Box Q statistics lag (k), reported is k=15, in brackets are p-values. ARCH-LM test with p-values in brackets. Own calculations using EViews. Data Reuters.

Table AE2: GARCH model estimates for EQUITIES market returns. Reduced sample May 2004 - March 2008.

			PX log returns (RPX)		**DJ STOXX 600 log returns (RDJ)**	
	Error distributional assumption		Normal	Student's t	Normal	Student's t
	Variance equation GARCH (1,1)		$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$		$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$	
	Return equation		$rpx_t=c+\rho AR(1)+\varepsilon_t$	$rpx_t=c+\rho AR(1)+\varepsilon_t$	$rdje_t=c+\varepsilon_t$	$rdje_t=c+\varepsilon_t$
Coefficient estimates	**c**	return constant	**0.1264** ***	**0.1459*****	**0.0717** ***	**0,0845** ***
			(3.961)	(4.870)	(3.225)	(3,886)
	ρ	AR(1) term	**0.0287**	**0.0202**	n/a	n/a
			(0.806)	(0.581)		
	ω	variance constant	**0.0574** ***	**0.0602** **	**0.0243** **	**0,0236** **
			(3.309)	(2.554)	(2.353)	(2,449)
	α	ARCH (1) term	**0.1401** ***	**0.1407** ***	**0.1160** ***	**0,1137** ***
			(3.771)	(4.313)	(3.965)	(4,233)
	β	GARCH (1) term	**0.8254** ***	**0.8207** ***	**0.8523** ***	**0,8546** ***
			(25,203)	(21.291)	29.746	(25.649)
Equation result	t-dist df		n/a	6.081 ***	n/a	8.287 ***
				(5.833)		(4.734)
	Schwarz criterion		3,0198	2.9583	2.3532	2.3251
	Log likelihood (LL)		-1439,9	-1407	-1122	-1105
	Adj. R-squared		-0,0044	-0.0081	-0.0058	-0.0086
	Wald test: H_0: $-1+\alpha_1+\beta_1=0$		-0,035* *SE: (0,019)*	-0.039 * *SE: (0.022)*	-0.032 *SE: (0.020)*	-0.032 * *SE: (0.018)*
Residuals test:	Q resid.(k=15)		15,073 (0,373)	15.558 (0.341)	11.139 (0.743)	11.228(0.736)
	Q Sq.resid. (k=15)		14,833 (0,390)	14.816 (0.391)	21.995 (0.108)	21.946(0.109)
	ARCH-LM: Obs*R-sq (k=15)		16,747 (0,334)	16.670 (0.339)	24.159 (0.062)	24.167(0062)
	Skewness		-0,5211	-0.5214	-0.6366	-0.6349
	Kurtosis		5,5563	5.5501	4.7297	4.7153
	Jarque-Bera statistics		306,4311 (0,000)	305.193 (0.000)	185.48 (0.000)	183.15 (000)
	Observations		965	965	965	965

Note: ***, **, * denotes 1%, 5%, 10% level of significance. Values in brackets are the z-statistics, and by the residuals test the p-values. Wald restriction test for $\sum \alpha+\beta=1$, with significance of rejection the null hypothesis and standard errors in parenthesis. Q stands for Ljung-Box Q statistics lag (k) reported is k=15, in brackets are p-values of Q. ARCH-LM test with p-values in brackets. For RDJ both distrib. assumptions lags for which Q was still significant at * k=11-14.,17 and ARCH-LM test at* up to k=21. Own calculations in EViews. Data Reuters.

Table AE3: EQUITIES markets. Unrestricted bivariate BEKK-GARCH (1,1) model estimates for returns of PX and DJ STOXX 600 indices.

FULL SAMPLE: 1999- 2008

Matrix:	Ω		A		B		modulus of eigenvalues
Coefficient:	ω_{11}	ω_{12}	a_{11}	a_{12}	b_{11}	b_{12}	
	0	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	
coefficient	0.2688*	0.0927*	0.3199*	0.0696*	0.9266**	-0.0255**	0.9595
t-values normal	*(9.909)*	*(4.658)*	*(17.035)*	*(4.319)*	*(97.365)*	*(-3.681)*	0.9690
t-values exact	*(11.376)*	*(5.305)*	*(12.004)*	*(3.563)*	*(112.016)*	*(-4.141)*	0.9892
							0.9744
coefficient	0	0.1003*	-0.0469	0.2342*	0.0124	0.9668**	
t-values normal		*(6.480)*	*(-2.606)*	*(14.490)*	*(1.929)*	*(185.799)*	LL
t-values exact		*(5.779)*	*(-1.544)*	*(8.738)*	*(1.495)*	*(143.620)*	-6 658.05

Residuals tests

Multivariate ARCH-LM	test statistics:	208.7310			
(k=16)	p-value(chi^2):	0.0003			
Portmanteau test : k=16	test statistic:	90.969			
H_0 $R_h=(r_1,...,r_h)=0)$	p-value:	0.0061			
Jarque-Bera test	variable	test statistics	p-val(chi^2)	Skewness	Kurtosis
(multivariate)	xi_1	270.318	0.0000	-0.2981	4.5716
	xi_2:	521.095	0.0000	-0.3985	5.1936

REDUCED SAMPLE: 2004- 2008

Matrix:	Ω		A		B		modulus of eigenvalues
Coefficient:	ω_{11}	ω_{12}	a_{11}	a_{12}	b_{11}	b_{12}	
	0	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	
coefficient	0.2405*	0.0750	0.3045*	0.0303	0.9349**	0.0017	0.9500
t-values normal	*(6.168)*	*(1.809)*	*(10.979)*	*(1.146)*	*(52.132)*	*(0.115)*	0.9498
t-values exact	*(7.491)*	*(1.515)*	*(3.650)*	*(0.226)*	*(30.228)*	*(0.024)*	0.9498
							0.9461
coefficient	0	0.1604	-0.0100	0.2614	-0.0081	0.9303**	
t-values normal		*(6.044)*	*(-0.245)*	*(7.521)*	*(-0.294)*	*(46.630)*	LL
t-values exact		*(0.818)*	*(-0.058)*	*(1.0508)*	*(-0.117)*	*(6.315)*	-2 409.41

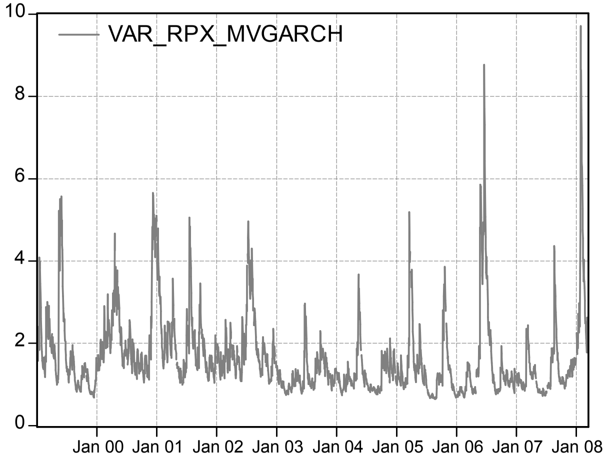
Residuals tests

Multivariate ARCH-LM	test statistics	263.6763			
(k=16)	p-value(chi^2):	0.0000			
Portmanteau test : k=16	test statistic:	88.1952			
H_0 $R_h=(r_1,...,r_h)=0)$	p-value:	0.0104			
Jarque-Bera test	variable	test statistics	p-val(chi^2)	Skewness	Kurtosis
(multivariate)	xi_1	251.010	0.000	-0.5092	5.2816
	xi_2:	99.290	0.000	-0.4305	4.3145

