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Exchange Rate Pass-Through to Domestic Prices: The Case of the Czech Republic

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Signature

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Abstract

In this thesis, we examine the exchange rate pass-through phenomenon in the Czech Republic over 1998:1-2014:1 period. As our vector autoregression results indicate, short-term pass-through effect slowed down and prolongated its duration substantially. Consequently, the accumulated value to be transmitted increased compared to previous findings. In the case of exchange rate pass-through effect to CPI, the accumulated response after 18 months accounts for about 40-60 per cent. In this regard, our time-varying results using unique Chebyshev Time Polynomials points to period 2008-2014 to be the leading cause. It seems that during macroeconomically less stable periods the exchange rate pass-through in the Czech Republic tends to increase. Even though the consensus on the pass-through levels and its development over time is rather scarce, we find support for our conclusions. More interestingly, having in mind November's currency interventions of the Czech National Bank to weaken koruna (and thus avoiding deflation), our results reveal that this measure has become much more effective in the latest years (as consequence of the crisis) than previous literature suggested. Following up on that, it seems that exchange rate regained some of its rather historical importance while conducting monetary policy within the Czech boundaries.

JEL Classification	E31, E52, E58, F31
Keywords	exchange rate pass-through, Czech Republic, inflation, VAR, time-varying cointegration

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Abstrakt

Tato práce se zabývá efektem změny směnného kurzu na cenovou hladinu v České Republice za období 1998:1-2014:1. Výsledky vektorové autoregrese ukazují, že krátkodobý efekt výrazně zpomalil na straně jedné a zároveň se na straně druhé prodloužila celková doba trvání efektu. Důsledkem této změny je vyšší celková velikost efektu, který má být přenesen do cenové hladiny, v porovnání s výsledky předochozích autorů. V případě efektu na agregátní index spotřebitelských cen, celková velikost přenesená po 18 měsících od původní změny se pohybuje mezi 40-60 procenty. Naše výsledky za pomoci jedinečné metody využívající Chebyshevovy časové polynomy naznačují, že ke zvýšení celkové velikosti efektu došlo zejména mezi lety 2008 a 2014. Zdá se, že tendence zvyšování efektu v rámci České Republiky koresponduje s výskytem makroekonomicky méně stabilního období. I přes poměrně vzácnou shodu v této oblasti výzkumu jsme našli publikace, jejichž závěry podporují naše výsledky. Daleko zajímavější je však přesah na nedávné devizové intervence, které Česká národní banka použila jako obranu proti potenciální deflaci na sklonku roku 2013. Naše výsledky naznačují, že toto opatření bylo v minulých letech (jakožto dědictví krize) mnohem více efektivní, než jak odhaduje dřívější literatura. To v důsledku znamená, že nástroj směnného kurzu zpětně získává větší význam pro činnost měnové politiky v rámci České Republiky.

JEL klasifikace	E31, E52, E58, F31
Klíčová slova	kurzové promítání, Česká republika, inflace, VAR, kointegrace měnící se v čase

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1 INTRODUCTION

Since the Czech Republic committed itself by accepting acquis communitaire to adopt the common currency euro at some future period of time, the policymakers should take into account conditions that such movement requires. Generally, the rules that specify entering Economic and Monetary Union (EMU) are known as Maastricht criteria and cover several macroeconomic variables – inflation, long-term interest rate, public deficit (and overall debt) and country's exchange rate. Speaking of which, the exchange rate criterion says that the applicant's currency must enter the Exchange Rate Mechanism-II and stay there for at least two consecutive years without devaluing domestic currency or departing from the central parity by more than 15 per cent in absolute. On the other hand, the inflation criterion says that the applicant's inflation has to be no more than 1.5 per cent higher than the average of inflation rates in the three EU member states with the lowest inflation.

However, considering the catching up process that has been so distinctive for new EU member states there are apparently pressures for real exchange rate appreciation through higher productivity growth. In this light, it is very important for the applicant's country to find balance between low inflation and stable exchange rate vis-á-vis euro as opposed by the two criteria mentioned above. In detail, what really matters is so-called *pass-through* effect of a variation in the nominal exchange rate on domestic inflation. Obviously, such analysis of transmission mechanism is immensely important not only from the point of view of entering the EMU but also from the side of monetary policy authorities in the Czech Republic that have a clear mandate of keeping the inflation low and stable. Also, the examined period between years 1998 and early 2014 corresponds to introduction of inflation targeting regime in January 1998 which is rather unique in comparison to previous literature.

