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„Macroeconomic determinants of exchange-rate volatility in the countries of Visegrad four“

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Andrea Kunstarova, Bc.

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Abstract

This master thesis describes possible macroeconomic determinants of exchange-rate volatility in countries in central Europe. At the beginning of the thesis, I measure volatility with the autoregressive conditional heteroskedasticity models, which are preferred in the literature. Thereafter I analyze the relationship between determinants and volatility. As all my data are stationary and I am interested in linear relationships between the variables, I follow the dynamic vector autoregression model. Then I use impulse response function analysis, which is useful for investigating shocks and responses on variables. The results point to some significant determinants of exchange-rate volatility in the Visegrad-Four countries. One of them, a share index, which measures stock market development, is significant in three out of four countries.

Abstrakt

Diese Masterarbeit beschreibt die möglichen makroökonomischen Determinanten der Wechselkurs-Volatilität in den Ländern der Visegrad-Gruppe (V4). Am Anfang der Arbeit messe ich die Volatilität mit ARCH-Modellen (Autoregressive Conditional Heteroscedasticity), die in der Literatur bevorzugt werden. Nachher analysiere ich die mögliche Beziehung zwischen den Determinanten und die Volatilität. Weil alle meine Daten stationär sind und ich mich interessiere für die linearen Beziehungen zwischen den Variablen, verwende ich das dynamische VAR-Modell (Vector Autoregression). Danach verwende ich die Impulse Response Function Analyse, die hilfreich ist bei der Entdeckung der Reaktionen von Schocks auf Variablen. Die Ergebnisse zeigen, dass es verschiedene Determinanten der Wechselkurs-Volatilität in der Ländern der Visegrad-Gruppe gibt. Der Aktienindex, der die Börsenentwicklung misst, ist signifikant in drei von vier Ländern.

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1 Introduction

The main interest of this master thesis is to find and analyze important macroeconomic determinants of exchange-rate volatility in the countries of Visegrad four, namely Poland, Hungary, Slovakia and Czech Republic. As many existing research papers conclude, exchange-rate volatility has a crucial role in a country's economy; therefore it is an interesting topic for empirical research. I used autoregressive conditional heteroskedasticity models (ARCH/GARCH) for measuring exchange-rate volatility and in analysis I built vector autoregression model for finding the relationships between the variables. Since this area has not so much been explored using these models yet, this topic has caught my attention and I decided to analyze it. Before doing the analysis I came up with two main research questions:

1. What are the determinants of exchange-rate volatility?
2. Are the same determinants responsible for exchange-rate volatility in a different country?

By answering the first question I want to find appropriate determinants of exchange-rate volatility and test whether they have some effect on volatility or not. In the second question I am interested in finding some similarities, which can be applied in different countries. For example when higher inflation leads to higher exchange-rate volatility in Slovakia, is it also the case in Hungary or other Visegrad four country? Could it be a warning signal for Hungarian policy makers that they should protect the country against higher inflation?

2 Literature Overview

The term volatility is defined as "the degree to which a variable changes over time. The larger the magnitude of a variable change, or the more quickly it changes over time, the more volatile it is" (Suranovic, 2012). This master thesis focuses on exchange-rate volatility, therefore the definition of exchange rate is important. Exchange rates are defined as "the price of one country's currency in relation to the other"[1]. They can be either defined as the price of the home currency in foreign units (direct quote) or as the price of the foreign currency in home unit (indirect quote). Usually there are two types of exchange rates – nominal and real. Nominal exchange rate has also two types – spot and forward rate. Spot rate "is the rate at which foreign exchange can be bought and sold for immediate delivery". Forward rate according to MacDonald (2007), p.2 "is that rate negotiated today at which foreign exchange can be bought and sold for delivery some time in the future." A real exchange rate "is measured by adjusting the nominal exchange rate by relative prices".

2.1 Different views on volatility

The literature on exchange-rate volatility is very extensive. There are different opinions about the impact of exchange-rate volatility; usually authors say that it is a negative phenomenon. But there are also some researchers, who state the opposite. To the first group we can classify, for example, Obstfeld and Rogoff (1998), who argue that exchange-rate volatility is costly to the domestic economy. They build a welfare analysis model, showing price setting behavior under uncertainty. An interesting outcome is offered by Vieira, Holland, Gomes da Silva and Bottecchia (2012), who apply panel data analysis to growth and exchange-rate volatility. Their results show that a more volatile real exchange rate has a significant negative impact on economic growth. In the context of trade, Cushman (1986) and Peree and Steinherr (1989) show that more exchange-rate volatility is theoretically related to negative effects on trade. In addition to trade, exchange-rate volatility has impact also on the investment

[1] The dictionary of International Business Terms, J.K. Shim, J.G. Siegel, M.H. Levine, Glenlake Publishing Co. Ltd., 1998.

activity. This is discussed by Darby et al. (1999). They find a negative effect between investment and exchange-rate volatility in case of France, Germany, Italy, the UK and the US. They show practical examples where exchange-rate volatility decreases the investment activity. Other authors who focus on this relationship, such as Braun and Larrain (2005) and Aghion et al. (2009), conclude that higher exchange-rate volatility leads to higher volatility of profits and net worth, which causes lower ability for companies to finance investment. Also Cermeňo and Grier (2006) say that this increase in exchange-rate volatility can raise inflation uncertainty and reduces consumption and investment.

The other group of authors, who consider volatility as a positive phenomenon, is not that big, because usually most researchers consider exchange-rate volatility to have negative effects on economy. But some authors mention that it can have also positive impact, usually in the short term. This can be seen in the work of Karemera, Managi, Reuben & Spann (2009). They analyze the impact of exchange-rate volatility on vegetable trade flows, and they find a positive effect of volatility on some commodities. Also, for example, Langley et al. (2000) and Klein (1990) state that the relationship between exchange-rate volatility and export is positive. The same opinion is held by Ramli and Podivinsky (2011) in their work about effects of exchange-rate volatility on exports. They investigate both long-run and short-run relationships between various determinants with cointegration analysis and error correction model. They find some positive relationships between volatility and export in some countries.

There are also many studies and researches that analyze the relationship between international trade and exchange-rate volatility, for example Auboin and Ruta (2013) come up with the conclusion that higher exchange-rate volatility reduces international trade. However the effect on international trade depends on factors such as existence of hedging instruments, structure of production or economic integration across countries. Égert and Morales-Zumaquero (2005) state that exchange-rate volatility weakens exports, with the impact changing across different sectors and countries. Of course there are some differences in various countries and regions, for example Hayakawa and Kimura (2009) focus on the East Asian market and their conclusion is in line with previous papers – there is a negative impact of exchange-rate volatility on the international trade. Many authors also compare the cases with developed and developing countries. For instance, Hausmann et al. (2006) or Ganguly and Breuer (2010) claim that exchange-rate volatility is higher in developing countries and one of the main reasons is the higher economic instability and not so well developed exchange-rate market.

Finally interestingly literature mentions the concept of “realized volatility”. This is emphasized in work of Bollerslev, Andersen, Diebold and Labys (2003), where they measured and forecasted return volatilities and distributions with realized volatility constructed from high-frequency intraday returns. They found that the use of traditional time-series methods produced good forecasts compared to more complicated methods such as multivariate ARCH or stochastic volatility models.

Summarizing all these findings, exchange-rate volatility has impact on a broad area of the economy. It influences economic stability and growth, trade and investment activity and it can cause a reduction in consumption or international trade. Therefore it is important to study and focus on the main characteristics and determinants of this phenomenon.

2.2 Literature about the causes of exchange-rate volatility

One popular and often discussed topic is the cause of exchange-rate volatility. There is a big group of research papers, which focuses on the relationship between exchange-rate volatility and inflation targeting. An interesting analysis is used by Berganza and Broto (2011), who use a panel data model to find out that inflation targeting can cause an increase in exchange rate instability and they also mention that there is a difference between countries, which use inflation targeting, and those that don’t use it. According to their results, in countries with inflation targeting, the forex interventions are more effective for decreasing volatility than in the countries without inflation targeting. Edwards (2007) deals also with the impact of inflation targeting on exchange-rate volatility. His results show that there is no relationship between inflation targeting and increase in nominal or real exchange-rate volatility, but he finds that there is an increase in volatility in some of the countries in case of floating exchange rate regime. Gregorio, Tokman and Valdés (2005) focus on one particular country, namely Chile, and analyze the flexible exchange rate regime and inflation targeting. There is an increase in exchange-rate volatility related to the flexible regime, but overall it has smaller real exchange rate valuations than in the past.

The other determinants, which are worth to mention, follow Kanas (2010) who examines the relationship between exchange-rate volatility and stock return volatility in the US, UK and Japan. Giannellis and Papadopoulos (2011) measure the stock development by the national stock indexes and conclude that it can cause exchange-rate volatility. Ganguly and Breuer (2009) compare developing and industrialized countries and find some nominal factors that influence short-run and long-run exchange-rate volatility. Krol (2014) examines the influence of economic policy uncertainty on exchange-rate volatility for some industrial and emerging countries. The result says that there is a direct increase in exchange-rate volatility with higher economic policy uncertainty, and this result is even stronger during bad economic periods.

Some papers also analyze how different economic shocks influence volatility. One example is described by Valcarcel (2012), who investigates exchange-rate volatility and the time-varying effects of aggregate shocks in the US. He mentions different types of shocks, for example he finds a relationship between monetary shocks and increases in exchange-rate volatility during the Great Inflation period. Furthermore, demand shocks seem to be significant for the increase of real exchange-rate volatility. Authors as Hausmann et al. (2006) or Berganza and Broto (2011) study how the real shocks influence exchange-rate volatility.

The last determinant I describe is the openness of the economy. The literature about the relationship between international trade, import and export is again very extensive. Hau (2002) studies the real exchange-rate volatility and openness of the economy. His results confirm that there is lower real exchange-rate volatility in the countries with a higher openness of the economy. This relationship is robust to adding various control measures. Other authors, as for example Obstfeld and Rogoff (2000) and Calvo et al. (2003), show that the more open is the economy, the lower is exchange-rate volatility.

3 Macroeconomic determinants of exchange-rate volatility

This chapter describes the individual determinants and focuses on these determinants in the countries of Visegrad four. Based on previous research I decided to analyze following determinants:

- Openness of the economy,
- Stock market development,
- Interest rates,
- Inflation,
- Terms of trade.

3.1 Openness of the economy

The openness of the economy, also called openness ratio or trade-to-GDP ratio, is calculated for the economy as the sum of imports and exports divided by GDP. In other words, it is a "simple average of total trade relative to GDP".[2]

The international Chamber of Commerce classified some countries of the world into five groups – most open, above average open, average open, below average open and very weak open countries. Openness of the economy also shows how important the international trade for the economy is. Generally small economies are more dependent on international trade than bigger ones. An interesting fact is that countries as Singapore, Hong Kong or United Arab Emirates have very high openness and the reason is the importance of transit trade (WBO, 2013). Table 1 shows the openness of some countries in the world. The countries of Visegrad four are highlighted. In three of four Visegrad countries is openness higher than the average. Only in case of Poland openness is average.

[2] OECD Science, Technology and Industry Scoreboard 2011

Table 1: Openness of some countries of the world, Source: The world business organization, International Chamber of Commerce, 2013

Openness	Countries
Most open	Hong Kong, Singapore
Above average openness	Luxembourg, Belgium, Malta, Netherlands, United Arab Emirates, Ireland, Estonia, Iceland, Switzerland, Sweden, Norway, Slovakia, Denmark, Austria, Finland, Slovenia, Canada*, Hungary, Czech Republic, Germany, Bulgaria, Australia, New Zealand, Lithuania, Chinese Taipei, Cyprus, United Kingdom
Average openness	Malaysia, Israel, Latvia, Chile, Poland, France, Ukraine, Romania, United States, Japan, Saudi Arabia, Italy, Portugal, Peru, Spain, Korea, Vietnam, Turkey, Greece, Thailand, South Africa, Jordan, Colombia, Indonesia, Mexico
Below average openness	Kazakhstan, Egypt, China, Philippines, Russian Federation, Uruguay, Morocco, Tunisia, Argentina, India, Sri Lanka, Nigeria, Brazil, Kenya, Pakistan, Venezuela, Uganda, Algeria
Very weak openness	Bangladesh, Sudan, Ethiopia

Now I look at openness of the economy for every country in Visegrad four. In case of Slovakia, the level of openness is very high. The ratio of international trade by GDP is growing in this country; in 2012 it was 186% of GDP, which is a 69 percentage point increase in a comparison with year 1993. This share was 185.7% in 2013 and even higher in 2014 – 188.3%.

The situation of the Czech economy is very similar, it is also a highly open economy and the ratio of international trade by GDP was 151% in 2012. They recorded a 57% increase since 1993 (NBS, 2013).

Hungary also has openness of the economy above the average, the country's export dropped down after 2000 and this drop was 16% in the period 2008-2013. Openness of the country was 160% of GDP in 2012, which is similar to the other Visegrad countries.[3]

Openness of the economy in Poland is the lowest among Visegrad four countries. A comparison can be seen in the following table, where exports, imports and trade volumes are used as % of GDP:

Table 2: Exports, Imports and Trade volume in some European countries, Source: National bank of Poland

	Exports	Imports	Trade volume
Bulgaria	60	82	142
Czech republic	78	70	150
Estonia	78	80	158
Hungary	80	80	160
Latvia	40	58	98
Lithuania	60	70	130
Poland	40	42	80
Romania	30	42	75
Slovakia	80	82	165

3.2 Stock market development

As already mentioned, there are researches that claim exchange-rate volatility has a relationship with the stock market development. Giannellis and Papadopoulos (2011) capture the relationship between exchange-rate volatility and stock market development and other variables. The authors focus on the shocks in stock markets and their impact on exchange-rate volatility. With the use of a bivariate CCC-

[3] http://ec.europa.eu/economy_finance/publications/occasional_paper/2014/pdf/ocp180_en.pdf

MGARCH model, they investigate the cases of Hungary, Czech Republic, Slovak republic, Italy and some other countries. They find a significant relationship between stock market and exchange-rate volatility in case of Poland or Spain.

Stock market development is measured by the national stock indices. The stock markets of the countries of Visegrad four are linked to each other. Reboredo, Tiwari and Albulescu (2014) analyze the relationship between the stock markets in CEE countries, namely Czech Republic, Hungary, Poland and Romania. Even though the analysis does not include Slovakia, the authors find positive dependence between these CEE countries and this dependence is stronger in case of Hungary, Poland and Czech Republic.

Slovakia

The national stock index of Slovakia is called SAX – Slovak stock index, which is computed as a weighted average. It contains only stocks from the listed market. The Slovak regulated market of securities is divided into listed market and free market (NBS, 2014).

Czech Republic

Similar to the Slovak republic, the Czech Republic also has its own national stock index, namely PX, which is the official index of the Prague Stock Exchange. Before, the country had used PX50 and PX-D indices, whereas PX was used for the first time in 2006.[4]

Hungary

The national stock index in Hungary is called Budapest stock index. It is a "capitalization-weighted index adjusted for free float." It shows the price of large, actively traded shares on the Budapest Stock Exchange. It has "a base value of 1000 points as of January 2, 1991 and is a total return index."[5]

4 http://www.bloomberg.com/quote/PX:IND

5 http://www.bloomberg.com/quote/BUX:IND

Poland

WIG index or Warsaw stock exchange index is a "total return index, which includes dividend and pre-emptive rights (subscription rights). It includes all companies listed on the main market, excluding foreign companies and investment funds. The index base value is 1000 as of April 16, 1991."[6]

3.3 Interest rate

There is a relationship between exchange-rate volatility and the interest rate differential. Giannellis and Papadopoulus (2011) show that this is the case for Poland, Hungary or Spain. The interest-rate differential is defined as a "national interest rate relative to the EU's interest rate. (Giannellis and Papadopoulus 2011, p.53)".

There are also other authors who focus on the interest rates and exchange-rate volatility. For example Hussain, Mubin and Lal (2010) study the effect of volatility on inflation and interest rates in Pakistan. With the use of ARCH and GARCH they find a positive relationship between these two variables. The case of small open economies is analyzed by Sanchéz (2005). He uses impulse response analysis to various shocks and finds a significant relationship between exchange-rate volatility and interest rates.

3.4 Inflation

There is a theoretic relationship between purchasing power parity and exchange rate and inflation according to Grossman and Orlov (2014). Higher inflation can lead to higher economic uncertainty, which can be related to increased exchange-rate volatility. Therefore inflation is an important determinant, and I will focus on it in my work.