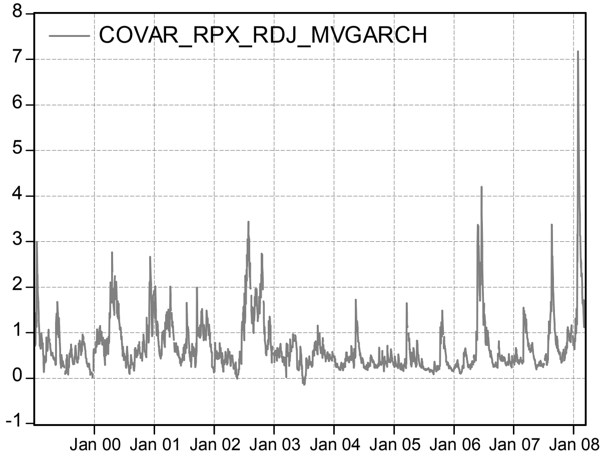
Note: i=1 stands for PX returns, i=2 for DJ STOXX returns. Note: Full sample 2296 observations (5.1.1999-7.3.2.2008). Reduced sample 965 (3.5.2004-7.3.2008). ** denotes significance at 5% level of significance based on t-values exact, which are compared to value of normal distribution quantile for 5% significance level (1.960), estimates in grey are non significant at 5% level, based on t-values exact. LL denotes log likelihood. “The model is estimated with a quasi maximum likelihood (QML) estimator under normality assumption. …the exact QML t-ratios which require to evaluate the 1st and 2nd order derivatives of the Gaussian likelihood function analytically” (Herwatrz, Kascha, 2005). Own calculation using JMulTi. Data Reuters.

Table AE4: EQUITIES market. Conditional variance and covariance processes. Returns PX index (rPX) and DJ STOXX 600 index (rDJ).

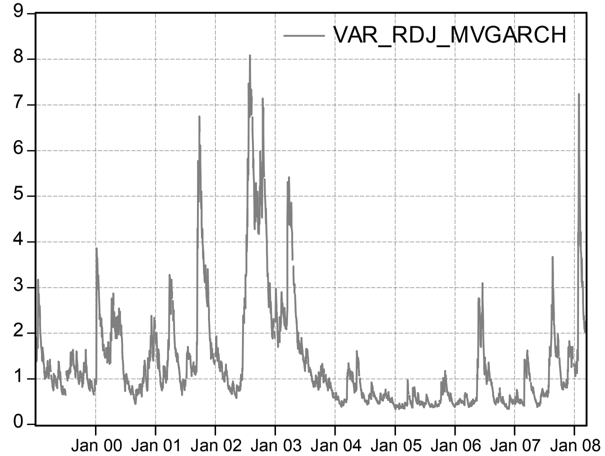
VARIANCE RPX



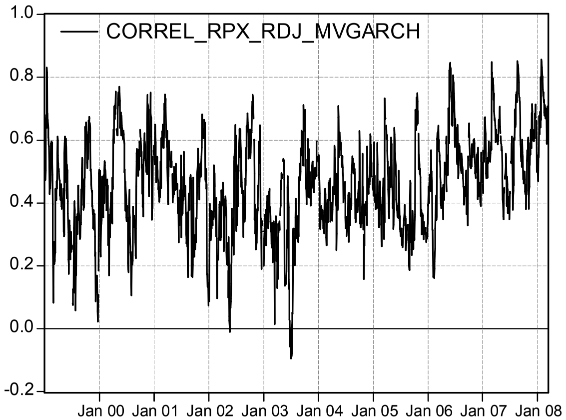
COVARIANCE RPX_RDJ



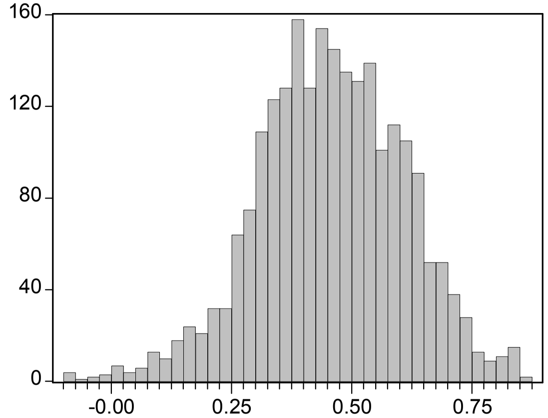
VARIANCE RDJ



CORRELATION RPX RDJ



Descriptive statistics of the conditional correlation coefficient.



CORREL_RPX_RDJ_MVGARCH
Sample 1/06/1999 3/07/2008
Observations 2295

Mean	0.455953
Median	0.452544
Maximum	0.856607
Minimum	-0.094621
Std. Dev.	0.153479
Skewness	-0.188075
Kurtosis	3.186786
Jarque-Bera	16.86607
Probability	0.000218

Results from JMulTi estimation of unrestricted bivariate BEKK-GARCH (1,1) for EQUITIES market. Sample 6.1.1999- 7.3.2008. Own calculations in JMulTi and EViews. Data Reuters.

Table AE5: EQUITIES market restricted diagonal bivariate BEKK- GARCH(1,1) model estimates.

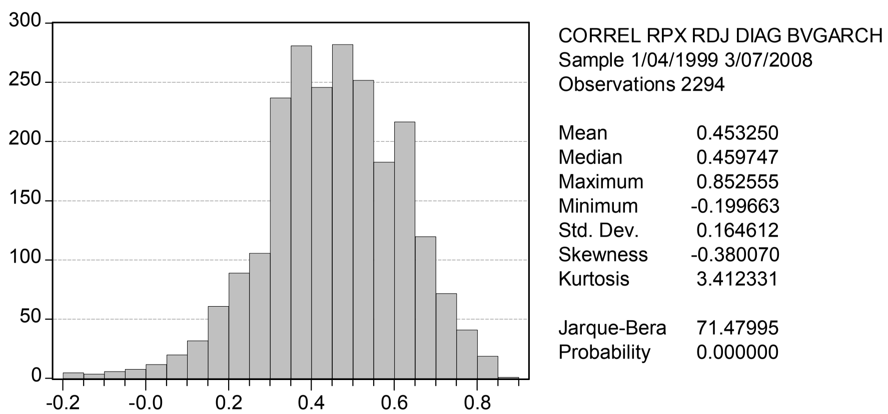
FULL SAMPLE: 1999- 2008

	Conditional variance equation						Return equation
Matrix:	**Ω**		**A**		**B**		
Coefficient	ω_{11}		a_{11}	a_{12}	b_{11}	b_{12}	
	ω_{21}	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	**μ_1**
							0.0973 ***
Coefficient	**0.2358*****	**0**	**0.2835 *****	**0**	**0.9409*****	**0**	*(4.173)*
	(11.554)		*(19.921)*		*(146.583)*		
							μ_2
Coefficient	**0.0580*****	**0.1064*****	**0**	**0.2818 *****	**0**	**0.9551*****	**0.0507 *****
	(7.813)	*(8.922)*		*(22.714)*		*(251.006)*	*(3.179)*