Other important aspect is that the Czech economy is generally defined as small and open so it is very sensitive to external shocks. Negative demand shock as huge as the one that appeared in 2008 changed to some degree the way how economists look at modern macroeconomy nowadays. The link between prices and exchange rates has not been spared in this regard. Moreover, the very latest (and rather unconventional) measure employed by the Czech National Bank (CNB) - currency interventions towards weakening of koruna - in early November 2013 and its implications for the Czech monetary transmission are yet to be seen. In this light, the significance of updated pass-through analysis in the Czech Republic might be of substantial value.

In general, evidence suggests that exchange rate pass-through (ERPT[1]) to domestic inflation is of incomplete nature but the consensus on exact pass-through levels is really scarce. Different results are assigned to various factors starting from the type of data used and ending with the choice of methodology. In the latest decade, ERPT researchers were desperate to find a way how to cope with structural breaks in data which made the results even more incomparable. On the other hand, the common perception is that small open low-inflationary economies applying inflation targeting tend to have lower pass-through levels with decreasing trend.

Therefore, the aim of this thesis is to re-evaluate the conditions of the Czech transmission mechanism with focus on ERPT to various domestic price levels. Previous papers estimated the short-run effect between 0 and 40 per cent. In order to be able to compare our results with the previous ones, we used several specifications already used in the literature and so this paper may be to some extent considered as an update of Babecka (2009). Our results suggest that the short-term impulse response dynamics slowed down and prolongated its duration substantially. As a consequence, the maximum impulse response of prices to changes in exchange rate decreased while the total effect to be transmitted increased. Such results contradict majority of papers published before. On the other hand, few publications in the latest 1 or 2 years came to similar conclusions indicating possible change in pattern caused by rather unclear reasons.

However, there are several arguments why to assume that the relationship between prices and exchange rate changes over time. Whether it is deepening of trade in the Czech Republic after joining the EU in 2004, potential heritage of economic transition from central planned economy to market-based one (e.g. bank industry consolidation in 1999), sometimes almost unnaturally strong appreciation of the Czech koruna or the effects of recent financial crisis, one could expect that economic environment in the Czech Republic went through significant structural changes in last two decades with much more to come in the years that lie ahead.

Following up on that, we studied the issue of structural breaks in the data by applying original time-varying methodology developed by Bierens, Martins (2009) that uses Chebyshev Time Polynomials. Our time-varying results indicate that pass-through tend to increase in macroeconomically less stable periods which could explain the logic behind the change in pattern discussed in previous paragraphs. This striking and quite unique evidence might have important implications for conducting monetary policy in the Czech Republic. Namely, the exchange rate possibly regained some of its rather historical importance and turns out to be much more effective as a monetary-policy tool than majority of previously published papers suggests.

The remainder of the thesis is as follows. Chapter 2 discusses the theoretical framework of ERPT analysis and summarizes the main empirical findings. General estimation strategy

[1] In this thesis the term 'pass-through' is often used and it always refers to 'exchange rate pass-through' (ERPT). If interested in exact definition of ERPT, see Section 2.

is presented in chapter 3 where the data are also being analyzed. Chapter 4 gives the results, time-invariant at first and then the ones that are allowed to vary. Finally, chapter 5 concludes the paper and offers the room for potential research.

2 EXCHANGE RATE PASS-THROUGH: THEORY AND EVIDENCE

2.1 Definition and Properties of ERPT

The new phenomenon of ERPT arose not long after the breakdown of Bretton-Woods system at early 1970s. Within such fixed system exchange rates were felt to be largely away from their equilibrium rates in the end. Therefore, the floating exchange rate regimes were implemented in order to find what has been lost during the Bretton-Woods era. However, as Menon (1995) puts it, the initial enthusiasm about the equilibrating role of floating exchange rates began to fade and the main problem was that trade balances were changing little while exchange rates were considerably volatile. Therefore, the call for 'equilibrating role' has not been answered completely and the room for further research has appeared.

A number of authors tried to answer this 'adjustment puzzle' by examining the underlying relationship between exchange rates and prices of internationally traded goods (Menon, 1995). This sort of study became popular as ERPT analysis. According to Goldberg, Knetter (1997), the textbook definition of the exchange rate pass-through is "the percentage change in local currency import prices resulting from a one percent change in the exchange rate between the exporting and importing countries".