A very popular topic related to exchange-rate volatility is also inflation targeting. Inflation targeting is a technique for controlling the increase in the price level. "The central bank estimates and makes public a projected, or target, inflation rate, and then

6 http://www.bloomberg.com/quote/WIG:IND

attempts to steer actual inflation toward that target, using such tools as interest rate changes" (Sarwat, 2011).

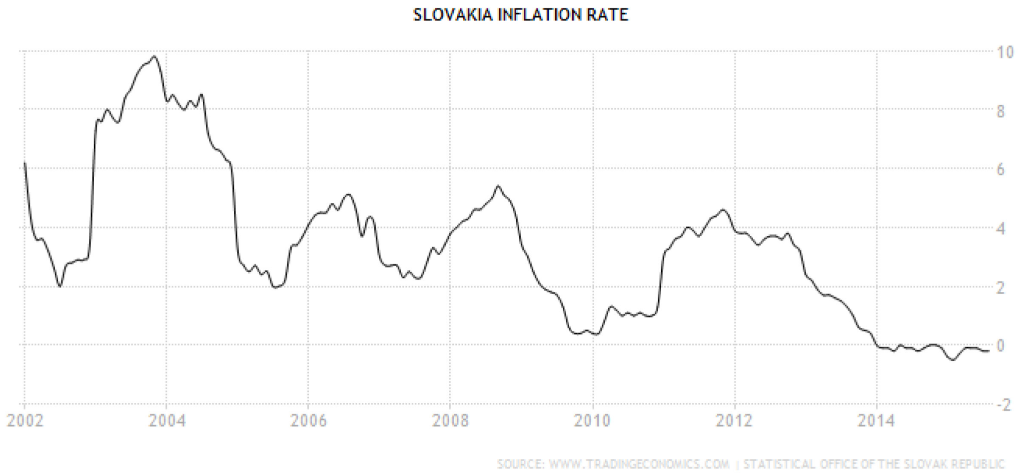
Berganza and Broto (2011) examine inflation targeting, forex interventions, and exchange-rate volatility in emerging countries. With the help of panel analysis, they find that flexible inflation targeting should be used by policymakers. Their results confirm that exchange-rate volatility is higher under an inflation targeting regime. An important finding is that a flexible inflation targeting regime is sustainable and effective with the right combination of forex interventions. Castillo (2014) is interested in inflation targeting and exchange-rate volatility smoothing in Guatemala. He describes an economy with two targets – an inflation target and a nominal exchange-rate volatility target – and the use of two monetary instruments. He concludes that the central bank should synchronize these two instruments to achieve both targets.

Slovakia

The inflation rate of Slovakia is depicted on Figure 1. The rate is currently negative. The average from 2002 until end of 2014 is 3.38% and Figure 1 shows inflation rate during this period.[7] During the period from 1999 until 2008, inflation rate was very volatile and Slovakia started to fulfill the Maastricht criterion firstly from August 2007. During this period, the development of the Slovak inflation rate was influenced mainly by liberalization and deregulation of energy prices, changes in tax system or adopting the uniform value added tax (Doliak, 2008). During 2014, the slowest inflation rate growth since 1993 (establishment of Slovak republic) was observed. This slow growth is related to the positive development of cost factors, mainly decrease of energy prices (Kavický, 2015).

[7] http://www.tradingeconomics.com/slovakia/inflation-cpi

Figure 1: Slovak inflation rate (CPI), Source: tradingeconomics.com



Czech Republic

Inflation in the Czech Republic is measured and published by the Czech statistical office. Figure 2 shows the evolution of inflation from 1996 until 2014.[8] [9]

Figure 2: Czech inflation rate (CPI), Source: tradingeconomics.com

In 1998, the Czech Republic started a new monetary policy regime, namely inflation targeting. The central bank tried to remove high inflationary and disinflationary pressures, which could cause inflation volatility. The central bank also set inflation target, which until 2005 should have been around 1-3%.

[8] https://www.czso.cz/csu/czso/inflation_rate

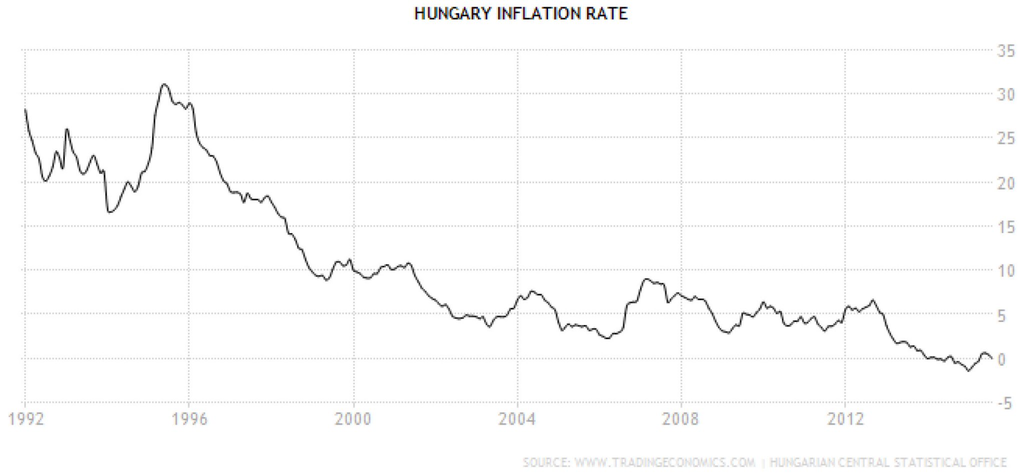
[9] http://www.tradingeconomics.com/czech-republic/inflation-cpi

Inflation peaked in 2008, and since that year the inflation rate has been decreasing. In the last two years, the inflation remained below 0.5% (CPI).

Hungary

In Hungary, the inflation rate is recorded by the Hungarian Central Statistical Office. The average interest rate of Hungary from 1992 until 2014 is 10.04%.[10] The rate has been decreasing since 2008, and, similarly as Slovakia, there are some periods with negative rates.

Figure 3: Hungary inflation rate (CPI), Source: tradingeconomics.com



Poland

Similar as in Slovakia and Hungary, also Poland has some negative interest rate periods. The average from 1992 until 2014 is 9.57% and the rate is reported by the Central Statistical Office of Poland.[11] Figure 4 shows inflation rate during this period.

[10] http://www.tradingeconomics.com/hungary/inflation-cpi

[11] http://www.tradingeconomics.com/poland/inflation-cpi

Figure 4: Poland inflation rate (CPI), Source: tradingeconomics.com

3.5 Terms of trade

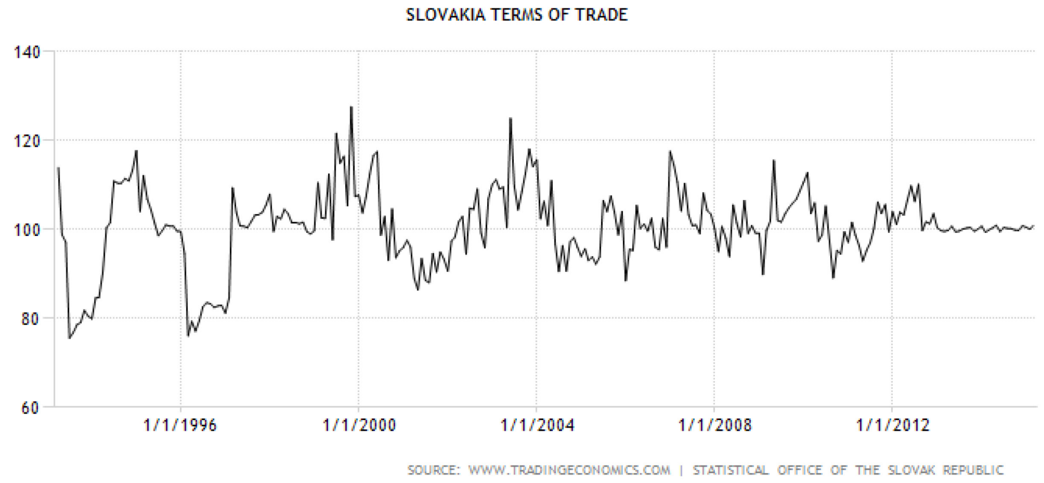
Terms of trade are defined as the ratio of export prices to import prices. They are typically defined as an index of 1 or 100 in a base year, so they are quite difficult to compare across countries. Broda (2004) claims that in many cases exchange-rate volatility can be caused by shocks in terms of trade.

Slovakia

Terms of trade are measured with the index points. Figure 5 shows the development from 1995 until end of 2014.[12]

[12] http://www.tradingeconomics.com/slovakia/terms-of-trade

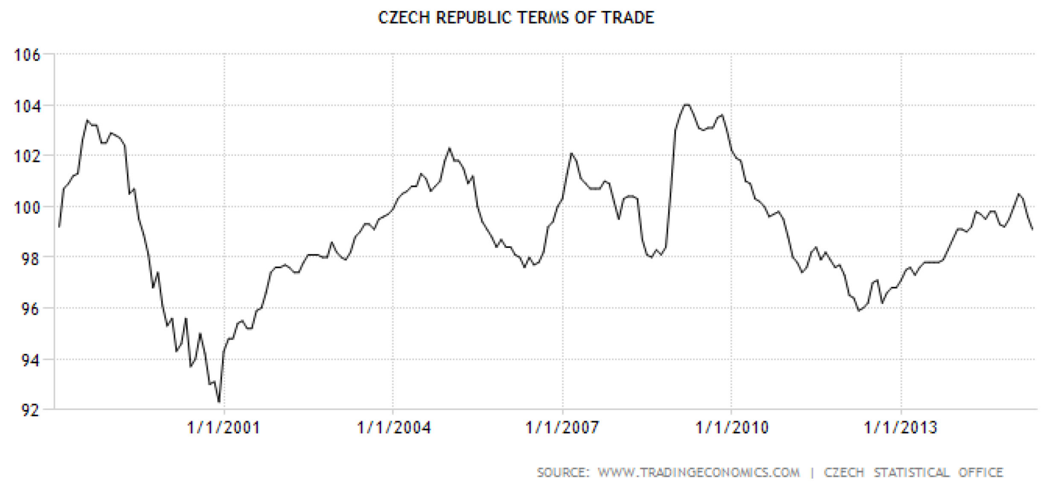
Figure 5: Slovak terms of trade, Source: tradingeconomics.com



Czech Republic

Terms of trade in Czech Republic are very similar to Slovakia. They are measured by the Czech Statistical Office.[13]

Figure 6: Czech terms of trade, Source: tradingeconomics.com

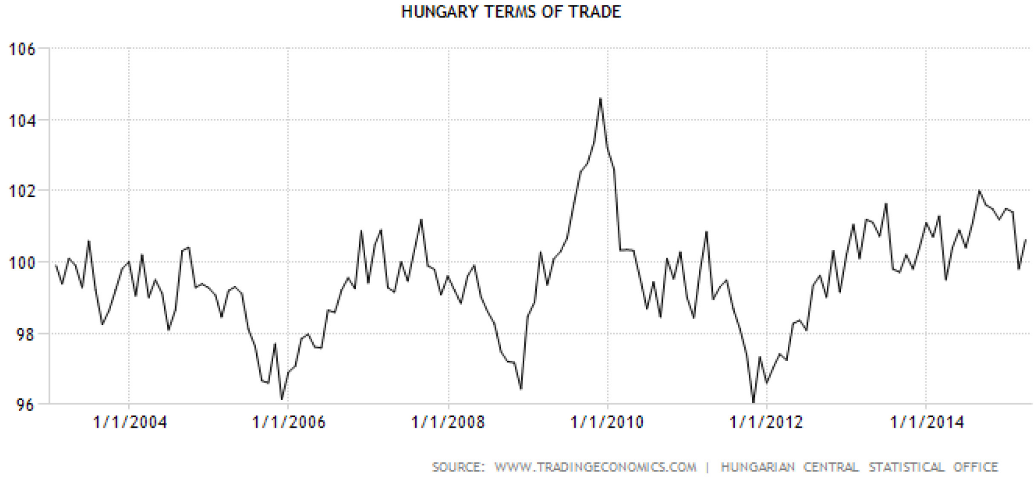


Hungary

Hungarian terms of trade are recorded by the Hungarian Central Statistical Office and similar as other Visegrad countries. The period from 2003 until end of 2014 is depicted on Figure 7. [14]

[13] http://www.tradingeconomics.com/czech-republic/terms-of-trade

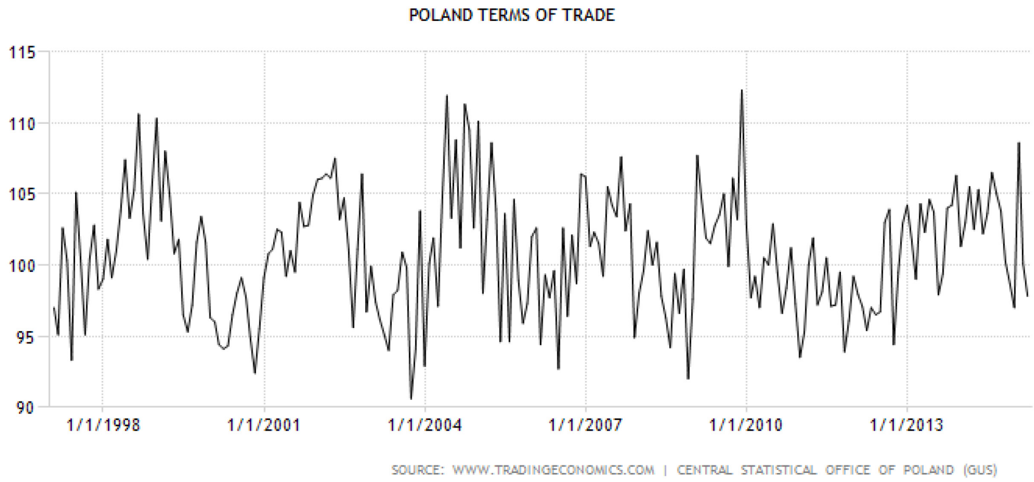
Figure 7: Hungarian terms of trade, Source: tradingeconomics.com



Poland

In case of Poland Figure 8 shows the period between 1997 and 2014. The main body taking care of this variable is the Central Statistical Office of Poland.[15]

Figure 8: Polish terms of trade, Source: tradingeconomics.com



[14] http://www.tradingeconomics.com/hungary/terms-of-trade

[15] http://www.tradingeconomics.com/poland/terms-of-trade

4 Methodology

This section describes the methodology of my master thesis or, in other words, general steps used for answering my research questions determined in Introduction. The first step in the methodology was to find an appropriate method for measuring exchange-rate volatility. I compared different views on how to measure exchange-rate volatility. Then I found possible determinants candidates and for all these variables I had to obtain and prepare data. Final step of the methodology was to find a method for measuring the relationship between determinants and volatility. I decided to use vector autoregression analysis.

4.1 Different views on exchange-rate volatility measurement

There is no unanimous agreement yet on the best measure of exchange-rate volatility. Different authors use different concepts. It is usually measured as a standard deviation of the first difference of logarithms of exchange rate. There are some critiques of this approach, mainly because it does not show the peak values of exchange rate as mentioned in Serenis and Tsounis (2012).

The next possibility how to measure exchange-rate volatility is with the use of forward rate as a prediction of the future spot rate according to Clark, Tamirisa, Wei, Sadikov and Zeng (2004). They suggest using the difference between the spot rate today and forward rate from the previous period as an indicator of exchange-rate risk.

Another possibility is to use ARCH or modifications of ARCH models. Sadorsky (2012) uses a multivariate GARCH approach for studying volatility spillovers between oil and stock prices. He uses four multivariate GARCH models - BEKK, diagonal, constant conditional correlation, and dynamic conditional correlation. The first model – BEKK is used as a benchmark and it is compared to the other three models. The results from his empirical analysis show that the best model for explaining the stock prices volatility in this case is the dynamic conditional correlation multivariate GARCH. Sadorsky enriched his research in 2014 by evaluating volatility and correlation between emerging market stock prices and prices of oil, copper and wheat. He uses VARMA-AGARCH and dynamic conditional correlation GARCH model for modeling volatilities and conditional correlations. He found that the DCC asymmetric GARCH model (AGARCH) fits the best in this case.