Model diagnostics

Log Likelihood:	Schwarz criterion	Likelihood ratio
-6 644.1	5.8229	LR: 556.4 (p-value= 0)

Descriptive statistics of the calculated correlation coefficient



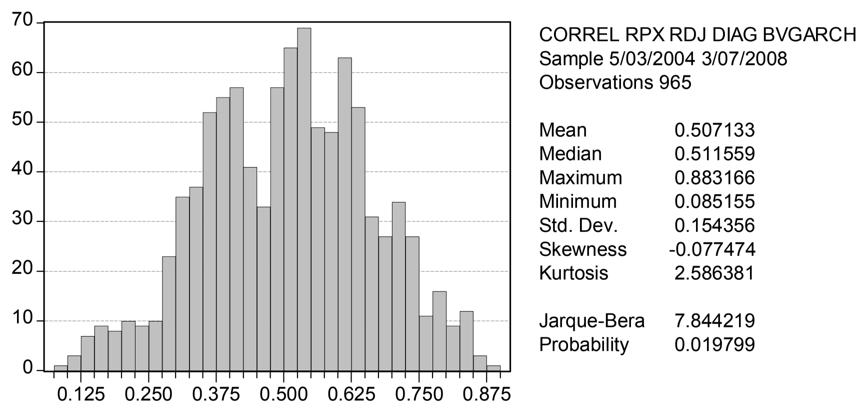
REDUCED SAMPLE: 2004- 2008

	Conditional variance equation						Return equation
Matrix:	**Ω**		**A**		**B**		
Coefficient:	ω_{11}		a_{11}	a_{12}	b_{11}	b_{12}	
	ω_{21}	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	**μ_1**
							0.1233 ***
Coefficient	**0.2531*****	**0**	**0.3264**	**0**	**0.9195 *****	**0**	*(3.901)*
	(8.627)		*(15.519)*		*(79.211)*		
							μ_2
Coefficient	**0.0729*****	**0.1271*****	**0**	**0.2924 *****	**0**	**0.9405 *****	**0.0815 *****
	(6.434)	*(7.034)*		*(12.645)*		*(93.029)*	*(3.442)*

Model diagnostics

Log Likelihood:	Schwarz criterion	Likelihood ratio
-2 397.8	5.0336	9059.0 (p-value = 0)

Descriptive statistics of the calculated correlation coefficient



Full sample 4.1.1999- 7.3.2008 (2294 obs.), reduced sample 3.5.2004 - 7.3 2008 (965 obs.). ***, **, * denotes 1% , 5%, 10% significance level. Numbers in brackets are z-statistics. Numbers in brackets are z-statistics. Likelihood ratio of likelihood comparing restricted (univariate) estimations against unrestricted (bivariate) one. Own calculations in EViews. Data Reuters

Box AB1: Yield to maturity ("ytm")

We follow the Concept and definitions part of the ECB, 2003 report on Bonds and long-term interest rate, section Pricing.

"The yield to maturity is the total internal rate of return on a bond or other fixed income security calculated by factoring in the purchase price, coupon, reinvestment of coupons at the same rate as the original coupon, and maturity date… A common yields-to-maturity used is formula 6.3 recommended by the International Securities Market Association (ISMA)…

$$P = \sum_{i=1}^{n} CF_i * V^{L_i}$$

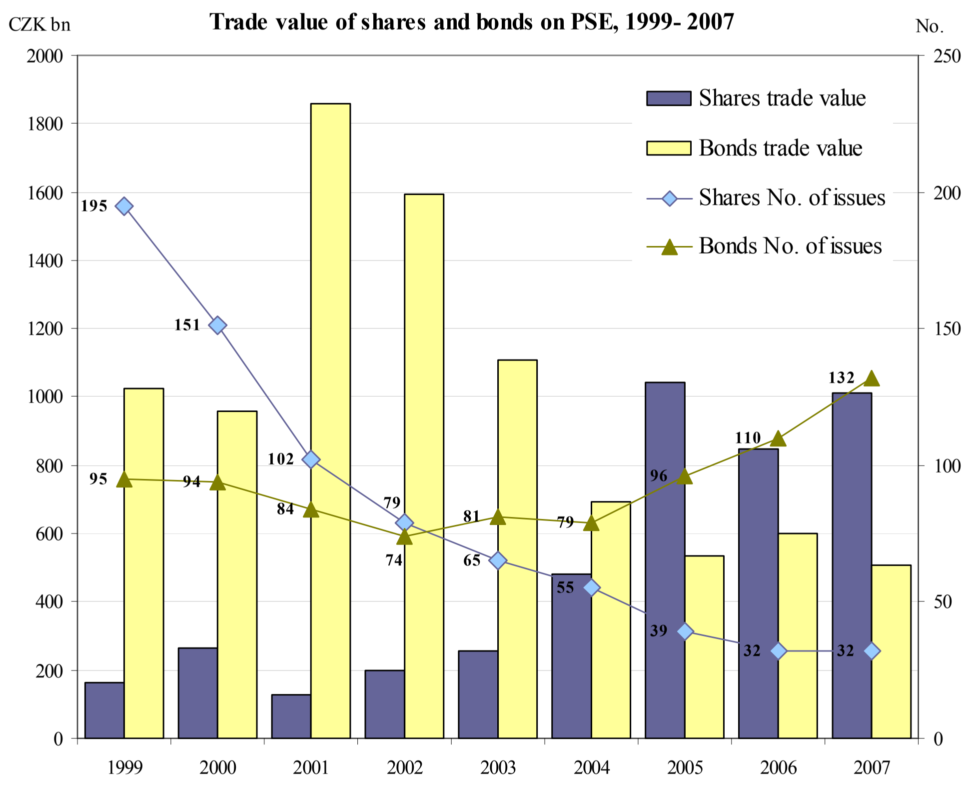
P= gross price (i.e. clean price plus accrued interest), n= number of future cash flows, CF_i=i-th cash flow (can be variable), L_i= time in years to the i-th cash flow, V= annualized discounting factor = 1/(1+y) where y is the annualized yield". (ECB, 2003, p. 263).

Table AB1: Market size of debt instruments by original maturities and sector of issuer. Czech Republic.