The most direct way of transmitting changes of nominal exchange rate into the domestic inflation is by altering the domestic currency prices of imported goods. How the exchange rate changes affects the domestic prices via import prices depends to a large extent on the pricing behaviour of exporting and importing firms on the relevant market (Mihaljek, Klau, 2008).

In extreme case when prices of imported goods are quoted in foreign currency and then sold to consumers for local currency at the going market exchange rate, the pass-through would be complete (i.e. equal to 1). That might be typical for countries with very high inflation or highly-dollarized economies. On the other hand, the zero pass-through (i.e. equal to 0) might appear when the strategy of pricing-to-market is applied. This happens when exporting firms and/or their importers/distributors fix the import price in the local currency of the market they are exporting to and in that case exchange rate movements might not be reflected in local currency prices (Mihaljek, Klau, 2008).

The most relevant case for smaller industrial and emerging market economies would seem to be an environment where foreign exporters selling goods to local importers/distributors at prices quoted in foreign currency, and distributors then re-selling goods in local market at prices quoted in local currency (Mihaljek, Klau, 2008). Considering to some extent competitive market, importers/distributors would partly absorb any effects of exchange rate changes by varying their mark-ups, so the pass-through would be incomplete. Empirical findings below are in line with these theoretical considerations suggesting that ERPT for industrialized countries lies somewhere in-between 0 and 1.

As the theory of ERPT widened throughout time, the aim of analyses transformed consequently. Firstly, studies focused on the effect on export and import prices in large trading nations such as the US, Japan or Germany. Useful survey of such studies published during 1974 and 1994 can be found in Menon (1995). He concludes that significant differences in estimated results between the papers studying the same country, commodity and time period lies in the choice of data and methodology. He also appeals for further research on the experience of small open economies to which has been paid little attention and claims that balance within the country-sample is of major importance despite the neglect from the authors' side.

Then, starting in the late 1980s the researchers emphasized the role of industrial organization, market segmentation and price discrimination. Goldberg, Knetter (1997) assigns the result of incomplete pass-through for the most part to third-degree price discrimination in measured countries. Authors also imply that national markets for goods are rather segmented than integrated and should be viewed as such while analyzing ERPT.

Another aspect that started to be taken into account is the 'two-channel' impact of exchange rate fluctuations on economic activity by which the ERPT analysis has been extended also to consumer and producer prices. To be specific, modern framework of monetary transmission in developed countries suggests that exchange rate shock is transmitted directly and indirectly into domestic inflation. The direct effect is the standard outcome of change in the amount of imported goods (i.e. as a part of final consumption) while the indirect effect lies in the import of inputs and intermediate goods for products produced in importing economy (Babecka, 2009).

In this context, McCarthy (1999) based his analysis on the so-called distribution chain of pricing which contains input and intermediate prices as well as the prices of final goods. He finds that exchange rates have a modest effect on domestic inflation while the effect of import prices is much stronger. This distinction is sometimes referred to as 'first-stage' and 'second-stage' pass-through and it allows for different pricing behaviour along a distribution chain. As Sekine (2006) states, the pricing behaviour of foreign exporters/domestic importers is thought to influence the first-stage pass-through while that of domestic distributors is considered to be relevant for the latter. These differences may lead to different development in each stage of pass-through. Getting back to findings of McCarthy (1999), pass-through is larger in countries with a larger import share and more persistent exchange rates or import prices.

Other important paper was Campa, Goldberg (2005) where authors provided cross-country, time series and industry-specific evidence on the pass-through into import prices across a large sample of OECD countries. They found 46 per cent pass-through on average in the short run and about 65 per cent on average over the long run and they also argue that pass-through into import prices is lower for countries with low average inflation and low exchange rate variability. Even more importantly, Campa, Goldberg (2005) assign observed changes in pass-through rates in estimated data set to widespread changes in the composition of industrial activity and trade rather than to changes in macroeconomic policy environments. Therefore, exchange rate movements have surprisingly much smaller effect on consumer prices than is generally expected.