In their panel VAR analysis, Grossman and Orlov (2014) use the first approach, namely the use of standard deviation. They employ the standard deviation of daily exchange rates over the annual period. Volatility is measured similarly in the work of Berganza and Broto (2011) or Hayakawa and Kimura (2009). On the other hand Kocenda and Valachy (2006) prefer the ARCH model; and Edmonds and So (2004) focus on ARCH too. Erdemlioglu, Laurent and Neely (2013) describe more approaches how to measure exchange-rate volatility and one of them is the GARCH model. The GARCH model was introduced by Bollerslev (1986). He extended the ARCH model developed by Engle (1982) and allowed for more flexible lag structure. The GARCH model and also all ARCH model variants are recommended to use in case of volatility clustering of exchange rate. Pacelli (2012) states, that different models measuring exchange-rate volatility can be summarized into these two groups:

- structural models
- black box forecasting models

The models as ARCH and GARCH can be included into the first group. To the second group belong models such as neural network models (ANN), genetic algorithm models or fuzzy models or series without white noise pattern.

4.2 GARCH model

The generalized autoregressive conditional heteroskedasticity model (GARCH) allows the conditional variance to change over time as a function of past errors. It is widely used because it is quite easy to estimate and it is successful in estimating conditional variances (Engle 2001).

The general form of GARCH (p,q) model can be written as follows:

$$\sigma_t^2 = \omega + \sum_{j=1}^{p} \alpha_j \epsilon_{t-j}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \qquad (1)$$

The p stands for how many autoregressive lags or ARCH terms are going to be used in the model and q states for how many moving average lags are specified or in other words number of GARCH terms.

There are three unknown parameters – ω, α_i and β_i. Usually GARCH (1,1) is used, whose form is:

$$\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \qquad (2)$$

The σ^2_t is non-negative and also α, β and ω are non-negative. The (1,1) is a notation where first number means how many autoregressive lags are present (ARCH terms) and the second refers to how many moving average lags are specified (GARCH terms).

GARCH (1,1) can be a more parsimonious version of the higher order ARCH model, which can avoid overfitting. Important in case of both ARCH and GARCH is their symmetry, the most important are the absolute values of the innovations. Thus, a very big negative shock influences volatility like a big positive shock (Verbeek, 2004, p.300).

Basically the ARCH model consists of 2 equations – mean and variance equation.

$$y_t = \beta + e_t \quad \text{where } e_t \text{ follows a specific distribution with variance } h_t \qquad (3)$$

$$h_t = \alpha + \alpha_1 e_{t-1}^2 \qquad (4)$$

The mean equation (3) is a linear regression function containing the constant and explanatory variables and it describes how the time series behave. In this notation it consists only of intercept term β and residual term e_t. The variance equation (4) describes the behavior of the conditional error variance, where h_t denotes the variance conditional on past information.

The GARCH model adds to the equation 5 a GARCH term, which is a lagged residual variance (volatility) denoted by h_{t-1}.

$$h_t = \alpha_0 + \alpha_1 e_{t-1}^2 + \beta h_{t-1} \qquad (5)$$

The exchange-rate volatility is measured with GARCH (1,1) by Bahmani-Oskooee, Hegerty and Hosny (2015), who analyze exchange-rate volatility and commodity trade between EU and Egypt. Kocenda and Valachy (2006) also suggest that GARCH model is appropriate tool for measuring the exchange-rate volatility. Bentes (2015) uses GARCH (1,1) together with other ARCH family models (IGARCH and FIGARCH) for forecasting volatility in gold returns.

4.3 VAR analysis

For estimating the relationship between exchange-rate volatility and various determinants I consider vector autoregression (VAR) analysis. Verbeek (2004), p.322 defines and describes the VAR model as "the dynamic evolution of a number of variables from their common history." In other words it shows the linear relationships between multiple time series. The first-order VAR, if two variables X and Y are used, has the form:

$$Y_t = \delta_1 + \theta_{11} Y_{t-1} + \theta_{12} X_{t-1} + \varepsilon_{1t} \tag{6}$$
$$X_t = \delta_2 + \theta_{21} Y_{t-1} + \theta_{22} X_{t-1} + \varepsilon_{2t} \tag{7}$$

The VAR model "extends the first order autoregressive model to the higher-dimensional case" (Verbeek, 2004, p.322) VAR (p) can be written as:

$$\vec{Y}_t = \delta + \Theta_1 \vec{Y}_{t-1} + \cdots + \Theta_p \vec{Y}_{t-p} + \vec{\varepsilon}_t \tag{8}$$

The equation uses a *k*-dimensional vector of white noise terms. The advantages of this model are for example that it is more parsimonious and has fewer lags, which leads to better forecasting results compared to univariate autoregressive moving average models. For estimating the VAR model the simple ordinary least squares estimator can be used. Since it is not easy to determine the length of lags (p), Verbeek recommends to estimate VAR for more values of *p*. Then choose the best value according to its significance, Akaike or Schwarz information criterion. An often mentioned approach related to the VAR models is impulse response analysis. It measures the response of one variable to shocks related to other variables. Grossman, Orlov and Love (2014) use this analysis in their panel VAR approach. They estimate vector, which includes five variables – real GDP growth, difference in foreign reserves, log-difference of interest rates, equity index and exchange-rate volatility. They mention these advantages of the panel VAR model:

- useful when not much is known about the relationships between the variables,
- mitigates the endogeneity problem,
- includes fixed effect,
- allows for common time effects to catch some macroeconomic shocks,
- effectively useful with short time-series dimension.

They use impulse response functions for analyzing the reaction of one variable to shocks. They transform the residuals to make them orthogonal because they need to isolate the shocks to one of the variables. When they analyze the dynamic effects of various variables on exchange-rate volatility, they place these variables at the end. This implies that exchange rates can react immediately to the macroeconomic news, but there is a lag between exchange-rate volatility and its effect on the economy. Then they change the order of the variables and check for the robustness of the results.

Olson, Vivian and Wohar (2014) use a VAR model in their multivariate GARCH analysis to find the relationship between energy and equity markets. They use a two-step procedure, where, in the first step, VAR with one lag is estimated and then MGARCH is used for modeling time-varying variances and covariances. They employ BEKK specification in case of MGARCH model. After estimation they create volatility impulse response functions.

A similar procedure is used by Sadorsky (2012), who uses a VAR with one lag for modeling the returns. Then MGARCH is used for modeling the time varying variances and covariances.

Giannellis and Papadopoulus (2011) use Granger causality tests for studying the relationships between the individual variables and also if exchange-rate volatility is caused by these variables. The principle of the Granger test is the explanation of today´s exchange rate returns by previous values of the variables. They combine all variables and present the results. They find some causality for example between interest rate differentials and exchange rates in case of Poland and Slovakia. Other example is in case of Czech Republic and Spain, where they find a relationship between exchange rate movements and stock returns.

Sensoy and Sobaci (2014) analyze the dynamic relationship between exchange rate, interest rate and stock market with the use of VAR model. Firstly they estimate the VAR model for all these variables and then check for the changes in volatility of the VAR return residuals series. They try to find out if the changes in correlation between some variables in high-volatility periods are temporary or permanent. Their results show that volatility shocks cause short-term changes only.

4.4 Impulse response function

The impulse response functions "describe the reaction of one variable to the innovations in another variable in the system" (Grossmann, 2014, p.12). Here, the "impulse" is a positive shock of one positive standard deviation to the VAR model. Such a unit shock is applied to each variable, and then its effects on VAR can be observed. If the residuals in the equations of VAR model are uncorrelated, they can be interpreted as the structural shocks. If the VAR model is stable, the impulse response function is converging to zero.

4.5 Methodology summary

According to previous literature and research I decided to measure exchange-rate volatility with generalized autoregressive conditional heteroskedasticity model (GARCH). I compared various models for measuring volatility as standard deviation, forward rate or modifications of ARCH model. I find GARCH model to better fit my purposes than standard deviation, therefore I use it in my analysis.

I follow vector autoregression (VAR) method for finding the relationship between the determinants and exchange-rate volatility, because it can capture linear relationships between multiple time series. An important part of the analysis are the impulse response functions estimated after VAR model to describe reaction of one variable to the innovations in the other variable.

5 Empirical analysis and results

In this section I analyze and estimate the relationship between macroeconomic determinants and exchange-rate volatility. I start with the description of data and its summary statistics. Then I measure volatility and estimate VAR model for finding the dynamic relationship between the variables. At the end of this section I present the results and conclusions. The main interest of my thesis is to analyze the relationship between determinants and volatility, so I did not include exchange rate itself in vector autoregression analysis. For those interested in the relationship between exchange rates and macroeconomic determinants, I provide impulse response function analysis in Appendix, where I found some significant results.

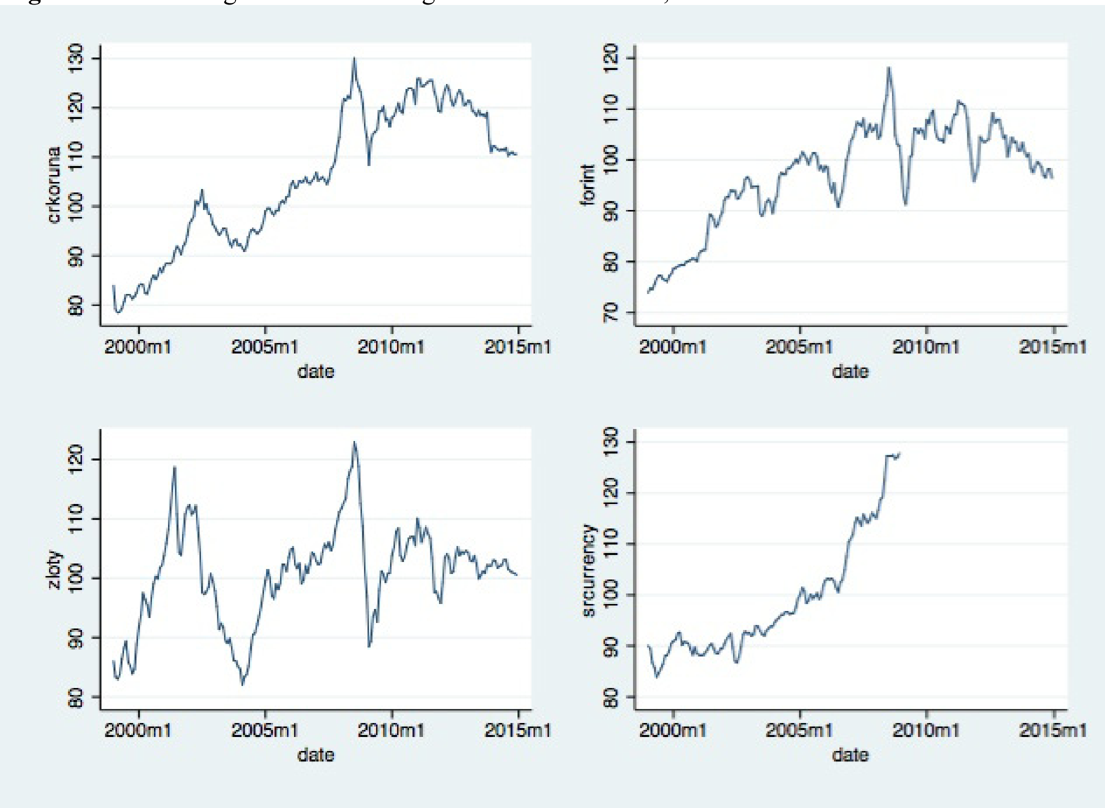
5.1 Description of the data

In the analysis I use monthly and quarterly data of the determinants for all Visegrad four countries taken from the Organization for Economic Cooperation and Development (OECD) database. The data are from the period 1999-2014. The quarterly data were changed to monthly with cubic spline interpolation.

Exchange rates of all four Visegrad countries are depicted in Figure 9. I used monthly real effective exchange rates (REER) from January 1999 until December 2014. The only exception is Slovakia, where I use the data until December 2008. After 2008 Slovakia adopted the euro and stopped using Slovak crown. The aim of real effective exchange rates is that they "take account of price level differences between trading partners. Movements in real effective exchange rates provide an indication of the evolution of a country's aggregate external price competitiveness."[16] REER depends on a basket of currencies of trading partners that are weighted by their importance in bilateral trade.

[16] OECD - https://stats.oecd.org/glossary/detail.asp?ID=2243

Figure 9: Exchange rates of Visegrad four countries, Source: own estimates



I use the log of first differences in case of exchange rates in all Visegrad four countries and from the figures below it seems they are characterized by random changes, in other words they are volatile. From Figure 10 and summary statistics we can see the distribution is leptokurtic.

Figure 10: Volatile exchange rates in Visegrad four countries, Source: own estimates

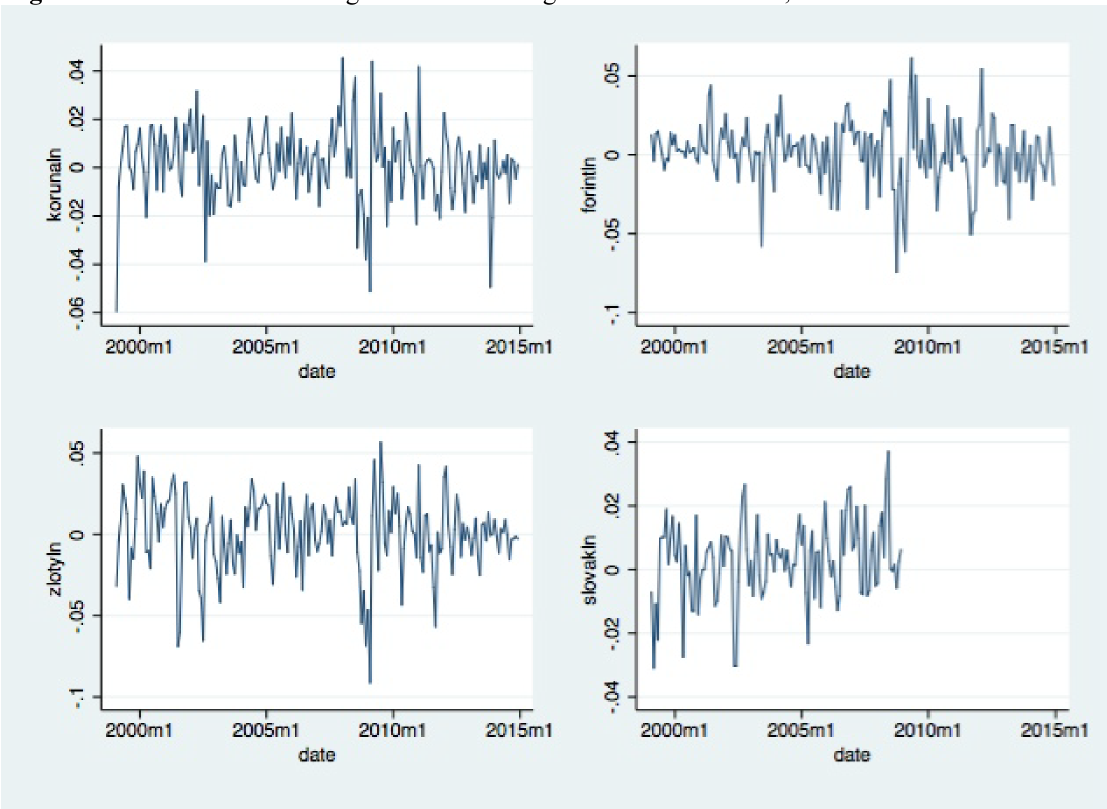
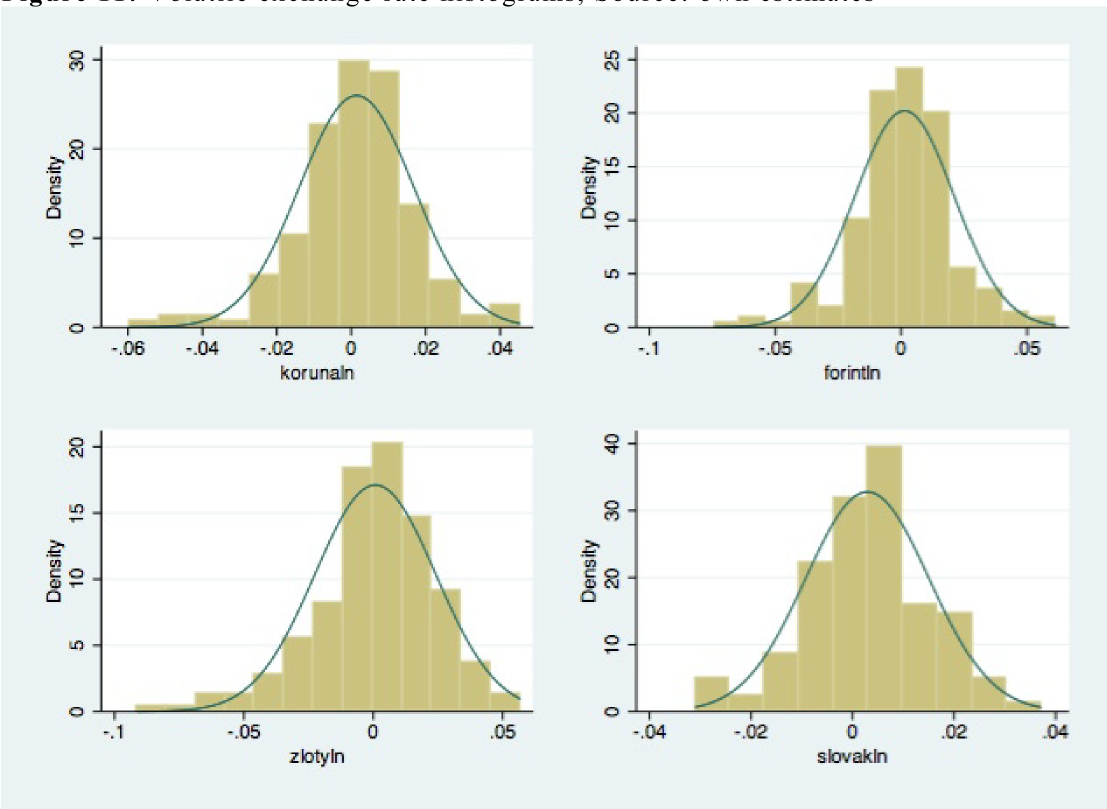


Figure 11: Volatile exchange rate histograms, Source: own estimates



Inflation is measured by the consumer price index (CPI) and monthly data are taken from the OECD database. Similarly as in case of exchange rates, I used first differences of the logarithm. The Figure 12 shows raw data of inflation in all Visegrad four countries and Figure 13 depicts log of first differences.