In EUR millions		2002	2003	2004	2005	2006
Money market Short term	Subtotal	28 953.3	27 958.6	18 540.7	15 268.4	14 306.9
Government sector		6 077.5	6 357.0	5 433.9	3 249.4	3 258.8
Monetary financial institutions		22 875.8	21 601.6	13 106.8	12 019.0	10 679.9
Non-financial and non-monetary institutions		0.0	0.0	0.0	0.0	368.2
Bond market 1< t < 5	Subtotal	2 155.0	2 376.2	1 455.1	3 006.8	4 467.1
Government sector		2 017.1	2 160.2	1 083.2	2 471.4	3 321.7
Monetary financial institutions		16.3	91.7	240.6	535.5	831
Non-financial and non-monetary institutions		121.6	124.4	131.3	0.0	314.4
Bond market 5 ≤ t <10	Subtotal	6 925.5	8 832.8	10 636.9	10 090.1	11 687.1
Government sector		3 333.5	4 127.7	6 157.5	5 780.1	6 574.4
Monetary financial institutions		1 766.3	2 520.4	2 652.8	2 999.5	3 753.3
Non-financial and non-monetary institutions		1825.7	2 184.6	1 826.6	1 310.4	1 359.5
Bond market t ≥10	Subtotal	3 922.1	5 978.6	8 185.6	14 749.8	19 611.3
Government sector		2 969.8	5 221.6	6 897.0	12 360.6	15 820.0
Monetary financial institutions		375.8	169.7	567.9	1 680.1	2 7311.3
Non-financial and non-monetary institutions		576.5	587.3	720.7	709.1	1 060.0
Total market		**41 955.9**	**45 146.3**	**38 818.3**	**43 115.1**	**50 072.4**

Source: ECB, ECB (2003), ECB (2004) and ECB Statistic tables (2006s, 2007s, 2008s). Amounts are the nominal values of amounts outstanding at the end-of-period. Converted to Euros using the end-of-period exchange rate for the year. (EUR/CZK, 30.6 (2002), 32.405 (2003), 30.465(2004), 29.005 (2005), 27.485(2006)). Monetary and financial institutions (central bank and credit institutions (banks)), Non-monetary and non-financial: financial auxiliaries, insurance companies, pension funds, non-financial corporations). See ECB for details.

Figure AB1: Trade value and No. if issues of shares and bonds on PSE



Data: PSE, own calculations.

Table AB2: Primary market activity. Czech republic Long -term debt securities

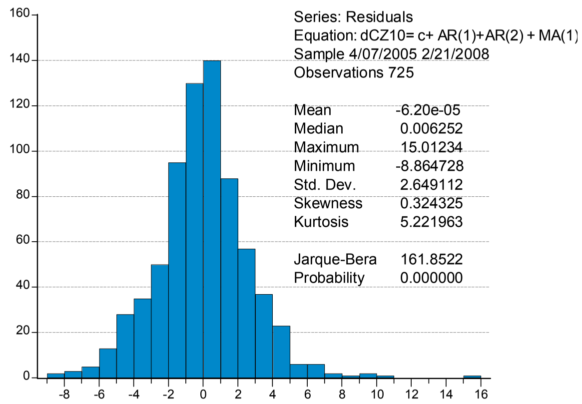
	2002	2003	2004	2005	2006
Nominal values in EUR millions (No.of transactions)					
Government sector	3 344.5 (15)	4 150.9 (16)	5 636.9 (27)	4 777.2 (18)	5 830.7 (26)
Monetary financial institutions	788 (8 e)	701 (13 e)	763 (24)	2 859.4 (39)	1 218.6 (29)
Non-financial and non-monetary institutions	362.8 (6 e)	331.7 (5 e)	179.7 (2)	134.3 (5)	1 029.6 (18)
Total primary market	**4 495.3 (29 e)**	**5 183.6 (34 e)**	**6 579.6 (53)**	**7 770.9 (62)**	**8 078.8 (73)**

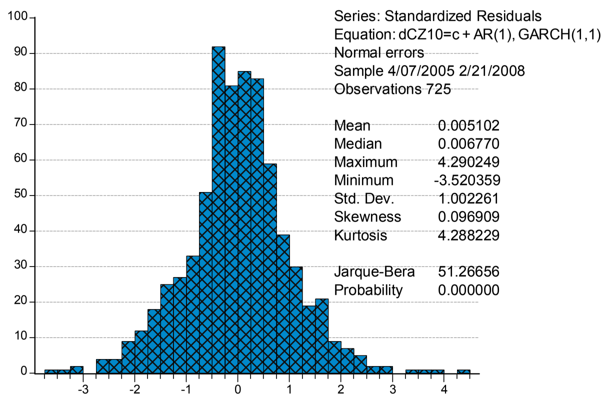
Source: ECB, Statistical tables (2006s for years 2002-2003, 2008s for years 2004-2007.Numbers in brackets denote the number of transactions; (e) denotes estimates of no. of transactions by no. of instruments issued, for government sector estimated that auctions amounted for 100% of issuance. Amounts are the nominal values of amounts outstanding at the end-of-period. Average exchange rate used (CZK/EUR: 31.891 (2004), 29.782 (2005), 28.342 (2006). Bills (t < 1 year) issued and kept by ČNB (to be used as collateral in its open market monetary operations) are also included, these amounted to in 2004: EUR 65,849 million (3 issues), in 2005: EUR 47,008 million (2 issues) and in 2006: EUR 49,397 million (2 issues). Issues of T-bills (t < 1 year) kept by the MoF (for the purpose of liquidity management) are also included, these amounted to: in 2004: EUR 2,920 million (13 issues), 2005: EUR 4,231 million (13 issues), 2006: EUR 3,881 million (11 issues),. ECB, 2008, p.12 Monetary and financial institutions (central bank and credit institutions (banks)), Non-monetary and non-financial: for ex. financial auxiliaries, insurance companies, pension funds, non-financial corporations. See ECB for details.