In the early 2000s, the focus shifted to endogeneity aspects of ERPT. In this context, the researchers tried to answer the question whether a transition to a low-inflationary environment (that is executed by monetary policy authorities) automatically decreases the pass-through levels. Taylor (2000) was the first one to find empirical evidence that low inflation itself may have reduced the measured pass-through levels. Swiftly followed by his publication, more papers were dedicated to the endogeneity of ERPT. Bailiu, Fujii (2004) estimated panel-data set of 11 industrialized countries over 1977-2001 period and for the period of early 1990s found evidence in support of Taylor's hypothesis. Similarly, Devereux et al. (2003) and Chdouri, Hakura (2006) also supported the hypothesis of ERPT endogeneity. Moreover, the latter paper confirms the findings of Campa, Goldberg (2005) that low inflation countries have smaller pass-through levels and also suggests the effect is even smaller with more credible monetary policy.

Recent development of ERPT studies emphasized many interesting topics that are being researched. In example, numerous papers has used micro data to explore reasons behind incomplete pass-through. Their main findings are that pass-through depends on currency of invoicing, frequency of price adjustment, competitor producer exchange rates, competition local markets and price stickiness.[1] In this sense, Frankel et al (2012) estimates determinants of pass-through coefficient on a set of narrowly defined brand commodities prices in 76 countries. They partially find support for Taylor's hypothesis and they also confirm significant role of distribution and retail costs in pricing to market.

Other example consists of asymmetric and threshold effects of exchange rate changes on inflation. By asymmetric effects is actually meant different reaction in absolute of domestic prices to exchange rate appreciation and depreciation whereas threshold effects are the effects of exchange rate that changes only above certain level (e.g. only above± 5 per cent over a quarter). This has been studied in Mihaljek, Klau (2008) where authors found some support for both effects over the period 1994-2006 (e.g. depreciation seems to

[1] See Devereux , Yetman (2008), Gopinath, Itskhoki, Rigobon (2008), Gopinath, Itskhoki (2010), Cao, Dong, Tomlin (2012), etc.

have a significant and stronger effect on inflation than appreciation in countries like Korea, Mexico or Poland, threshold effects seem to apply in Malaysia, Thailand and Hungary). Once again, such properties are very country-specific and cannot be generalized into simple premise that is generally valid.

2.2 Approaches to ERPT Modeling

As Table 2.1 (column 2) suggests, there are various approaches to ERPT estimation and the consensus on the method or specifications of the model is rather scarce. This of course results in incomparability and diversity of estimated results. On the other hand, the literature suggests that there are generally two approaches that are applied in ERPT research. A summary of studies exploring the case of the Czech Republic may be found in Table 2.1.

First one is the single equation model (OLS) which can be applied very easily. Among others, papers like Mihaljek, Klau (2001) or Campa, Goldberg (2005) represent such technique. However, from econometric point of view, one of the shortcomings of OLS method is that it cannot account for possible endogeneity of ERPT which has been proven in several studies (as it is discussed in previous section). What is more, the information on the long-term aspects of ERPT is usually lost by first differencing of the data and that may limit the extent of research.

Other approach is the one of McCarthy (1999) and it is based on structural Vector Auto Regressive model (VAR). This technique has been heavily used in the literature because the impact of exchange rate shock on consumer prices can be comfortably analyzed by impulse response functions (IRF). Within VAR framework, the short-run pass-through is then measured as an impulse response to a given shock whereas the accumulated response may be interpreted as the long-run pass-through. However, the main drawback of this technique lies in lower effectiveness of results when the time series is short and in rather imprecise measurement of impulse response parameters in case of long forecasting horizon (Jimborean, 2011). Moreover, Coricelli et al. (2006) criticizes the VAR approach since in its framework any kind of shock may cause simultaneous movement of both exchange rate and price level.

Table 2.1: Pass-through estimates for the Czech Republic

Author	**Estimation method**	**Period**	**Frequency**	**Short-run ERPT**	**Long-run ERPT**
Babecka (2009)*	VAR	1996-2006	(m)	0.10	0.25
Babecka (2009)	VECM	1996-2006	(m)	-	<0.30
Beirne, Bijsterbosch (2009)	VECM	1998-2008	(m)	0.25	0.51
Bitans (2004)	VAR	1993-1997	(m)	0.21	-
Bitans (2004)	VAR	1998-2003	(m)	0.13	-
Ca'Zorzi et al (2007)	VAR	1993-2004	(q)	-	0.61
Campa, Goldberg (2005)**	OLS	N/A-2003	(q)	0.38	0.60
Coricelli et al (2006)	VECM	1993-2002	(q)	-	0.46
Darvas (2001)	TVC-VAR	1993-2000	(q)	0.10	0.15
Egert, MacDonald (2006)*	N/A	1993-N/A	N/A	0.10	0.23
Egert, MacDonald (2006)* **	N/A	1993-N/A	N/A	0.34	0.65
Jimborean (2011)	VAR	1996-2006	(q)	0.07	-
Korhonen, Wachtel (2006)	VAR	1999-2004	(m)	0.03	-
María-Dolores (2008)	OLS	2000-2006	(q)	0.11	-
Mihaljek, Klau (2001)	OLS	1994-2000	(q)	0.06	-
Mihaljek, Klau (2006)***	OLS	1994-2006	(q)	0.13	-
Vonnak (2010)*	VAR	1998-N/A	(m)	0.20	-

Source: Mentioned papers.