Figure 12: Inflation (CPI) in all Visegrad four countries, Source: own estimates

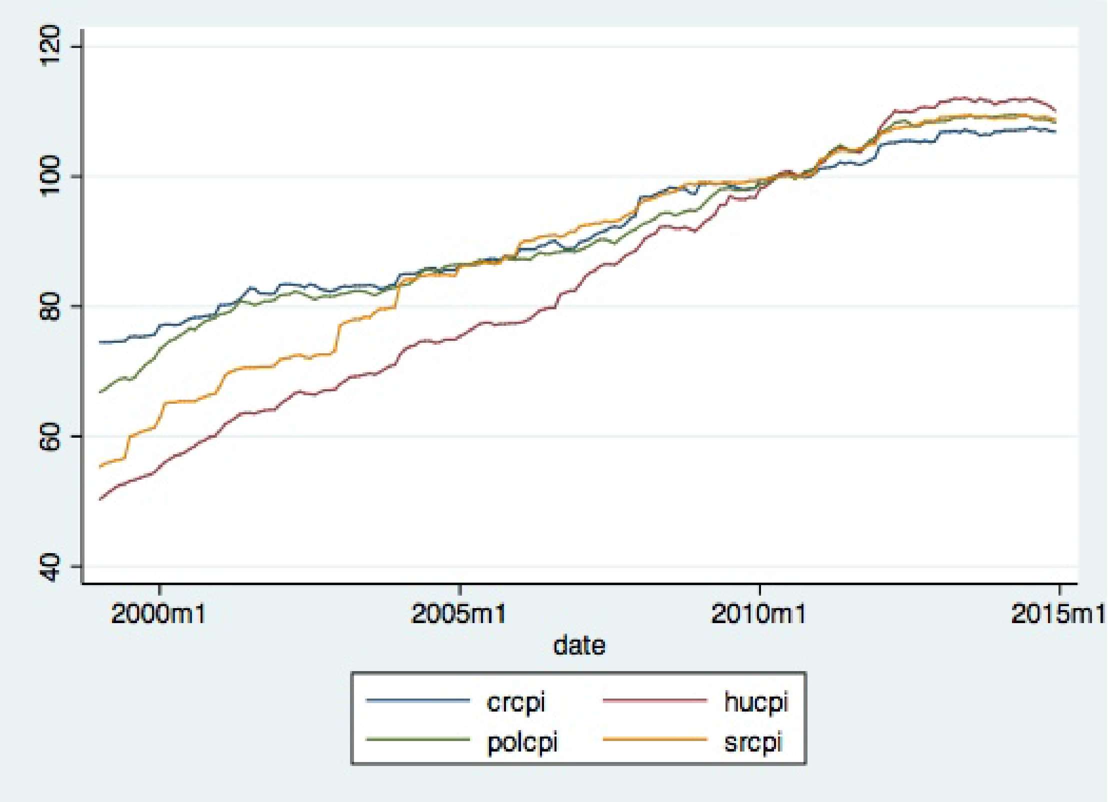
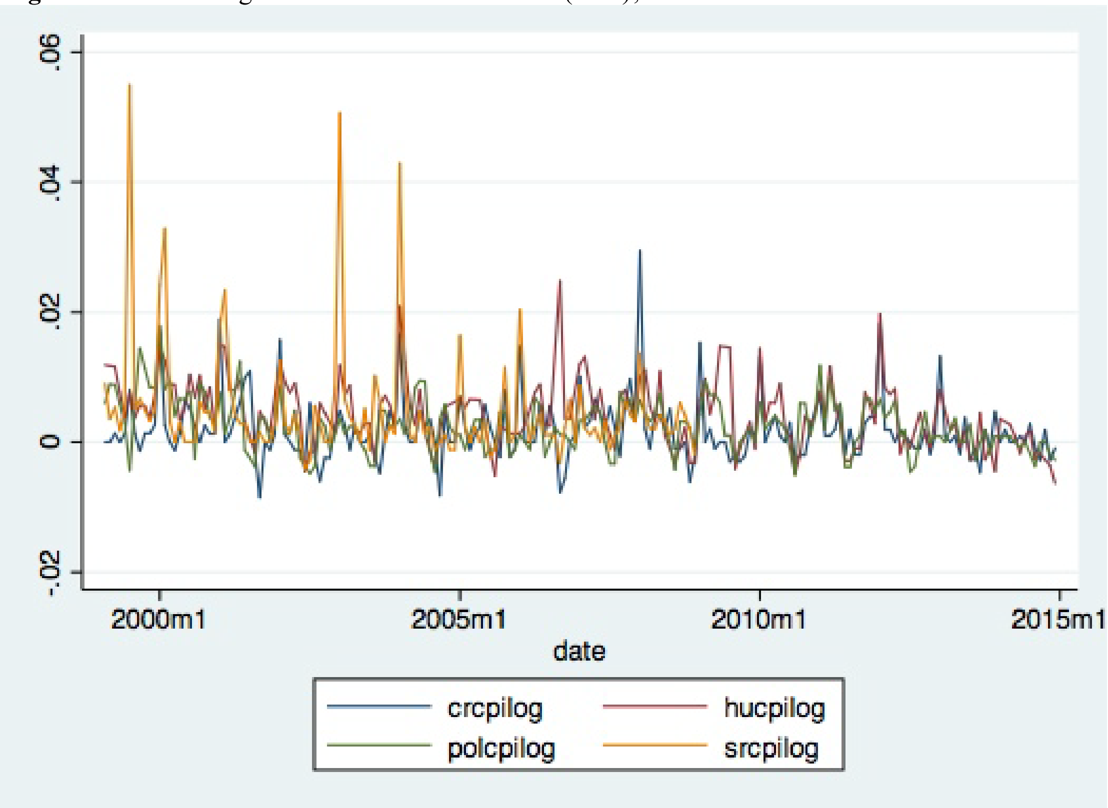


Figure 13: First log differences of inflation (CPI), Source: own estimates



Next determinant used in the analysis is interest rate. I used monthly money market interest rates of Visegrad four countries. Figures 14 and 15 show interest rates as raw data from OECD and as first log differences. I chose these interest rates following Giannellis and Papadopoulos (2011) and also Grossman, Love and Orlov (2014) who examine the importance of monetary variables as interest rates on exchange-rate volatility.

Figure 14: Interest rates in all Visegrad four countries, Source: own estimates

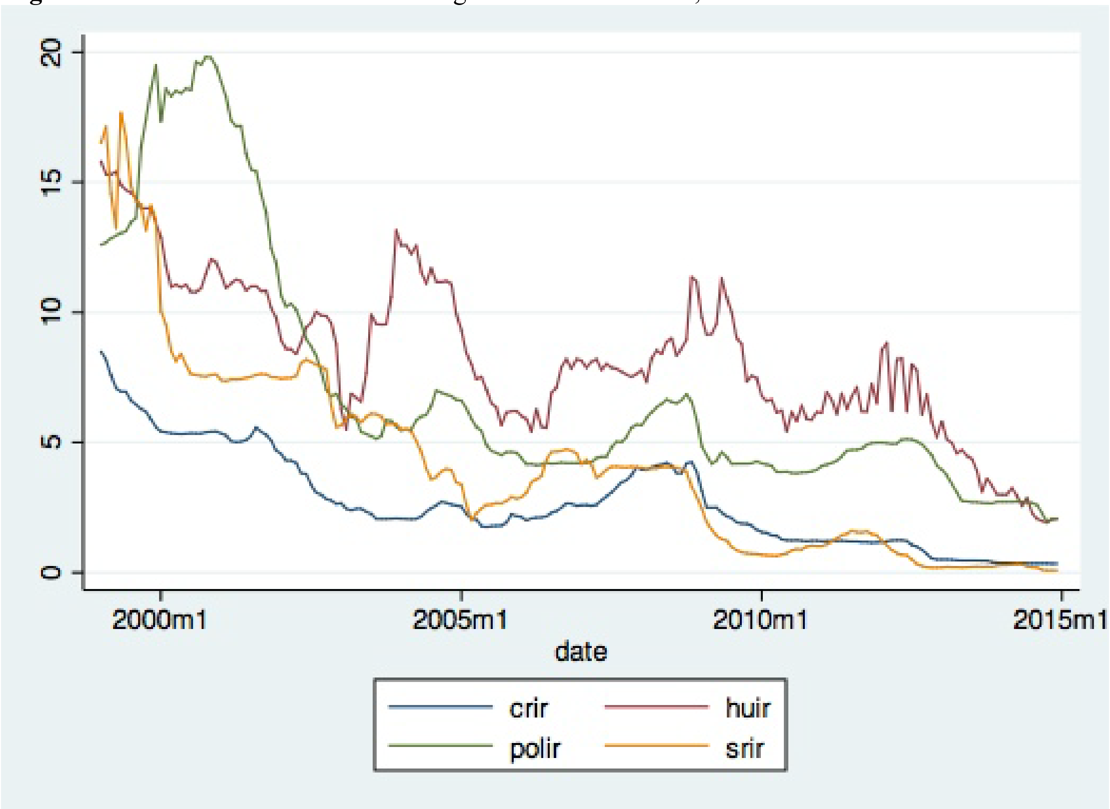
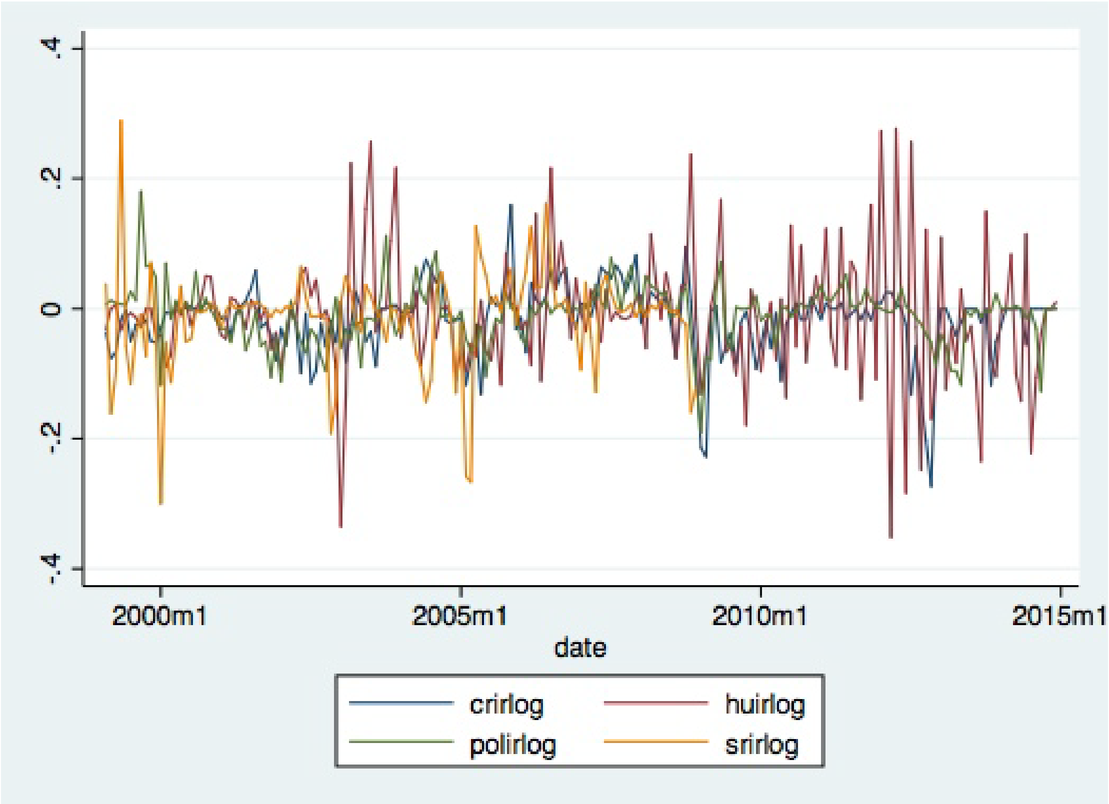


Figure 15: First log differences of interest rates in all Visegrad four countries, Source: own estimates



As mentioned already in the methodology part of the work, stock market development is measured by the national stock indices. I got the index data from OECD database, the date is from March 1999 until December 2014 for every Visegrad country.