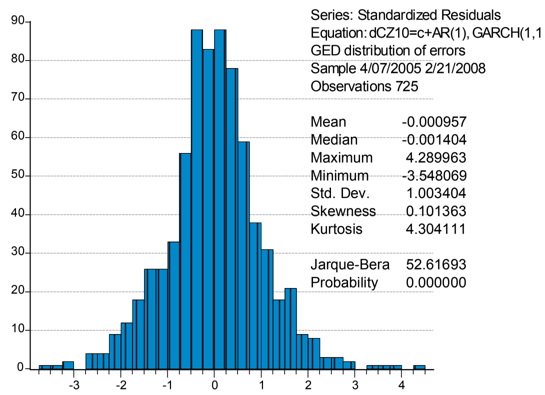
Figure AB2: BOND market. Histograms of standardized residuals: OLS vs. GARCH. Differences in yields on 10-year Czech (dCZ10) and German (dGER10) gov. bonds

	OLS estimates of returns	GARCH (1,1) estimates assuming Normal distribution of errors	GARCH (1,1) estimates assuming GED distribution of errors

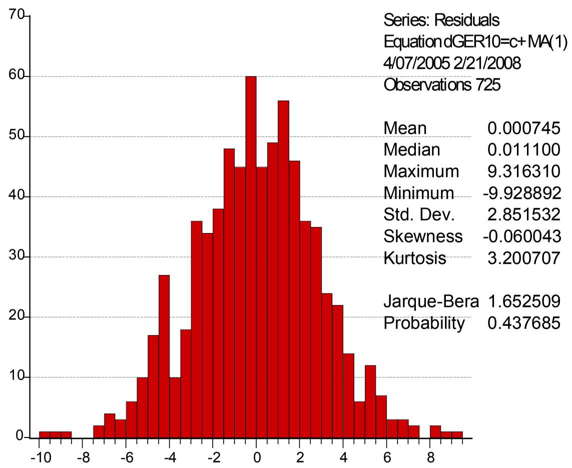
dCZ10

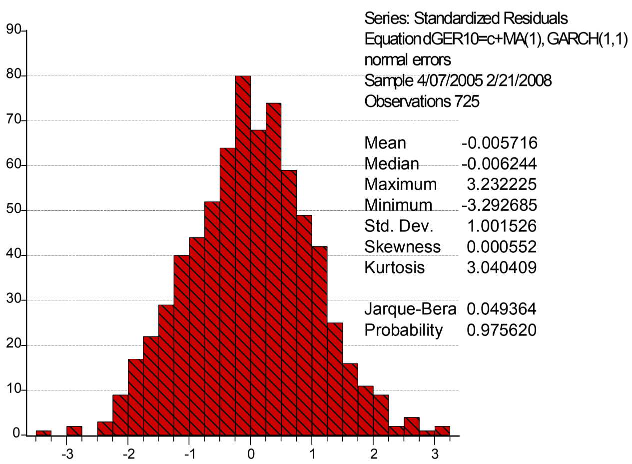






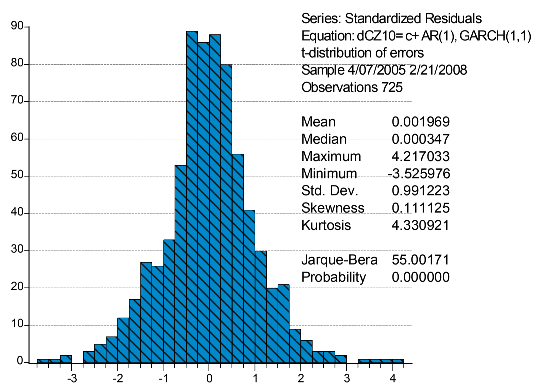
dGER10





dCZ10: GARCH (1,1) estimates for returns

assuming Student t-distribution of errors

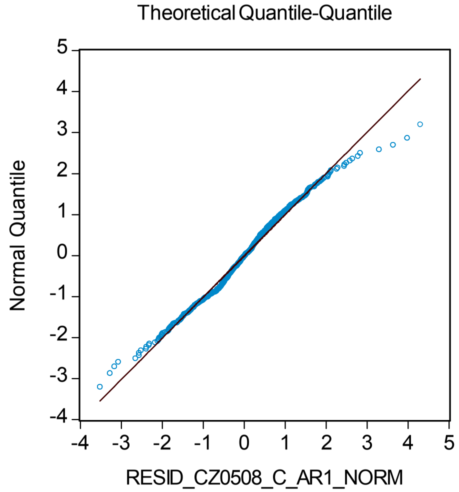


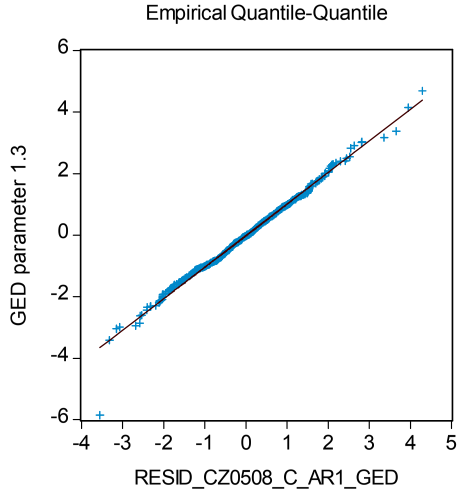
dCZ10, dGER10 stands for difference in yields on 10-year CZ and GER bonds. Own calculations in EViews. Data Reuters

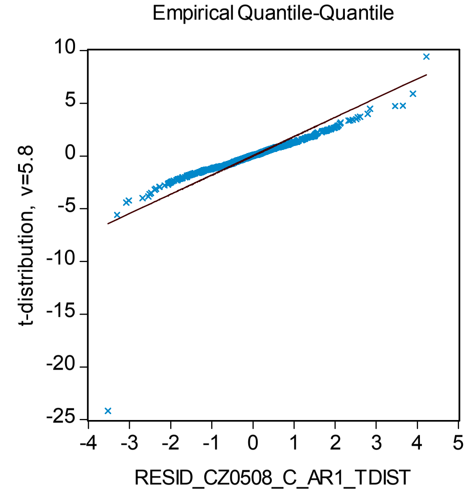
Figure AB3: Quantile plots of standardized residuals from GARCH estimated equation BOND market.

	Assuming Normal distribution of errors	Assuming GED distribution of errors	Assuming Student t-distribution of errors

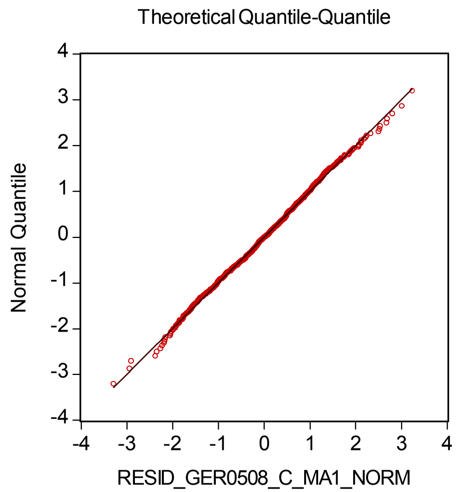
dCZ10







dGER10



Note: bond yield changes dCZ10, dGER10. Equation: dCZ10=c+AR(1), dGER10=c+MA(1) both with GARCH (1,1) variance. Own calculation using EViews. Data Reuters.