Notes: Figures are based on macroeconomic data and represent the exchange rate pass-through to consumer prices estimates. *Figures representing average of estimated models. **Figures relating to import prices. N/A: not available. ***Figure representing ERPT estimate when controlling for strong trend appreciation of CZK. VECM: Vector Error Correction Model, sometimes referred to as cointegrated VAR (C-VAR). In this thesis, the term C-VAR and VECM always refer to the same thing and it is used interchangeably throughout the paper. TVC-VAR: Time-varying cointegrated VAR. Most of the authors used effective exchange rate, Mihaljek, Klau (2001) used preferred bilateral exchange rate which is more transparent for firms. Darvas (2001) exclude food, energy and administrated prices from the aggregate price index. Coricelli (2006) uses inflation and interest rate differentials. Korhonen, Wachtel (2006) compared the estimates when US dollar and euro is used and confirms that pass-through tends to be higher when euro is used. Short-run pass-through represents either peak impulse response or the value after the shortest period available in the papers (e.g. pass-through after 3 months), long-run pass-through represents the total amount to be transmitted.

Following up on McCarthy's VAR model introduced in 1999, there evolved many extensions that has been used for estimation throughout the years. One of them is Vector Error Correction Model (VECM) which allows one to measure so called equilibrium pass-through (i.e. equilibrium to which the exchange rate coefficient tends to converge). The advantage of this method lies in preservation of the long-term information because it keeps the data in levels. Moreover, it takes into account causal relationships and non-stationarity issues (Babecka, 2009).

Even though it cannot be extracted from Table 2.1, most of the authors also divided period of their interest into smaller sub-periods in order to account for possible structural breaks and also to examine whether the pass-through levels declined. However, estimations done by split sample estimations or rolling regressions incorporate underlying assumption that parameters do not change over time. As Darvas (2001) states, there are several reasons to expect time-varying nature of pass-through. Among others, it is changing inflationary environment, behavioural changes, aggregation or exchange rate expectations and nonlinear exchange rate mean reversion.

As a consequence, some authors started applying time-varying methodology in order to get more stable findings over time. Once again, there is a number of different methods that can be used in such case. In example, Sekine (2006) studied given area of interest by using a time-varying parameter with stochastic volatility model in six major industrialized countries. Author on statistically significant level confirms that exchange rate pass-through levels decline over time and that this decline is not negligible. Some authors also build a state-space model where changes in the CPI index are explained by exchange rate changes and the error correction term and then (by applying the Kalman filter) the coefficient is allowed to vary. According to Darvas (2006), this version is one of the three main versions of time-varying cointegrated VAR and it is also the most appropriate one due to its flexibility in capturing various time paths of parameters that random-walk specification provides.[2]

Other authors employ the time-varying parameter VAR (T-VAR) method due to which one is able to reveal the timings and magnitude of the pass-through changes. Shioji (2012) provides the evidence of stable down-trended movement of pass-through to consumer prices as well as to import prices during the years 1980-2000 in Japan. On the other hand, his updated paper Shioji (2014) do not find such support and author claims that pass-through has regained some of its historical importance because his results suggest pass-through in Japan increased in recent years.

As far as specifications of the models are concerned, the researchers differ a lot also. As evidence suggests, pass-through to consumer prices is less transparent than pass-through to import prices but due to lack of data it is in fact more common to use consumer prices. Moreover, Babecka (2009) claims that import prices data unavailability may be sometimes replaced by foreign consumer prices reflecting the impact of external environment but also adds that such replacement may suffer from misspecification due to the neglect of possible pass-through determinants.