Figure 16: Share indices in all Visegrad four countries, Source: own estimates

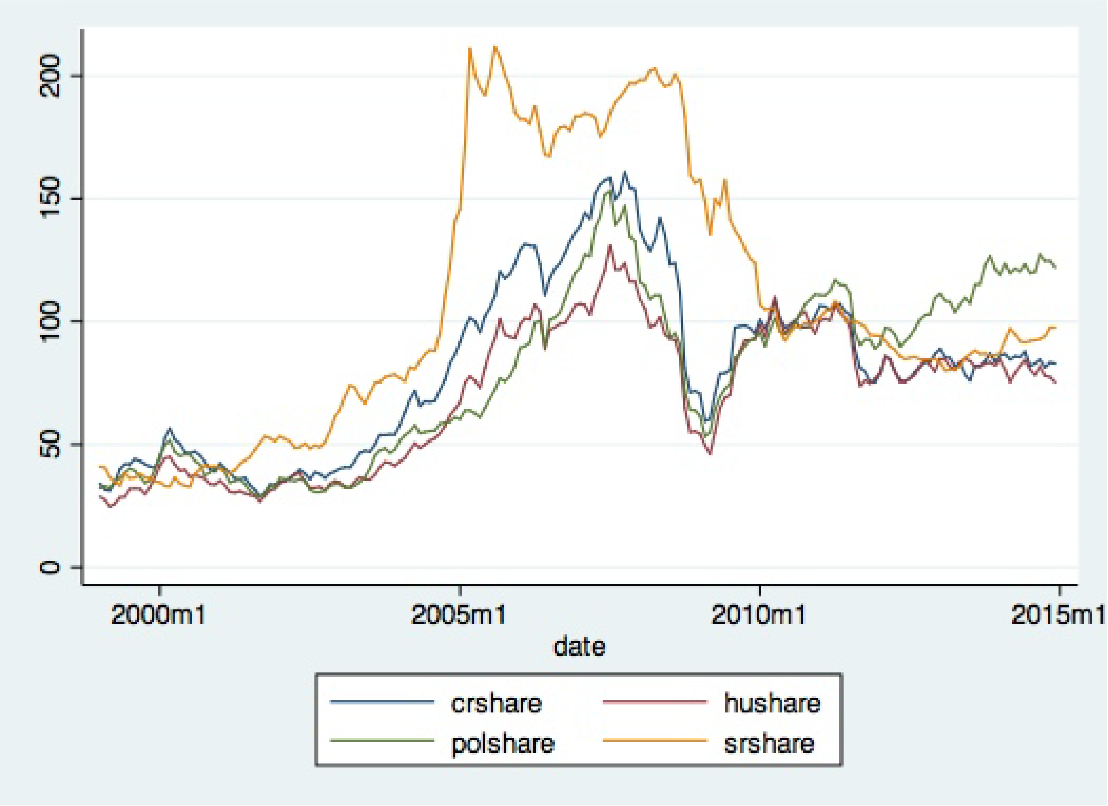
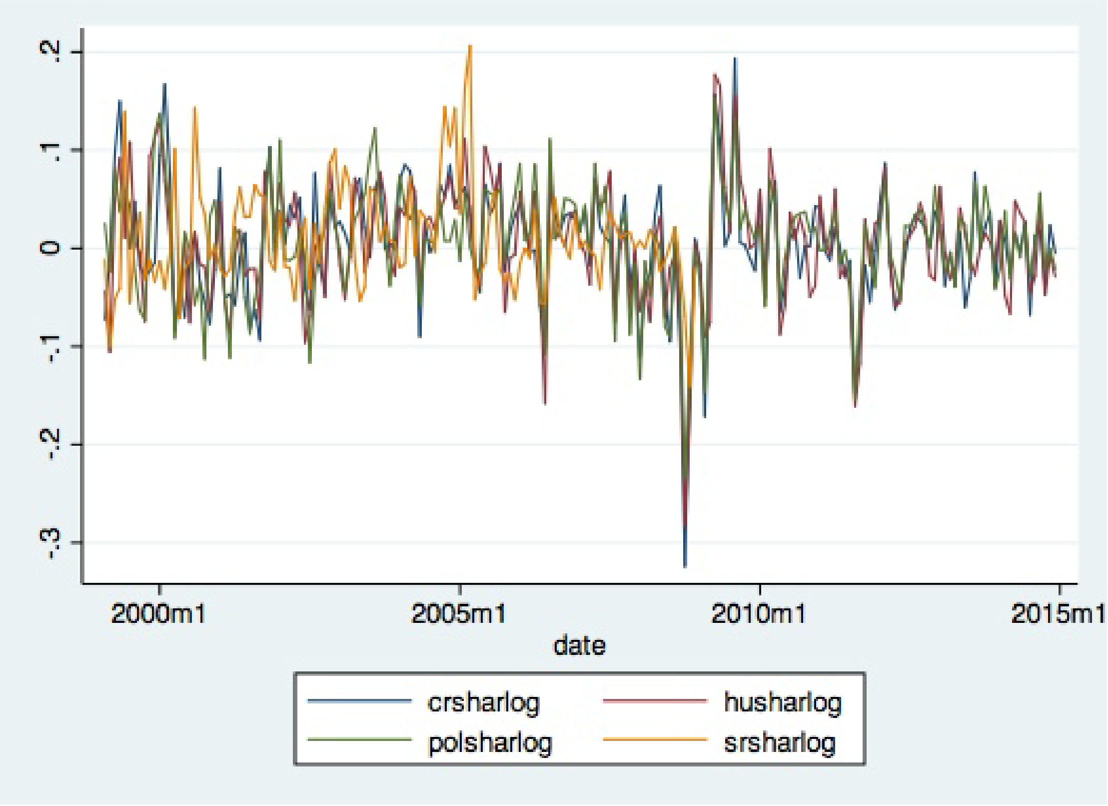


Figure 17: First log differences of share index in all Visegrad four countries, Source: own estimates



Openness of the economy is measured as the sum of imports and exports divided by GDP. In case of exports and imports I used sum of goods and services, all of the data are USD converted and seasonally adjusted. In case of GDP I used real GDP and components in USD, current prices and also seasonally adjusted. I got quarterly data for imports, exports and GDP and I applied cubic spline interpolation to get the monthly data.

Figure 18: Openness in all Visegrad four countries, Source: own estimates

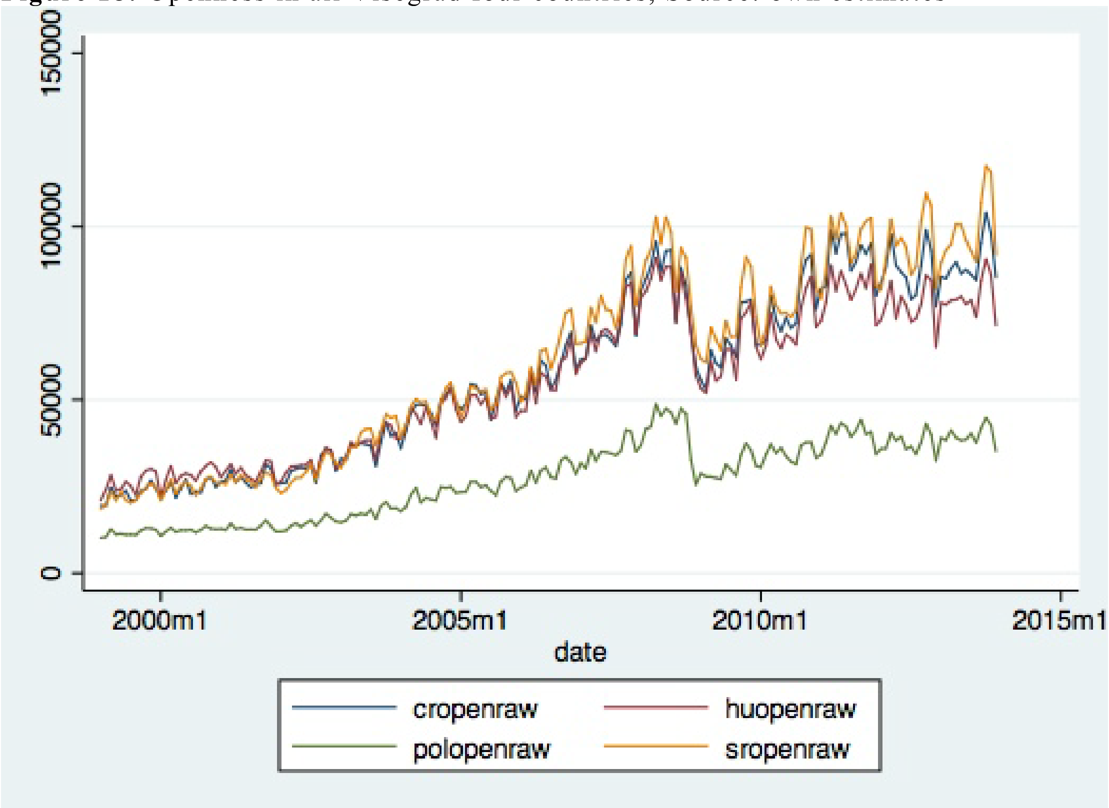
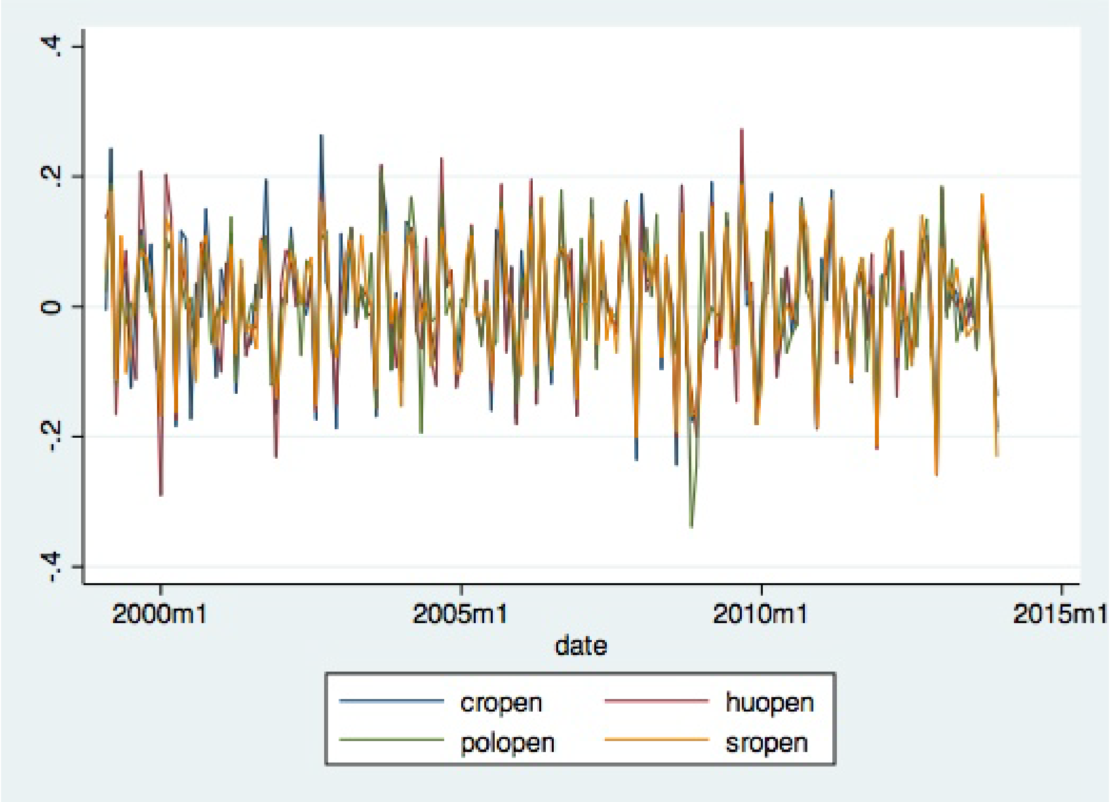


Figure 19: First log differences of openness in all Visegrad four countries, Source: own estimates



Terms of trade are measured as a ratio of export prices to import prices. Monthly data are taken from OECD database.

Figure 20: Terms of trade in all Visegrad four countries, Source: own estimates

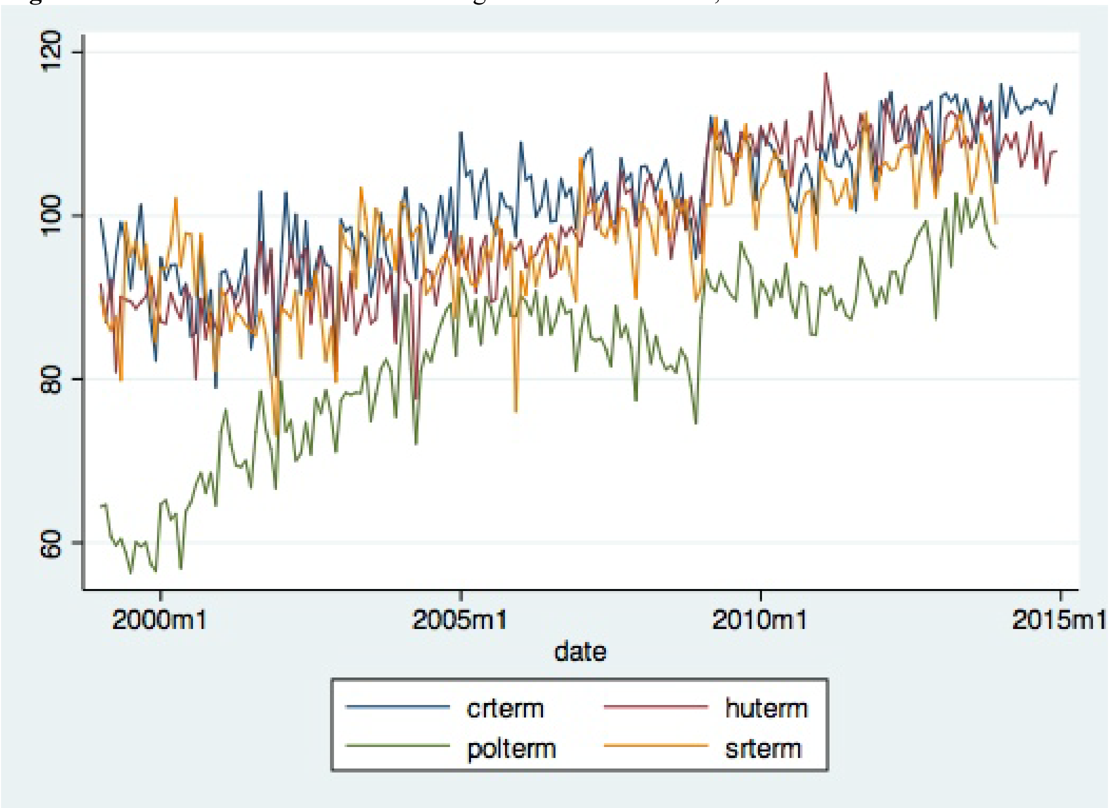


Figure 21: First log differences of terms of trade in all Visegrad four countries, Source: own estimates

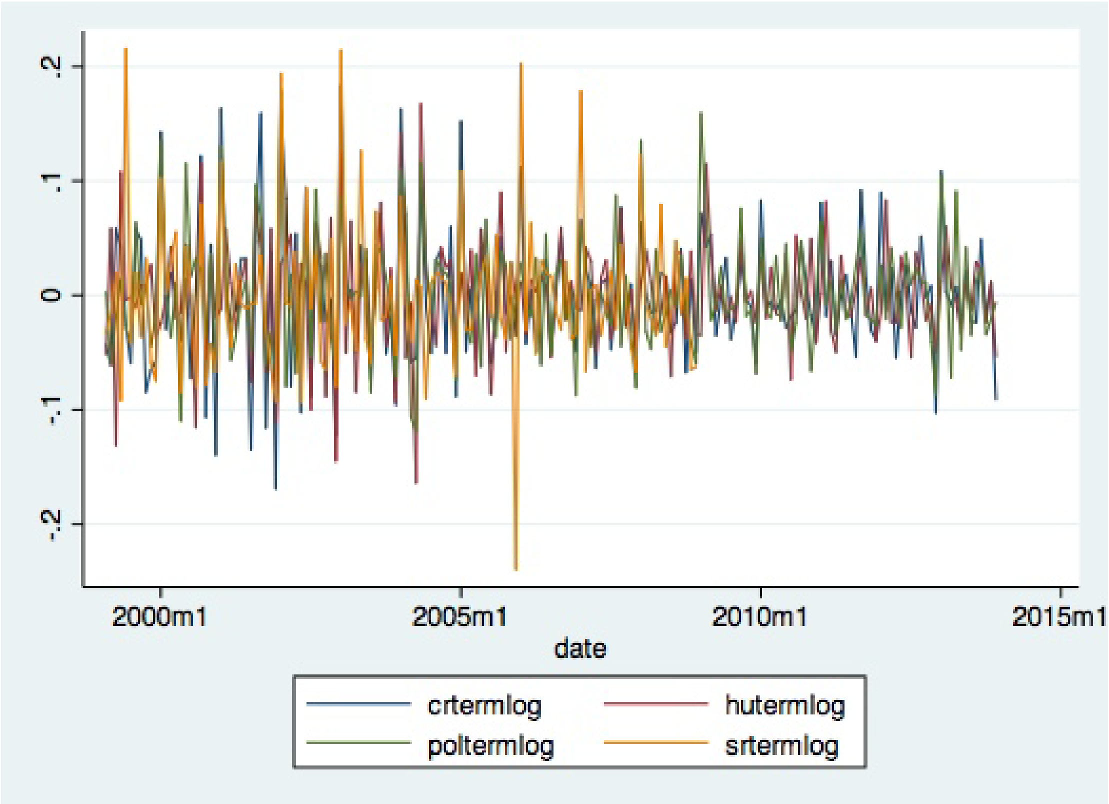


Table 3 shows summary statistics of all macroeconomic determinants.

Table 3: Summary statistics – monthly macroeconomic determinants in Visegrad four countries, rows in the cell represent countries CR, HU, POL, SR in this order, Source: own estimates

	Inflation	Interest rate	Openness	Share indices	Terms of trade
Mean	0.002 0.005 0.003 0.005	-0.016 -0.011 -0.008 -0.014	0.008 0.007 0.007 0.009	0.005 0.005 0.007 0.011	0.001 0.001 0.002 0.001
Median	0.001 0.004 0.002 0.002	-0.005 -0.011 -0.002 -0.003	0.013 0.015 0.002 0.008	0.006 0.006 0.015 0.003	-0.002 0.004 -0.003 -0.005
Std.	0.005 0.005 0.004 0.009	0.053 0.096 0.044 0.075	0.100 0.104 0.092 0.093	0.059 0.061 0.055 0.053	0.060 0.050 0.052 0.060
Max	0.029 0.024 0.017 0.054	0.159 0.276 0.180 0.288	0.263 0.271 0.207 0.186	0.193 0.176 0.152 0.206	0.183 0.167 0.179 0.215
Min	-0.008 -0.006 -0.005 -0.004	-0.273 -0.352 -0.190 -0.299	-0.243 -0.289 -0.338 -0.256	-0.324 -0.283 -0.234 -0.140	-0.168 -0.163 -0.119 -0.239

Table 4 depicts the correlation among the variables for all Visegrad four countries. The highest correlation is between exchange rates and interest rates in case of Czech Republic, between exchange rates and share index in Hungary and Poland and between inflation and terms of trade in Slovakia.