Table AB3: GARCH results for BOND market. Differences in yields for Czech (dCZ10) and German (dGER10) 10-year government bonds. April 2005-February.2008.

			changes in yields in CZ 10-year bond (dCZ10)			**changes in yields in German 10-year bond (dGER10)**
	Error distribution assumption		Normal	GED	Student's t	Normal
	Variance equation		$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$			$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$
	Return equation		$dCZ10_t=c+\rho AR(1)+\varepsilon_t$			$dGER10_t=c+\delta\ MA(1)+\varepsilon_t$
Coefficient estimates	**c**	return constant	0.0726	0.0928	0.0847	0.0921
			(0.651)	*(0.879)*	*(0.778)*	*(0.761)*
	ρ	AR(1) term	0.1936 ***	0.1879 ***	0.1773 ***	n/a
			(6.653)	*(5.230)*	*(4.940)*	
	δ	MA(1) term	n/a	n/a	n/a	0.2028 ***
						(5.500)
	ω	variance constant	3.3028 ***	3.0969 ***	3.0173 **	0.0839
			(2.671)	*(2.594)*	*(2.473)*	*(0.643)*
	α	ARCH term	0.1714 **	0.1629 ***	0.1501 ***	0.0227 *
			(2.365)	*(2.834)*	*(2.601)*	*(1.671)*
	β	GARCH term	0.3585 *	0.3941 **	0.4301 **	0.9681 ***
			(1.733)	*(2.062)*	*(2.222)*	*(36.191)*
Equation results	t-dist df/ GED parameter		n/a	GED: 1.3 ***	t-dist dof: 5.8 ***	n/a
				(13.276)	*(3.872)*	
	Schwarz criterion		4.8002	4.7623	4.7681	4.9576
	Log likelihood (LL)		-1 723.6	-1 706.6	-1 708.7	-1 780.7
	Adj. R-squared		0.0145	0.0155	0.0192	0.0342
	Wald test: H_0: $-1+\alpha_1+\beta_1=0$		-0.470 *** *SE: (0.166)*	-0.443 ** *SE: (0.174)*	-0.420 ** *SE: (0.173)*	-0.009 *SE: (0.017)*
Residuals test:	Q resid.(k=15)		10.961 (0.689)	11.322 (0.661)	12.120 (0.597)	11.835 (0.620)
	Q Sq.resid. (k=15)		14.598 (0.406)	15.027 (0.376)	15.881 (0.321)	8.531 (0.860)
	ARCH-LM Obs*R-sq. (k=15)		12.935 (0.607)	13.252 (0.5828)	13.978 (0.527)	8.829(0.886)
	Skewness		0.0969	0.1014	0.1111	0.0006
	Kurtosis		4.2882	4.3041	4.3309	3.0404
	Jarque-Bera statistics		51.267 (0.000)	52.617 (0.000)	55.001 (0.000)	0.0494 (0.9756)
	Observations		725	725	725	725

Note: ***, **, * denotes 1%, 5%, 10% level of significance. Values in brackets are the z-statistics, and by the residuals test the p-values. Wald restriction test for $\sum \alpha+\beta=1$, with significance of rejection the null hypothesis and standard errors in parenthesis. Q stands for Ljung-Box Q statistics lag (k), reported is k=15, in brackets are p-values. ARCH-LM test with p-values in brackets. For dCZ10, t-distribution the Q of st. residuals also significant at * for lag k=2. Own calculations using EViews. Data Reuters.

Table AB4: BOND market. Unrestricted bivariate BEKK-GARCH (1,1). Differences in yields for Czech (dCZ10) and German (dGER10) 10-year gov. bonds.

SAMPLE: April 2005- February 2008

Matrix:	Ω		A		B		modulus of
Coefficient:	ω_{11}	ω_{12}	a_{11}	a_{12}	b_{11}	b_{12}	eigenvalues
	0	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	
coefficient	0.8921**	0.5319	0.1971	-0.0412	0.9299**	0.0360	0.9171
t-values normal	*(6.665)*	*(1.867)*	*(4.999)*	*(-0.699)*	*(32.352)*	*(0.929)*	0.9171
t-values exact	*(2.289)*	*(0.930)*	*(0.176))*	*(-0.121)*	*(4.855)*	*(0.327)*	0.9268
							0.9260
coefficient	0	0.0166**	0.0817	0.1879	-0.0505	0.9504**	
t-values normal		*(0.003)*	*(2.074)*	*(3.693)*	*(-1.685)*	*(37.051)*	LL
t-values exact		*(2.418)*	*(0.029)*	*(0.339)*	*(-0.133)*	*(6.111)*	-3 374.7

Model diagnostics

Multivariate ARCH-LM	test statistics:	169.983			
(k=16)	p-value(chi^2):	0.0686			
Portmanteau test : (k=16)	test statistic:	121.744			
H_0 $R_h=(r_1,...,r_h)=0$)	p-value:	0.000			
Jarque-Bera test	variable	test stat.	p-val (chi^2)	Skewne	Kurt.
(multivariate)	xi_1	284.4	0.000	0.3443	5.9901
	xi_2	0.073	0.964	-0.0115	2.9565

SAMPLE: October 2001- February 2008

Matrix:	Ω		A		B		modulus of
Coefficient:	ω_{11}	ω_{12}	a_{11}	a_{12}	b_{11}	b_{12}	eigenvalues
	0	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	
coefficient	1.0291	0.3496	0.2334	-0.0397	0.9459**	0.0339	0.9615
t-values normal	*(11.233)*	*(3.370)*	*(22.991)*	*(-3.806)*	*(121.803)*	*(5.819)*	0.9580
t-values exact	*(1.257)*	*(0.824)*	*(1.434)*	*(-0.206)*	*(10.746)*	*(0.157)*	0.9580
							0.9612
coefficient	0	0.0074	0.0370	0.1928**	-0.0337	0.9659**	
t-values normal		*(0.001)*	*(1.771)*	*(9.143)*	*(-4.278)*	*(155.919)*	LL
t-values exact		*(1.637)*	*(0.078)*	*(1.981)*	*(-0.169)*	*(12.374)*	-7 875.8

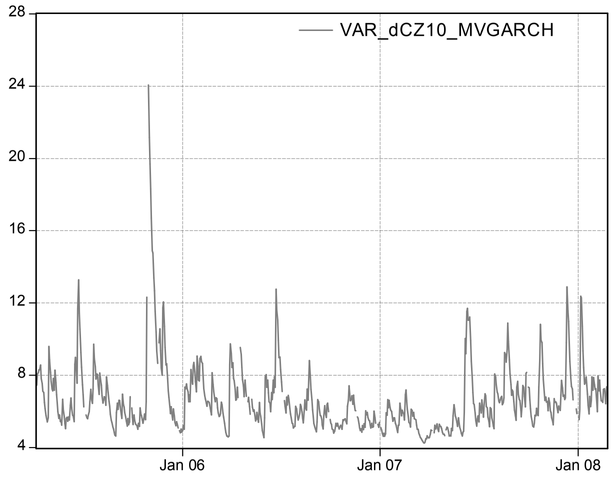
Model diagnostics

Multivariate ARCH-LM	test statistics	404.532			
(k=16)	p-value(chi^2):	0.0000			
Portmanteau test: k=16	test statistic:	116.088			
H_0 $R_h=(r_1,...,r_h)=0$)	p-value:	0.000			
Jarque-Bera test	variable	test stat.	p-val (chi^2)	Skewne	Kurt.
(multivariate)	xi_1	15805.8	0.000	-0.7614	18.878
	xi_2	74.317	0.000	0.2796	3.940