What is more, some authors criticize the use of aggregate price indices in a sense that pass-through estimates on aggregate price indices assume the same pass-through effect for all goods in the set. From theoretical point of view, there are several reasons for asymmetric behaviour of firms (e.g. quantity restraints, long-term contracts, etc.). Also, Babecka (2009) claims that different industries may have different sensitivities to inflation changes as a consequence of different degree of competition among market segments. Following up on that, Pollard, Coughlin (2003) study pass-through effect based on disaggregate data in the US and find support for such asymmetric aspects of ERPT. Authors provide

[2]The other two TVC-VAR models use either the property of Markov switching process (i.e. conditionally independent on past values) or the possibility of changing from one regime to another smoothly and permanently in time. The latter specification is the multivariate extension of the Smooth Transition Threshold Autoregression (STAR) model. If interested in the use of Markow property or smooth transition models, see Sims and Zha (2004) or He, Teräsvirta and González (2005) cited in Darvas (2006), respectively.

evidence that fraction of firms in different industries react differently to the same exchange rate changes. As a result, Pollard, Coughlin (2003) claim that pass-through estimates in manufacturing industry based on the assumption of symmetric behaviour may be biased. In the context of transition economies, pass-through analysis using disaggregate data can be found in Bitans (2004) or in Frankel et al (2012) who does not provide estimation results for individual countries studied in the paper, unfortunately.

2.3 Empirical Evidence

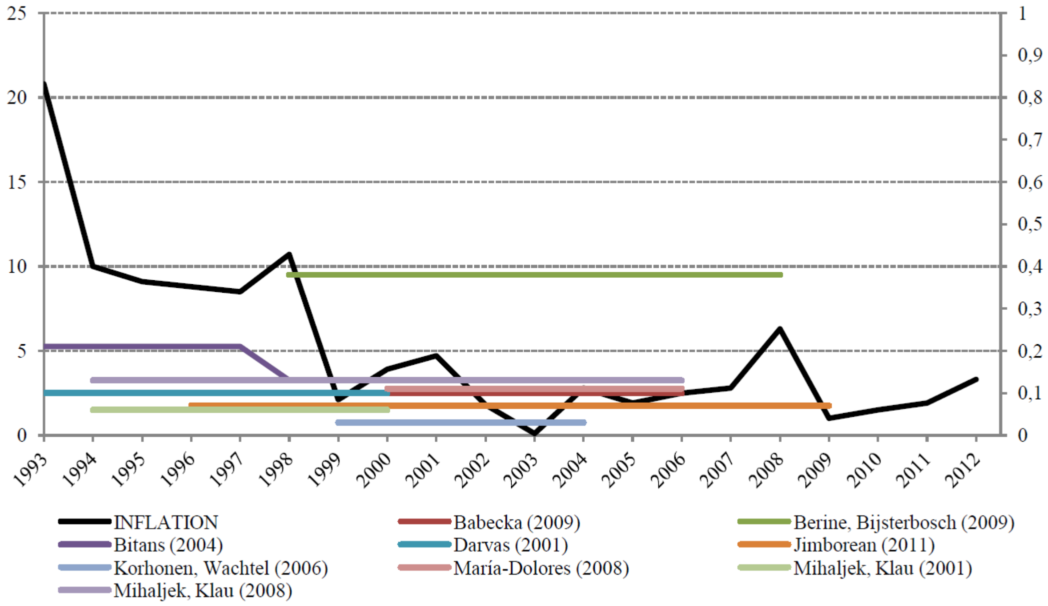
As mentioned above, with the early development of ERPT analyses little attention has been paid to the situation in small open economies. That has been answered in post-2000 era motivated by higher interest in new EU candidate countries before enlargement in 2004. What is more, a very useful survey may be found in Beirne, Bijsterbosch (2009) or Jimborean (2011) where authors study the ERPT situation in central and eastern European economies (CEEs).

Focusing on CEEs, several authors find pass-through estimates to be the lowest in the Czech Republic. Korhonen, Wachtel (2005) finds 3, 6, 9 and 18 per cent pass-through effects for Czechia, Hungary, Poland and Slovakia, respectively. María-Dolores (2008) estimates the effect at 11 per cent for Czechia, 32 per cent for Hungary, 12 per cent for Poland and 31 per cent for Slovakia. On the contrary, more recent studies suggest potential change in this pattern. Beirne, Bijsterbosch (2009) for example estimated the highest effects for Czech republic (38 per cent) and Poland (36 per cent) while the lowest were for Slovakia (18 per cent) and Hungary (24 per cent). Jimborean (2011) then finds the lowest values for Poland (1 per cent) followed by more or less same estimates for Czechia (7 per cent), Hungary (8 per cent) and Slovakia (8 per cent). According to these numbers, it seems impossible to declare one country to have constantly lower pass-through levels than the other. In our humble opinion, the effect of data and methodology is just too great.