Table 4: Correlation table of variables, rows in the cell represent countries CR, HU, POL, SR in this order, Source: own estimates

	Openness	Terms of trade	Inflation	Interest rate	Share index	Exchange rate
Openness	1.000					
Terms of trade	0.245 0.312 0.080 -0.106	1.000				

Inflation	-0.063 0.197 0.151 -0.141	0.234 0.172 0.135 0.344	1.000			
Interest rate	0.127 -0.043 0.096 0.183	0.010 -0.125 -0.147 -0.059	0.027 0.002 0.163 -0.144	1.000		
Share index	0.010 -0.015 -0.058 -0.065	0.092 -0.071 -0.049 0.082	0.036 0.137 0.005 -0.164	-0.059 -0.073 -0.100 -0.220	1.000	
Exchange rate	0.247 0.082 -0.025 -0.047	0.107 -0.010 -0.082 0.001	0.382 0.284 0.217 0.059	0.288 0.023 0.121 -0.200	0.162 0.529 0.459 0.109	1.000

5.1.1 Test for unit root

All data I used are transferred to first log differences. Therefore I assume they are all stationary. The stationarity can be seen also from the graphs under the section 6.1. All graphs, where first log differences are used, show stationary process, which is confirmed by Augmented Dickey Fuller test (ADF) I conducted. The results from ADF are shown in Table 11 in Appendix. Results are shown on 5% significance level.

5.2 Measurement of exchange-rate volatility

As indicated in the methodology part of the thesis, I use the GARCH or ARCH model (in case of Czech Republic) for measuring exchange-rate volatility.

For finding the ARCH effects, I used a Lagrange multiplier test. Before performing this test, the number of lags must be specified. The null hypothesis of LM test is that there are no ARCH effects.

I find ARCH effects in all exchange rate log differences, therefore I can conclude that the variance is autoregressive conditionally heteroskedastic. I used 1 lag for Czech Republic, Poland and Slovak republic and I only used different lag in case of Hungary

(3 lags). Table 5 shows the estimates, p-value is in parentheses. The interpretation of the results is as follows. In case of Hungary there is a coefficient value 0.734 with p-value 0.000. Therefore I conclude that the previous month's volatility of forint influences volatility of forint. Same holds for Czech Republic and Poland. In case of Slovakia the estimates are insignificant both in ARCH and GARCH.

Table 5: ARCH/GARCH estimates, Source: own estimates

	ARCH	**GARCH**
Czech Republic	0.403 (0.001)	-
Hungary	0.148 (0.030)	0.734 (0.000)
Poland	0.215 (0.001)	0.773 (0.000)
Slovak republic	0.208 (0.109)	0.052 (0.901)

After modeling ARCH and GARCH I predict the conditional variance, which is stored and its squared root is used as measure of exchange-rate volatility. Figure 22 depicts exchange-rate volatilities in countries of Visegrad four from 1999 until end of 2014. Also Table 6 shows the summary statistics of exchange-rate volatility in Visegrad four countries.

Figure 22: Exchange-rate volatility in countries of Visegrad four, Source: own estimates

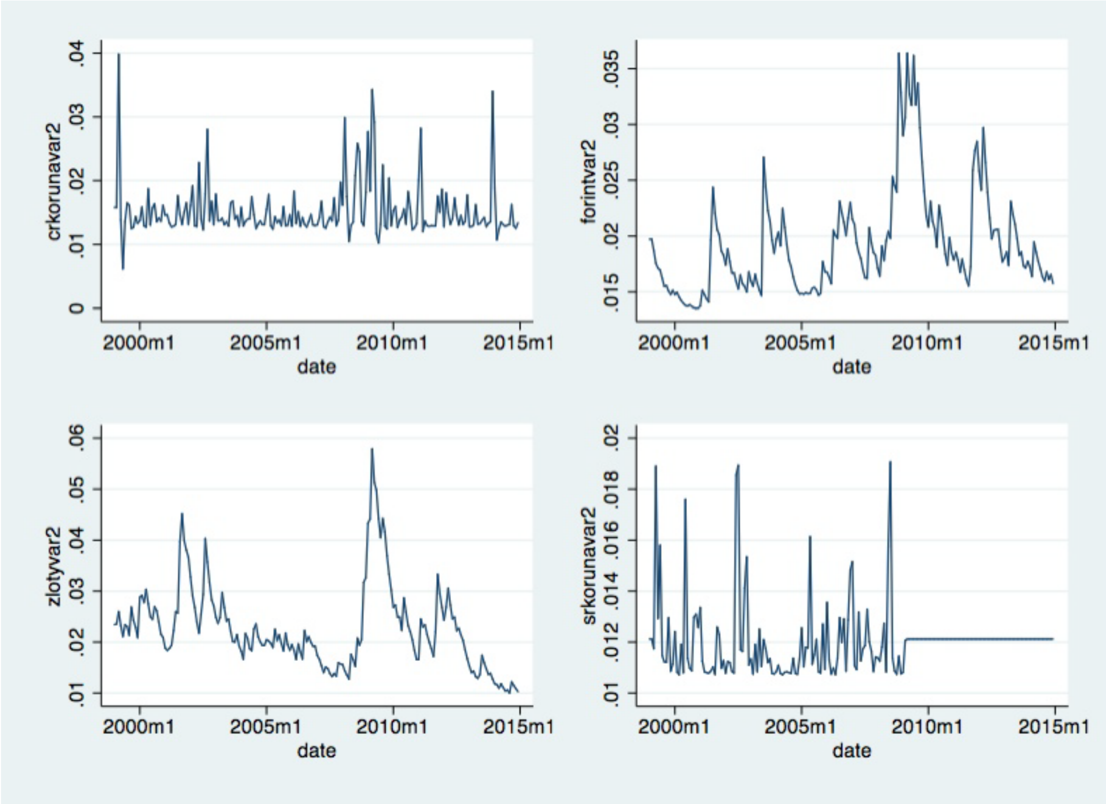


Figure 23: Exchange rate-volatilities in countries of Visegrad four, Source: own estimates

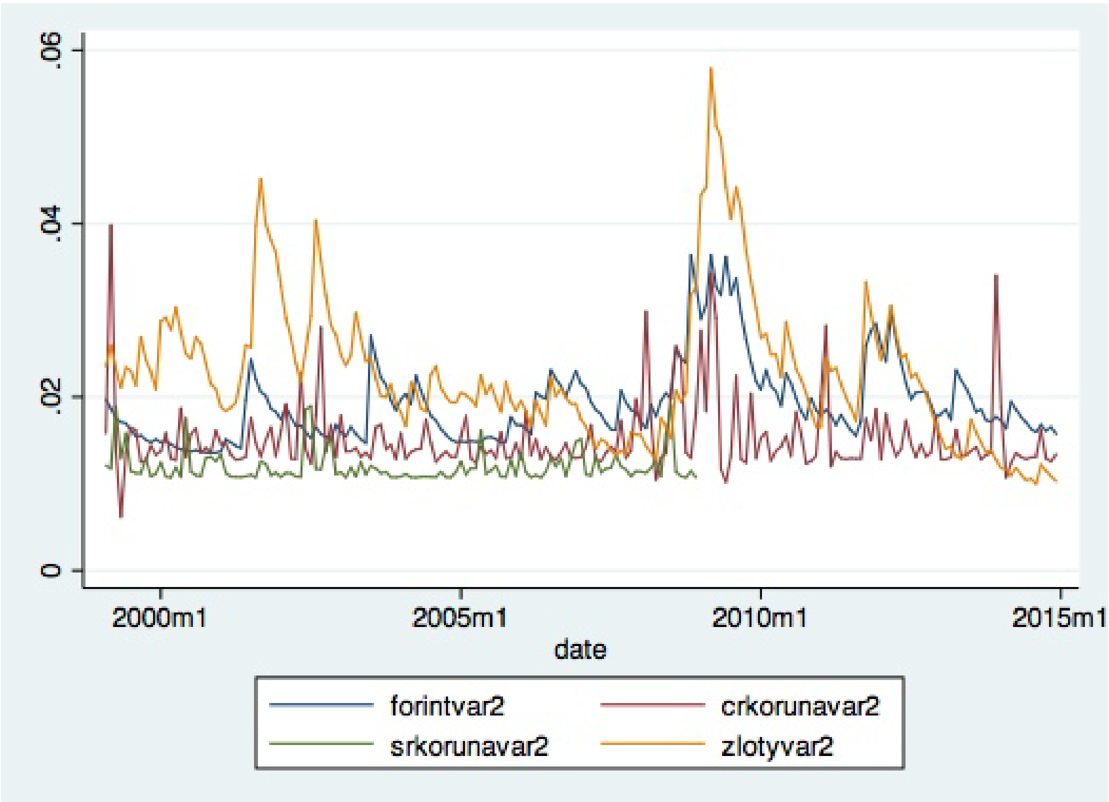


Table 6: Summary statistics – monthly exchange-rate volatility in Visegrad four countries, Source: own estimates

	Czech Republic	Hungary	Poland	Slovakia
Mean	0.015	0.019	0.023	0.012
Median	0.014	0.018	0.021	0.012
Std.	0.004	0.005	0.008	0.001
Max	0.039	0.036	0.058	0.019
Min	0.006	0.014	0.010	0.011

5.3 VAR model

Firstly I have to adopt some ordering in the VAR model. The idea is that the variables at the beginning simultaneously affect all the following variables, and that the variables that are later in the model affect the previous variables with a lag only (Love, Ariss, 2013). I start with the following ordering, and then I investigate other possible orderings:

1. Openness
2. Terms of trade
3. Inflation
4. Interest rates
5. Share index
6. Exchange-rate volatility

Volatility is put at the end of the ordering, which means it can affect other variables only with the lag, but it can be affected itself by the others simultaneously.

The VAR in this case can be written as:

$$X_t = A_0\varepsilon_t + A_1\varepsilon_{t-1} + A_2\varepsilon_{t-2} + \cdots = \sum_{i=0}^{\infty} A_i L^i \varepsilon_t = A(L)\varepsilon_t \qquad (9)$$

X_t is a vector of endogenous variables – openness, terms of trade, interest rates, share index, inflation and measure of exchange-rate volatility. A(L) is a power series with infinite degree, whose coefficients represent the relationships between endogenous variables at the lag values. L represents the lag operator and ε_t is an n x 1 vector of errors of structural shocks in the model.

At the beginning of the VAR analysis I stuck to the strategy of selecting lags based on Schwarz Bayesian information criterion (SBIC) to avoid autocorrelation in errors. SBIC proposes to use 1 lag at significance level of 1% in all Visegrad four countries.

Afterwards I checked for the stability of the model calculating the eigenvalues of a companion matrix. The model is stable if

$$\det(I_n - A_1 z - \cdots - A_n z^p) \neq 0 \quad \text{for } |z| \leq 1 \tag{10}$$

where I_n denotes an identity matrix (Lutkepohl, 2005). I found all eigenvalues are less than one, therefore I can conclude the model is stable.

VAR estimates for all Visegrad four countries are in Tables 12, 13, 14 and 15 in Appendix.

5.4 Impulse response functions

After I checked for the right number of lags, no autocorrelation and stability of the model, I proceeded with the impulse response analysis. Almost in all cases the responses die out after some periods and become statistically insignificant. If the shocks die out quickly, it reflects the stationarity of the variables. In order to identify the effects of shocks to the determinants and exchange-rate volatility I make assumptions about the ordering in the impulse response function. I follow the same order as used in VAR model:

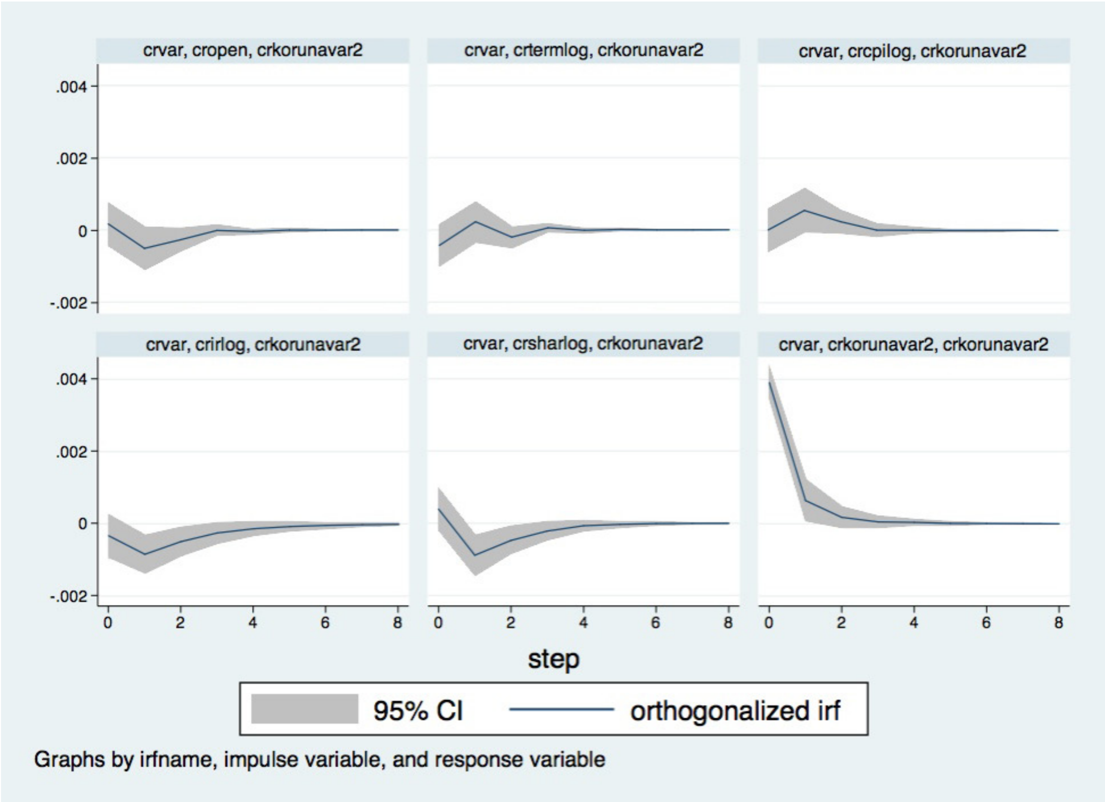
1. Openness
2. Terms of trade
3. Inflation
4. Interest rates
5. Share index
6. Exchange-rate volatility

I have tried to change the order of the variables, but I did not find any noticeable changes.

The main interest is how volatility of exchange rate responds to impulses in its own innovations, in innovations of openness of the economy, inflation, interest rates, share index and terms of trade. For each country I provide a figure with impulse in macroeconomic determinants and its response to exchange-rate volatility.

In the case of the Czech Republic, not all impulse response functions are significant. According to the confidence intervals, only some of them are different from zero. The significance is seen in case of interest rates, share index and also little bit in case of inflation and terms of trade. Figure 24 shows positive impact on exchange-rate volatility from inflation, volatility and terms of trade in Czech Republic. For example in case of interest rate, one standard deviation shock causes 0.1% change in volatility. The negative impact on exchange-rate volatility is in case of interest rates, openness and share index. The size of this effect is not the same for all determinants, the largest in negative terms is in case of share index. Observed response has similar pattern in openness, share index and interest rates. Almost in all cases the responses die after 4 periods.

Figure 24: Impulse response functions – exchange-rate volatility response to the determinants, Czech Republic, Source: own estimates



Similarly the impulse response analysis is done for Hungary. Figure 25 shows only significant response in case of share index and volatility itself. Response of exchange-rate volatility to inflation, interest rates, openness and terms of trade is small. In case of inflation and terms of trade slight increase can be observed at the beginning. Positive impact is seen in case of inflation, exchange-rate volatility itself, interest rates, openness and terms of trade. Negative impact is visible in case of share index.