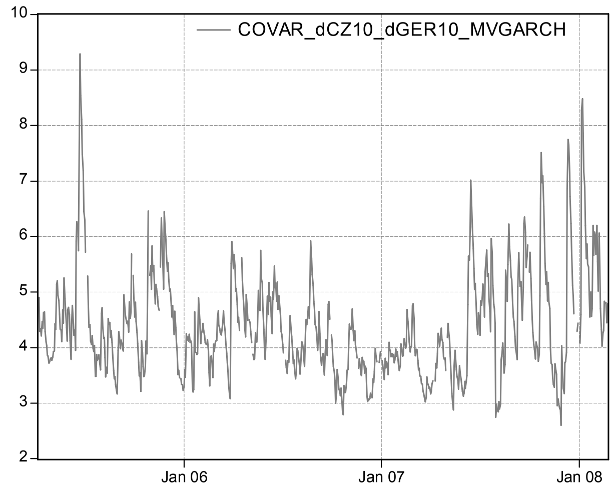
Note: i=1 stands for dCZ10, i=2 for dGER10. ** denotes significance at 5% level of significance based on t-values exact, which are compared to value of normal distribution quantile for 5% significance level (1.960), estimates in grey are non significant at 5% level, based on t-values exact. LL denotes log likelihood. Sample 2005- 2008 has 725 observations (7.4.2005- 21.2.2008). ARCH-LM test was significant also for lags k=5, 10, 15 or 30. Sample full 2001- 2008 has 1491 observations (4.10.2001- 21.2.2008), The ARCH-LM test for sample 2001-2008 was significant also for lags tested 4, 35, 50 or 100. “The model is estimated with a quasi maximum likelihood (QML) estimator under normality assumption. …… exact QML t-ratios which require to evaluate the 1st and 2nd order derivatives of the Gaussian likelihood function analytically” (Herwartz, Kascha, 2005). Own calculation using JMulTi. Data Reuters.

Table AB5: Conditional variance and covariance processes for BOND market - differences in yields 10-year CZ (dCZ10) and German (dGER10) bonds. SAMPLE 2005-2008

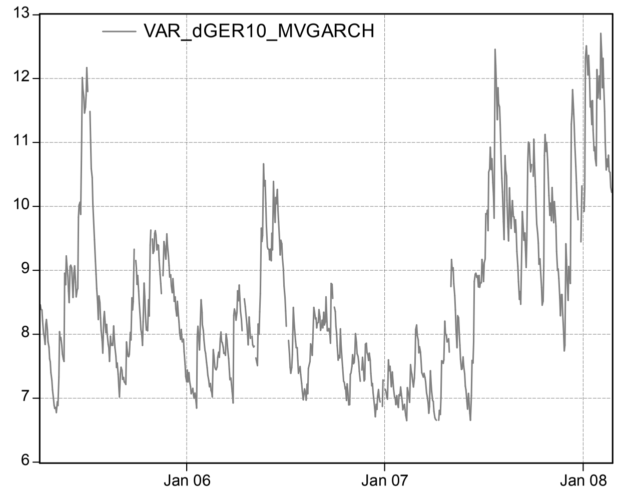
VARIANCE dCZ10



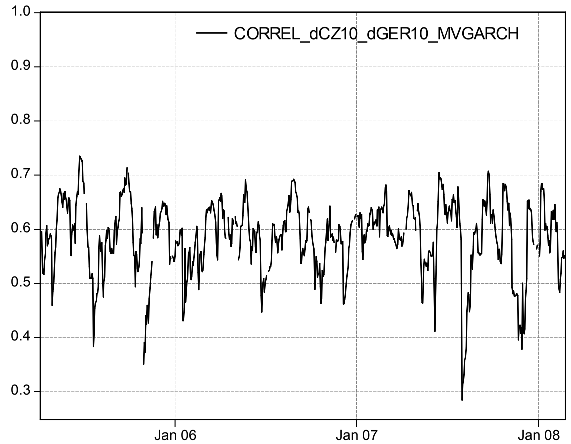
COVARIANCE dCZ10_dGER10



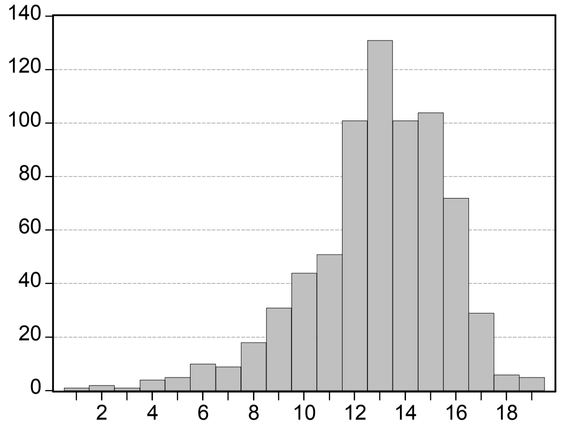
VARIANCE dGER10



CORRELATION dCZ10_dGER10



Descriptive statistics of the estimated conditional correlation coefficient



CORREL_dCZ10_dGER10_MVGARCH
Sample 4/07/2005 2/21/2008
Observations 725

Mean	0.584026
Median	0.590229
Maximum	0.735220
Minimum	0.284330
Std. Dev.	0.068997
Skewness	-0.895430
Kurtosis	4.336855
Jarque-Bera	150.8714
Probability	0.000000

Results from JMulTi estimation of unrestricted bivariate BEKK-GARCH for 10-year BOND market. Sample 7.4.2005 - 21.2.2008. Own calculations using JMulTi and EViews. Data Reuters

Table AB6: BOND market. restricted diagonal bivariate BEKK- GARCH(1,1) model estimates.

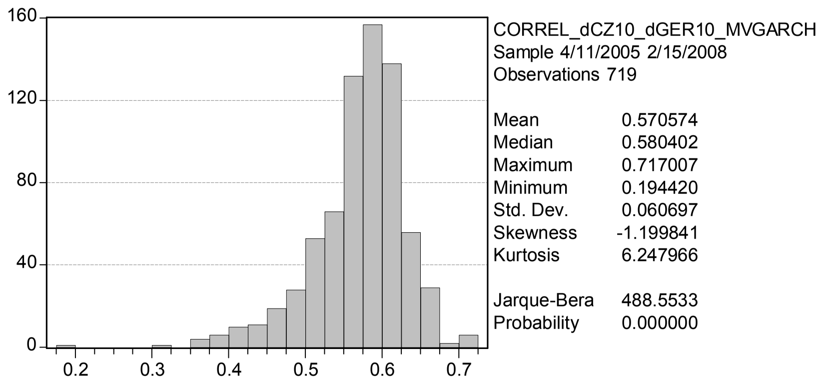
SAMPLE: 2005- 2008

	Conditional variance equation						Conditional
Matrix	**Ω**		**A**		**B**		mean
Coefficient	ω_{11}		a_{11}	a_{12}	b_{11}	b_{12}	equation
	ω_{21}	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	μ_1
							0.0608
Coefficient	**1.6776*****	**0**	**0.3938*****	**0**	**0.6781*****	**0**	*(0.577)*
	(10.714)		*(12.717)*		*(11.273)*		
							μ_2
Coefficient	**0.7378*****	**-0.0004**	**0**	**0.1654 *****	**0**	**0.9516*****	**0.1012**
	(7.438)	*(0.000)*		*(3.439)*		*(28.572)*	*(0.958)*