Moreover, the definition of data, methodology and first observations in Mihaljek, Klau (2008) are the same as in Mihaljek, Klau (2001) which allowed the authors to update the pass-through levels estimated before and evaluate instantly whether and how they changed. Stunningly, they found that pass-through in Czech Republic increased from 6 (1994-2000) to 27 per cent (1994-2006) which stands against most of the findings. Authors also did not find any clear reasons for such increase. However, the Czech Republic as several other countries experienced a period of relatively strong trend appreciation of the Czech koruna and after controlling for such trend they re-estimated the initial analysis and get the value of 13 per cent as the new pass-through estimate. They also did not find any asymmetric or threshold effects of exchange rate changes on inflation that would be statistically significant.

Despite the diversity across researchers, estimates presented in Table 2.1 (columns 5, 6) confirm that pass-through effect in the Czech Republic varies from 6 to 40 per cent in the short-run which is far from complete levels (i.e. those equal to 1). Moreover, Figure 2.1 shows the rates of inflation and selected pass-through estimates from Table 2.1. It seems that as the inflation rates decline, the pass-through levels decline too which suggests potential evidence for Taylor endogeneity hypothesis.[3]

Figure 2.1: Inflation rates and selected pass-through estimates for the Czech Republic



Source: Czech Statistical Office (http://www.czso.cz/cz/cr_1989_ts/0304.xls), mentioned papers.

Notes: Figures for inflation rates (left vertical axis) are represented by y-o-y change of average consumer prices per unit with December as base month. Figures for pass-through estimates (right vertical axis) have short-term nature (it is either short-term peak or the value after the shortest period available in the papers - e.g. 3months). Studies included only in case of availability of all information about the data used.

In the case of long-run aspect of the pass-through, it is even more difficult to somehow generalize the findings due to larger effect of different methods and time spans. However, long-run pass-through estimates do not exceed the value of 0.65 in the surveyed papers.

As far as we are concerned one of the most important papers that studied the ERPT in the Czech Republic is Babecka (2009). She followed the McCarthy-type specifications within VAR framework and applied them to the Czech Republic data over the period 1996-2006.[4] Since part of the estimation included in this thesis will be an update of what Babecka (2009) studied, her findings will be presented more closely in the next paragraphs.

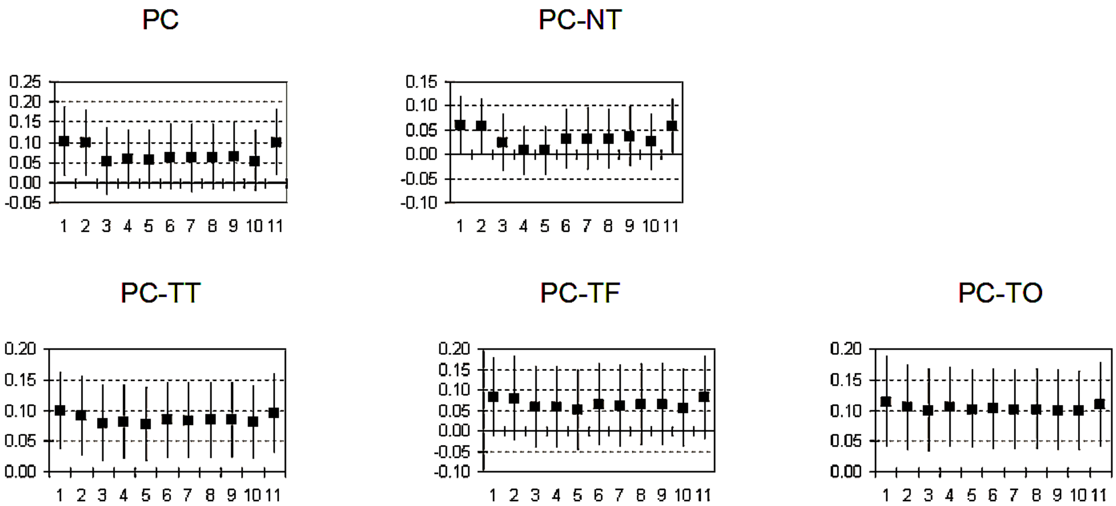
In the short-term horizon, due to impulse responses she finds that pass-through is incomplete and fast as it is presented at Figure 2.2 which plots the peak impulse responses and

[3]Other reasons that might played some role in the decline are the shift in the composition of "high pass-through" goods to "low pass-through" goods or increased competition and contestability of markets with reduced pricing power of dominant firms (via globalisation). If interested in broader discussion, see Mihaljek, Klau (2008).