Figure 25: Impulse response functions – exchange-rate volatility response to the determinants, Hungary, Source: own estimates

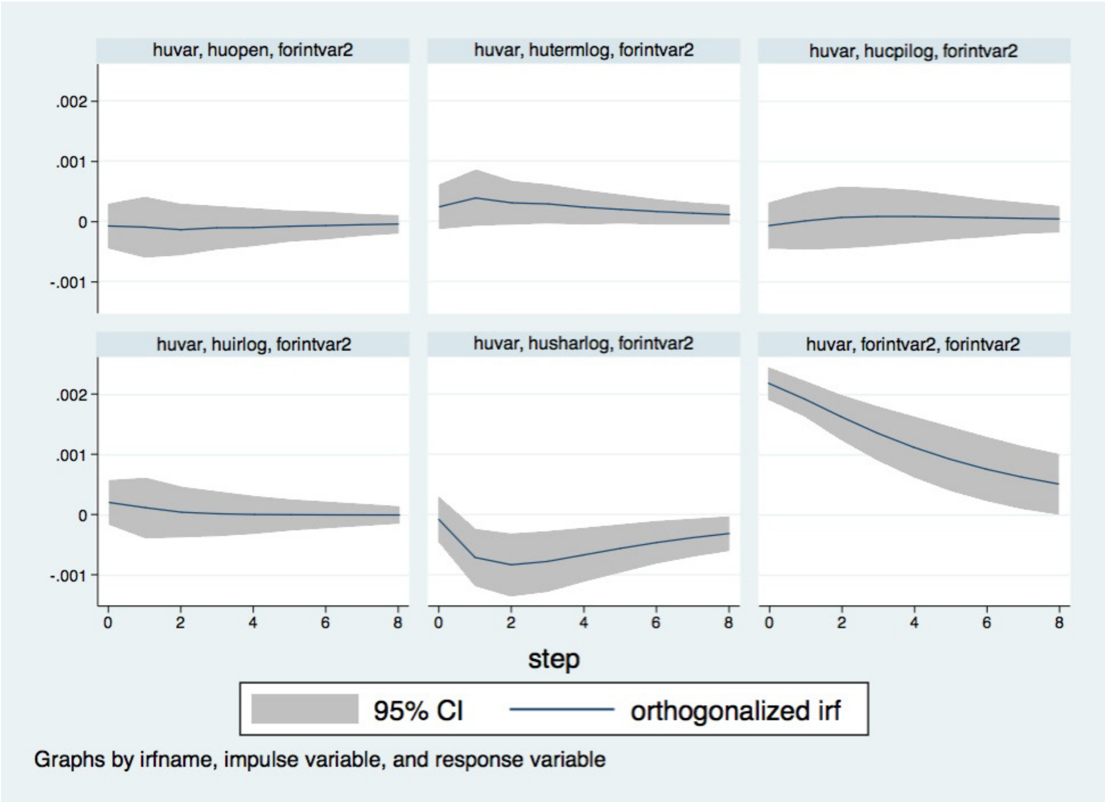
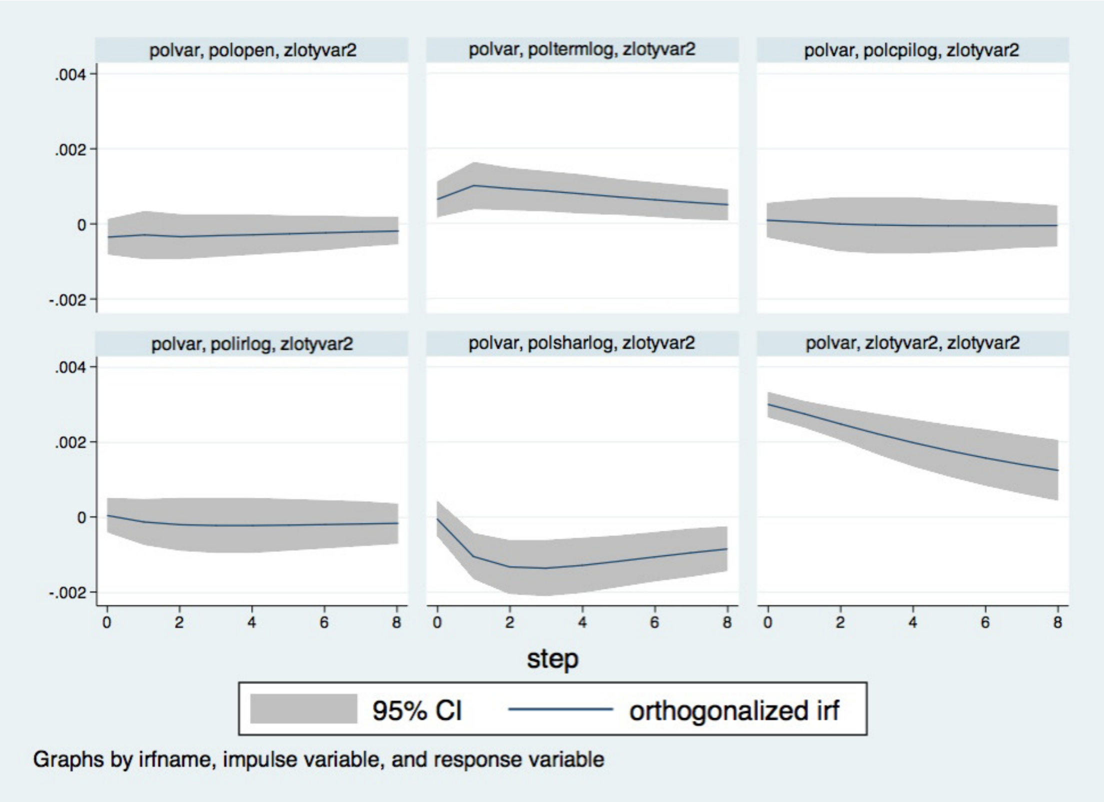


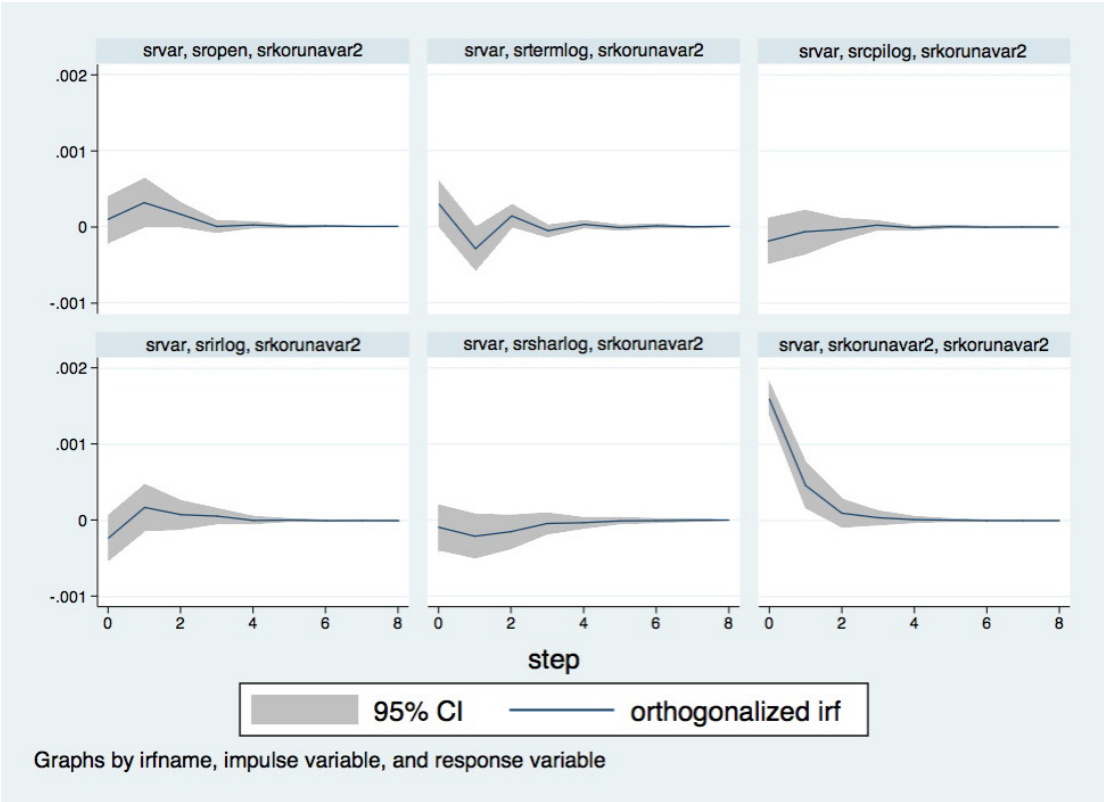
Figure 26 is similar compared to Figure 25 with resembling patterns of impulse response functions. There are three significant determinants of exchange-rate volatility – share index, terms of trade and exchange-rate volatility itself. There is almost no exchange-rate volatility response to inflation, interest rates and openness in Poland. Very small decrease caused by interest rates impulse can be seen at the beginning and similarly small increase caused by openness impulse. Positive impact is apparent after impulse in terms of trade and exchange-rate volatility. Negative impact is in case of share index.

Figure 26: Impulse response functions – exchange-rate volatility response to the determinants, Poland, Source: own estimates



Slovakia has similar impulse response functions with Czech Republic, but there is almost no significance. It can be caused by the limited sample size, because the measured period in case of Slovakia was only until end of 2008. There is very small significance in case of openness and also in case of exchange-rate volatility itself. In figure 27 the responses die out after approximately 4-5 periods. There is negative impact in exchange-rate volatility response after shock in inflation, terms of trade and share index and after 4 periods starts to stagnate. Positive response of volatility is in case of openness, exchange-rate volatility and interest rates.

Figure 27: Impulse response functions – exchange-rate volatility response to the determinants, Slovak republic, Source: own estimates



5.5 Granger causality

The other tool used in the analysis, which is useful for finding the dynamics between volatility and other determinants, is the Granger causality test (Granger, 1969).

Tables 7, 8, 9 and 10 depict estimates and p-values for all Visegrad four countries. P-values are in parentheses. Boldface denotes estimates significant at the 5% level, and italics denote significance at the 10% significance level.

Table 7: Granger causality estimates – Czech Republic, Source: own estimates

Null hypothesis	Chi2 (p-value)
Openness does not cause volatility	3.176 (0.075)
Terms of trade do not cause volatility	0.073 (0.786)
Inflation does not cause volatility	0.095 (0.757)
Interest rates do not cause volatility	0.036 (0.849)

Share index does not cause volatility	0.680 (0.409)
Volatility does not cause openness	0.800 (0.371)
Volatility does not cause inflation	5.95 (0.015)
Volatility does not cause interest rates	9.61 (0.002)
Volatility does not cause terms of trade	2.30 (0.129)
Volatility does not cause share index	11.264 (0.001)
Volatility does not cause ALL	30.825 (0.000)

Table 8: Granger causality estimates – Hungary, Source: own estimates

Null hypothesis	**Chi2 (p-value)**
Openness does not cause volatility	3.205 (0.073)
Terms of trade do not cause volatility	0.358 (0.549)
Inflation does not cause volatility	2.004 (0.157)
Interest rates do not cause volatility	0.999 (0.317)
Share index does not cause volatility	5.026 (0.025)
Volatility does not cause openness	0.400 (0.527)
Volatility does not cause inflation	1.480 (0.224)
Volatility does not cause interest rates	0.204 (0.651)
Volatility does not cause terms of trade	0.004 (0.945)
Volatility does not cause share index	15.449 (0.000)
Volatility does not cause ALL	15.99 (0.007)

Table 9: Granger causality estimates – Poland, Source: own estimates

Null hypothesis	Chi2 (p-value)
Openness does not cause volatility	0.001 (0.978)
Terms of trade do not cause volatility	0.272 (0.602)
Inflation does not cause volatility	1.351 (0.245)
Interest rates do not cause volatility	3.899 (0.048)
Share index does not cause volatility	3.831 (0.05)
Volatility does not cause openness	0.186 (0.666)
Volatility does not cause inflation	5.952 (0.933)
Volatility does not cause interest rates	2.257 (0.134)
Volatility does not cause terms of trade	2.843 (0.092)
Volatility does not cause share index	20.828 (0.000)
Volatility does not cause ALL	27.711 (0.000)

Table 10: Granger causality estimates – Slovak republic, Source: own estimates

Null hypothesis	Chi2 (p-value)
Openness does not cause volatility	0.239 (0.625)
Terms of trade do not cause volatility	3.352 (0.067)
Inflation does not cause volatility	0.013 (0.906)
Interest rates do not cause volatility	1.335 (0.248)
Share index does not cause volatility	0.150 (0.698)
Volatility does not cause openness	1.839 (0.175)
Volatility does not cause inflation	1.625 (0.202)
Volatility does not cause interest rates	1.859 (0.173)
Volatility does not cause terms of trade	3.930 (0.047)
Volatility does not cause share index	2.191 (0.139)
Volatility does not cause ALL	15.333 (0.009)

5.6 Empirical analysis summary

The main interest of my master thesis is to find appropriate determinants of exchange-rate volatility in countries of Visegrad four. In the analysis part of the thesis I used vector autoregression model and impulse response functions analysis to find possible relationships between variables of interest. According to my results in section 6.4 I found some significant determinants in case of Czech Republic, Hungary and Poland. Interestingly share index was found significant in all these three countries. The response of volatility on a shock in share index is negative. In other words, volatility decreases after a shock in stock markets, represented by share index. The result can have some economic and financial implications. First of all it indicates that there is a link between exchange rate market and stock market. Share index represents the performance of the stock market of a particular country. It is usually calculated as a weighted average market capitalization. Market capitalization is a multiple of number of outstanding shares and companies' current share prices (market value). Therefore if the share index increases, stock performance also increases, it means the market capitalization is higher. There is either increase in outstanding shares or in share price. As a result of this, investors notice that stock performance increases and they invest more into these shares. This could lead to lower volatility of stock returns. The relationship between this volatility and market performance is strong, which means that when stock market rises, volatility is usually decreasing. As was shown already for example in the work of Karoui 2006, there is a significant relationship between exchange-rate volatility and stock returns volatility. Therefore the result, that after increase in share index volatility of exchange rates declines, is expected. The more are investors investing in shares and stock performance is higher, the lower is the volatility of exchange rates in this country.

Another determinant that was found significant in more than one country was the terms of trade. Czech Republic and Poland recorded an increase of exchange-rate volatility after shock in the terms of trade. In other words, an increase in export or import prices (terms of trade are measured as a ratio between export and import prices) can cause an increase in exchange-rate volatility. Both Czech Republic and Poland are open economies, where shocks or fluctuations in terms of trade affect large share of their economies. Therefore it is not surprising that the shock in terms of trade increased the volatility of Czech koruna and Zloty. According to Broda and Tille (2003), it depends on the exchange rate system in the country, how they handle shocks in terms of trade. They claim that a country with flexible exchange rate regime will better cope with these shocks. They found that shocks in terms of trade caused almost third of the exchange-rate volatility. For related results, see Broda (2004) where he mentioned that flexible exchange rate regime increased exchange-rate volatility. All Visegrad four countries have floating exchange rate regime. That could be a reason why volatility increased after shocks in terms of trade. It can be seen from the impulse response function that after few periods the volatility fluctuates around zero.

The only country where shock in interest rates and inflation caused small significant change in volatility was Czech Republic. After shock in interest rate Czech Republic recorded increase of volatility and similarly after a shock in inflation. Higher interest rates are attractive to investors, which leads to increased currency demand. It increases currency value and therefore lower exchange-rate volatility can be expected, which is seen in Czech Republic on Figure 25. There is also a relationship between interest rates and inflation. Higher interest rates usually cause increase in inflation and higher inflation is inclined to decrease the currency value. Inflation, or in my case fluctuations or shocks in inflation rates, cause uncertainty in the economy. If the country is economically uncertain, investors don't want to invest their money into this currency, therefore the exchange-rate volatility is not very high, which is captured by the impulse response function on Figure 25 with only very small significance level and small increase in exchange-rate volatility.

The final step of the empirical analysis was Granger causality analysis. The output confirms the results from impulse response functions. For example share index was found significant in case of Hungary and Poland and results also showed that volatility has some impact on share index in Czech Republic, Hungary and Poland.

6 Conclusion

The main interest of this thesis and main research question was to find possible macroeconomic determinants of exchange-rate volatility. Based on the results from the analysis I found that share index, which measures stock market performance in the country, is significant determinant in most of the countries analyzed, namely in Czech Republic, Hungary and Poland. With an increase in stock performance, the volatility of exchange rate is decreasing in all three cases. Increase in stock performance means, that market capitalization increases and investors invest more. The volatility of stock returns is more stable or is decreasing and because there is a relationship between this volatility and exchange-rate volatility, exchange-rate volatility declines as well. Next significant determinant is terms of trade, which caused increase in exchange-rate volatility in Poland and Czech Republic. Countries with flexible exchange rate regimes better handle shocks in terms of trade and it has been shown that these flexible regimes increase exchange-rate volatility. Both Czech Republic and Poland have flexible exchange rate regimes, therefore increase in volatility is expected. The Czech Republic also recorded an increase in volatility after increase in inflation and interest rates. There is a relationship between these two variables, where higher interest rates cause higher inflation. When interest rates in the Czech Republic grow, investors find the Czech koruna more attractive and start to invest. Therefore the decrease in exchange-rate volatility conforms to expectations.