Model diagnostics

Log Likelihood:	Schwarz criterion	Likelihood ratio
-3 335.8	9.361	327.0 (p-value =0)

Descriptive statistics of the calculated conditional correlation coefficient



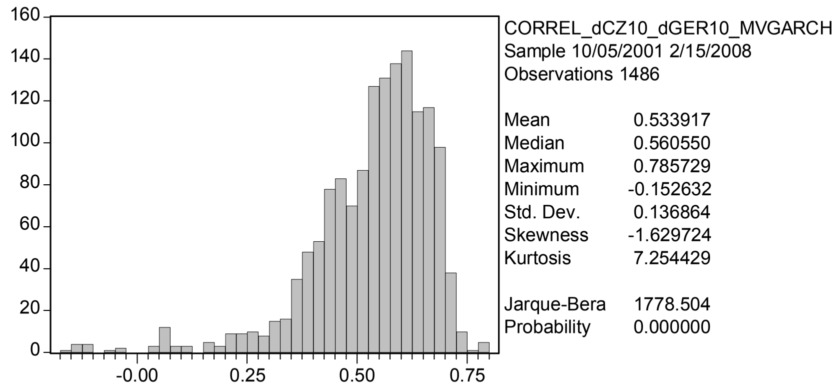
FULL SAMPLE: 2001- 2008

	Conditional variance equation						Conditional
Matrix	**Ω**		**A**		**B**		mean
Coefficient	ω_{11}		a_{11}	a_{12}	b_{11}	b_{12}	equation
	ω_{21}	ω_{22}	a_{21}	a_{22}	b_{21}	b_{22}	μ_1
							-0.0092
Coefficient	**0.5669*****	**0**	**0.2930*****	**0**	**0.9493*****	**0**	*(-0.102)*
	(16.700)		*(28.506)*		*(351.260)*		
							μ_2
Coefficient	**0.2326*****	**0.0573**	**0**	**0.1656*****	**0**	**0.9843*****	**0.0189**
	(7.282)	*(0.328)*		*(14.601)*		*(493.997)*	*(0.220)*

Model diagnostics

Log Likelihood:	Schwarz criterion	Likelihood ratio
-7 811.4	10.558	481.5 (p-value =0)

Descriptive statistics of the calculated conditional correlation coefficient



Sample 2005-2008: 719 observations (11.4.2005- 15.2.2008). Sample 2001-2008: 1486 observations (5.10.2001 - 15.2.2008) ***, **, * denote respectively 1%, 5%, 10% level of significance level, numbers in brackets are z-statistics. Likelihood ratio of likelihood comparing restricted (univariate) estimations against unrestricted (bivariate) one. Estimated in EViews. Data Reuters

Table AB7: GARCH results for BOND market, Sample 5.10.2001- 21.2.2008. Differences in yields for Czech (dCZ10) and German (dGER10) 10-year government bonds.

			changes in yields in CZ 10-year bond (dCZ10)			**changes in yields in German 10-year bond (dGER10)**
	Error distribution assumption		Normal	GED	Student's t	Normal
	Variance equation			$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$		$h_t=\omega+\alpha\varepsilon_{t-1}^2+\beta h_{t-1}$
	Return equation			$dCZ10_t=c+\rho AR(1)+\varepsilon_t$		$dGER10_t=c+\delta MA(1)+\varepsilon_t$
Coefficient estimates	c	return constant	-0.0025	0.0057	-0.0156	0.0269
			(-0.023)	*(0.074)*	*(-0.175)*	*(0.0285)*
	ρ	AR(1) term	0.1889 ***	0.1228 ***	0.1480 ***	n/a
			(5.822)	*(5.358)*	*(5.750)*	
	δ	MA(1) term	n/a	n/a	n/a	0.1070 ***
						(4.191)
	ω	variance constant	0.1925 *	0.4912 ***	0.7210 ***	0.0697
			(1.666)	*(3.355)*	*(3.624)*	*(1.552)*
	α	ARCH term	0.0891 ***	0.0999 ***	0.1224 **	0.035 ***
			(4.031)	*(5.429)*	*(5.051)*	*(3.128)*
	β	GARCH term	0.9052 ***	0.8697 ***	0.8403 ***	0.9603 ***
			(44.964)	*(45.051)*	*(34.828)*	*(77.133)*
Equation results	t-dist df/ GED parameter		n/a	GED: 1.1 ****(27.456)*	t-dist dof: 4.2 ****(8.748)*	n/a
	Schwarz criterion		5.4692	5.3503	5.3481	5.3742
	Log likelihood (LL)		-4 056.3	-3 9641.1	-3 962.4	-3 988.2
	Adj. R-squared		-0.0317	-0.0142	-0.0201	0.0009
	Wald test: H_0: -1+α+β=0		-0.006 *SE: (0.016)*	-0.030 *** *SE:(0.011)*	-0.037 ** *SE: (0.016)*	-0.005 *SE:(0.004)*
Residuals test:	Q resid.(k=15)		13.155 (0.514)	14.937 (0.382)	12.046 (0.603)	16.731 (0.271)
			significant at ** for k=2	at * for k=2,3	at * k=2	
	Q Sq.resid. (k=15)		43.914 (0.000)	28.336 (0.020)	23.078 (0.059)	15.854 (0.870)
			at * up to k=91	at * k=1-23, k=34-73	at * k=1-17, k=34-59	
	ARCH-LM Obs*R-sq. (k=15)		44.021 (0.000)	28.336 (0.020)	22.94 (0.084)	8.365 (0.910)
	Skewness		-0.2350	-0.4616	-0.5856	0.1922
	Kurtosis		9.1796	11.440	12.7940	3.6832
	Jarque-Bera statistics		2384.535 (0.000)	4474.903 (0.000)	6 040.3 (0.000)	38.176 (0.000)
	Observations		1490	1490	1490	1491

Note: ***, **, * denotes 1%, 5%, 10% level of significance. Values in brackets by the coefficients denote the z-statistic, by the residuals test the p-values. Observation for 6.4.2005 removed (value of change between the data break).Wald restriction test for ∑ α+β=1, with significance of rejection the null hypothesis and standard errors in parenthesis. Q stands for Ljung-Box Q statistics lag (k) reported is 15, in brackets p-values of Q. The additional significance of Q-statistics shows max lag for which Q was still significant at *. ARCH-LM test with p-values in brackets. Own computations in EViews. Data Reuters.