Exchange-rate volatility has its role in country´s economy and as it is usually a negative phenomenon, it is important to study its determinants. This thesis is not focused on what are the effects of volatility on economy, but it focuses on the possible triggers of volatility. There are many other possible determinants of volatility, which could be included in the future research, but I picked the ones, that could have impact on volatility in countries of Visegrad four. I found some similarities between the countries, so I can answer my second research question. The share index was found significant in three out of four countries. Therefore if there is an increase in stock performance in Czech Republic for instance, followed by decrease in exchange-rate volatility, it could be a signal for Hungary, that exchange-rate volatility will decline too.

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8 Appendix

Results from ADF tests: CV in parentheses, outside parentheses is test statistic

Table 11: Results from ADF, Source: own estimates

	1 lag	2 lags	3 lags	4 lags	5 lags
Openness	CR -16.703 (-2.885) HU -16.514 POL - 15.005 SR -13.168	-12.011 -12.985 -11.585 -12.194	-10.990 -9.983 -9.161 -11.325	-9.228 -9.213 -8.113 -9.215	-6.682 -6.453 -5.856 -6.689
Terms of trade	CR -21.003 HU -23.383 POL - 18.497 SR -20.196	-16.182 -14.131 -12.831 -11.643	-12.766 -11.403 -11.970 -10.631	-7.695 -10.267 -8.378 -8.990	-9.187 -7.895 -9.235 -8.735
Inflation	CR -12.347 HU -8.998 POL -8.344 SR -9.207	-7.577 -4.397 -6.140 -6.220	-7.813 -3.638 -4.846 -5.397	-6.661 -3.894 -4.787 -4.677	-4.650 -3.139 -3.639 -5.234
Interest rates	CR -7.520 HU -15.963 POL -8.183 SR -8.279	-5.693 -6.570 -5.209 -5.008	-4.816 -6.719 -4.772 -5.216	-4.443 -5.625 -4.127 -4.115	-4.199 -4.711 -3.629 -3.685
Share index	CR -9.727 HU -9.830 POL -9.858 SR -7.452	-6.423 -6.552 -6.539 -5.088	-5.760 -5.548 -5.556 -3.976	-5.072 -5.189 -5.039 -2.999	-5.843 -5.163 -5.061 -3.637
Exchange rate	CR -12.350 HU -10.502 POL -9.266 SR -7.656	-7.631 -7.388 -7.193 -5.746	-6.729 -7.259 -6.584 -6.692	-5.688 -6.547 -6.497 -5.873	-4.460 -5.471 -5.345 -5.469

Table 12: Results from VAR model – Czech Republic, Source: own estimates

	Openness		Terms of trade		Inflation		Interest rates		Share index		Volatility	
	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|
Openness L1	-4.03	0.000	-2.67	0.008	-3.30	0.001	-0.15	0.880	-0.16	0.873	-1.54	0.124
Terms of trade L1	2.43	0.015	-6.3	0.000	-2.81	0.005	-0.82	0.412	-0.37	0.715	1.07	0.285
Inflation L1	-2.02	0.043	2.66	0.008	1.83	0.067	1.31	0.191	-0.52	0.601	1.99	0.047
Interest rates L1	0.27	0.790	-0.20	0.840	0.92	0.360	8.31	0.000	-0.88	0.380	-3.13	0.002
Share index L1	2.58	0.010	1.000	0.315	0.42	0.676	-0.68	0.495	4.99	0.000	-3.45	0.001
Volatility L1	1.69	0.091	1.18	0.237	-0.12	0.907	-0.35	0.726	-1.29	0.198	2.25	0.024
Cons.	-1.06	0.289	-1.35	0.176	1.58	0.114	-0.39	0.700	1.46	0.144	10.77	0.000

Table 13: Results from VAR model – Hungary, Source: own estimates

	Openness		Terms of trade		Inflation		Interest rates		Share index		Volatility	
	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|
Openness L1	-3.41	0.001	-1.74	0.081	-1.83	0.067	0.27	0.791	0.97	0.333	-0.72	0.470
Terms of trade L1	2.54	0.011	-6.06	0.000	-1.45	0.146	-0.86	0.388	0.35	0.723	0.34	0.732
Inflation L1	-0.05	0.964	0.54	0.589	4.89	0.000	1.33	0.183	-0.73	0.462	1.14	0.253
Interest rates L1	-0.84	0.401	0.14	0.891	-1.03	0.303	-2.47	0.013	1.26	0.206	-0.41	0.682
Share	2.82	0.005	0.78	0.433	1.79	0.074	-	0.012	4.49	0.000	-3.86	0.000

index L1							2.52					
Volatility L1	-1.99	0.046	-0.05	0.961	-1.29	0.196	1.02	0.308	2.26	0.024	22.09	0.000
Cons.	2.35	0.019	0.26	0.792	3.18	0.001	-1.47	0.142	-1.68	0.093	2.58	0.010

Table 14: Results from VAR model – Poland, Source: own estimates

	Openness		**Terms of trade**		**Inflation**		**Interest rates**		**Share index**		**Volatility**	
	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|
Openness L1	-1.92	0.055	-1.47	0.141	-0.58	0.562	1.93	0.054	0.55	0.580	-0.46	0.645
Terms of trade L1	3.95	0.000	-4.31	0.000	-0.01	0.990	1.02	0.308	-1.29	0.198	1.23	0.220
Inflation L1	-1.11	0.267	-0.69	0.487	5.86	0.000	2.47	0.013	-0.27	0.787	0.10	0.923
Interest rates L1	0.99	0.323	-0.70	0.485	2.36	0.018	6.76	0.000	-0.26	0.794	-1.43	0.154
Share index L1	3.13	0.002	0.78	0.438	0.07	0.942	2.33	0.020	4.43	0.000	-4.7	0.000
Volatility L1	0.05	0.957	0.15	0.885	1.18	0.238	-1.99	0.046	1.95	0.051	30.67	0.000
Cons.	0.46	0.647	0.23	0.818	0.92	0.358	0.65	0.513	-1.44	0.150	2.7	0.007

Table 15: Results from VAR model – Slovakia, Source: own estimates

	Openness		**Terms of trade**		**Inflation**		**Interest rates**		**Share index**		**Volatility**	
	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|	z	P > |z|
Openness L1	-0.55	0.580	-2.23	0.026	-2.41	0.016	-0.35	0.724	0.63	0.527	1.22	0.221

Terms of trade L1	1.87	0.062	-6.24	0.000	-0.54	0.592	1.17	0.243	-0.83	0.408	-2.32	0.020
Inflation L1	2.13	0.034	1.77	0.077	1.43	0.153	-0.33	0.745	0.86	0.392	-0.40	0.688
Interest rates L1	1.32	0.187	1.69	0.091	-1.76	0.079	2.65	0.008	1.43	0.151	1.30	0.195
Share index L1	2.48	0.013	1.31	0.191	1.36	0.175	-0.66	0.507	4.43	0.000	-1.34	0.018
Volatility L1	-1.22	0.223	1.17	0.240	0.63	0.527	0.83	0.405	-0.36	0.716	3.24	0.001
Cons.	1.13	0.256	-1.22	0.222	0.08	0.939	-0.98	0.325	0.51	0.611	7.72	0.000

Impulse response functions of Czech Republic, Hungary and Poland after VAR model with following order of variables:

1. Openness
2. Terms of trade
3. Inflation
4. Interest rates
5. Share index
6. Exchange rate

Figure 28: Impulse response functions of Czech Republic, use of exchange rates instead of volatility, Source: own estimates.

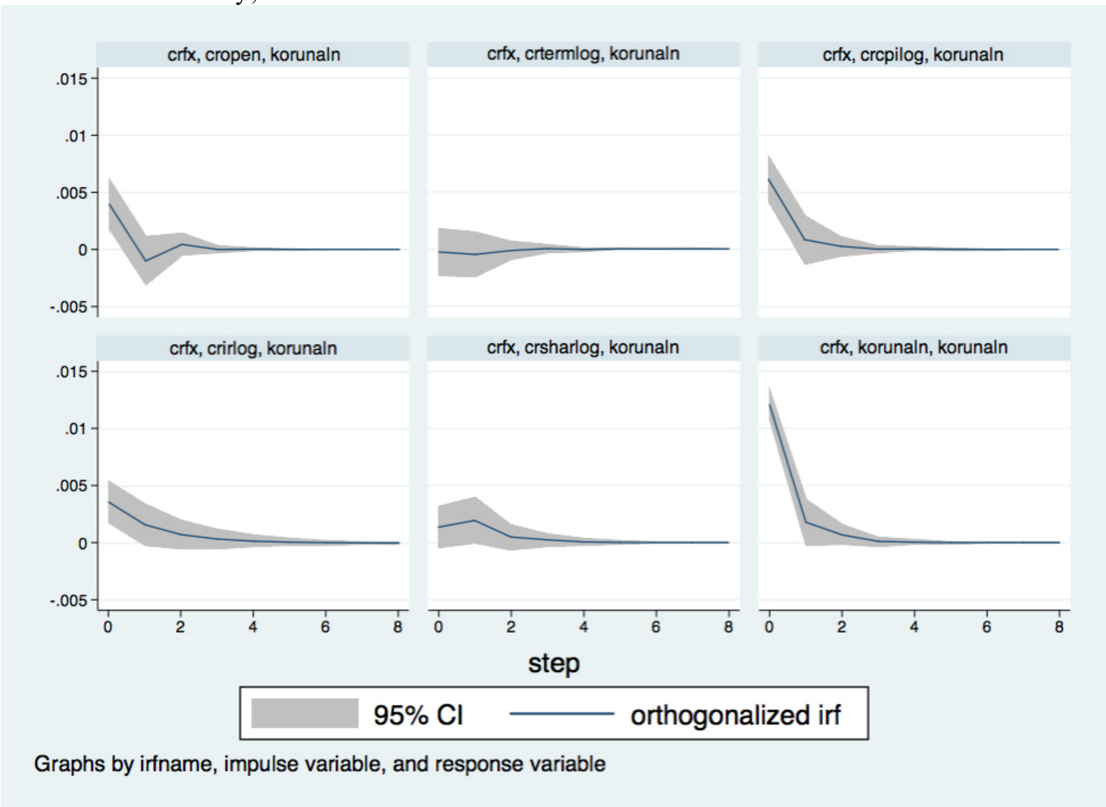

Figure 29: Impulse response functions of Hungary, use of exchange rates instead of volatility, Source: own estimates.

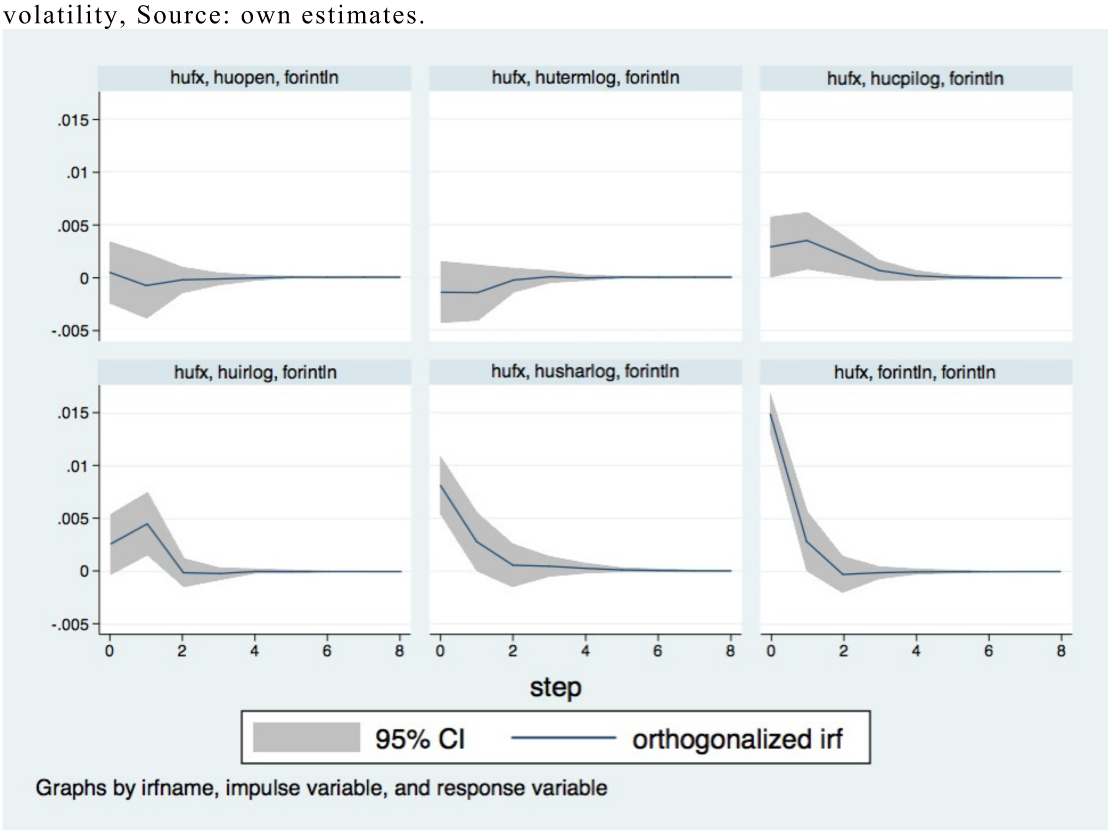

Figure 30: Impulse response functions of Poland, use of exchange rates instead of volatility, Source: own estimates.

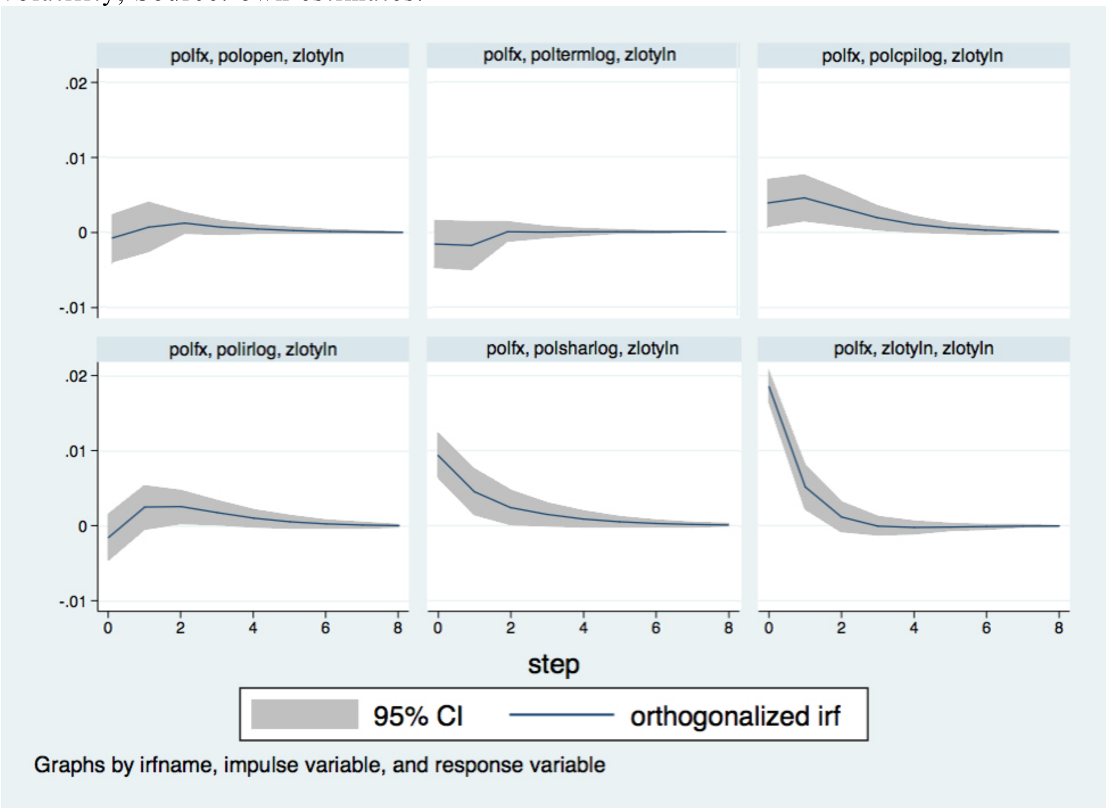

Figure 31: Impulse response functions of Slovakia, use of exchange rates instead of volatility, Source: own estimates.