[4]Methodology used in Babecka (2009) will be discussed more thoroughly in Section 3.

its confidence intervals for five different CPI indices. She also adds that the maximum effect of the exchange rate shock is attained roughly after 6 months and more than 50 per cent of this effect occurs during the first 3 months. As expected, it is also confirmed that there is substantial difference between the effect on tradables and non-tradables (i.e. the effect on non-tradables is much smaller and almost insignificant). After 6 months the effect is mostly transmitted into domestic consumer prices and the effect on aggregate CPI does not exceed 25 per cent.

Figure 2.2: Peak impulse response to a 1% exchange rate shock (whole period)



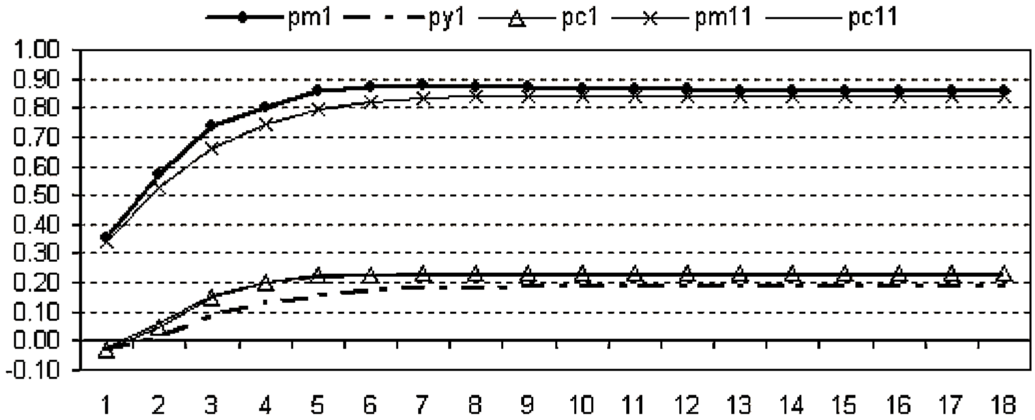
Source: Babecka (2009)

Notes: The numbers from 1 to 11 on the horizontal axis denote the specification number. For details on individual specifications see Babecka (2009). PC: aggregate CPI. PC-TT: tradables only. PC-TF: food only. PC-TO: other tradables (excluding food and beverages). PC-NT: non-tradables excluding regulated prices.

Another area of interest is the pass-through evolution along the distribution chain (i.e. the effect of exchange rate shock to import prices, producer and consumer prices). Figure 2.3 presents findings for two selected specifications. The highest effect about 85 per cent (almost complete) is found for import prices, for the other two indices the effect is much lower. As Bacchetta and van Wincoop (2003) states, this can be explained by high competition in the domestic market. On the other hand, estimates provided suggest a larger pass-through effect to consumer than to producer prices, quite surprisingly. Such result is being assigned to substantial presence of foreign component in the consumption basket.

Moreover, in case of non-stationary time series in levels but still cointegrated the VAR may suffer from possible omission variable bias to which Babecka (2009) reacts by employing VECM instead of standard VAR. In four selected specifications, she comes to conclusion that the pass-through effect varies from 0.15 to 0.36 when impulse responses are based on Cholesky ordering.

Figure 2.3: Pass-through along the distribution chain (accumulated impulse response)



Source: Babecka (2009)

Notes: The numbers from 1 to 11 on the horizontal axis denote the time period in months. Selected models are 1 and 11. For details on individual specifications see Babecka (2009). pc is the aggregate CPI, py is the producer price index and pm is the import price index.

Author also tried to counter possible issue of time-varying aspect of ERPT in the Czech Republic by building a state-space model where changes in the CPI index are explained by exchange rate changes and the error correction term and then Kalman filter is used to allow the coefficient to vary. However, time-varying coefficients were found to be insignificant in all models over the measured period.

On a different note, Franta et al (2014) evaluated changes in monetary transmission mechanism that appeared during 1996-2010 in the Czech Republic. Even though it was not of their primary concern, they found that exchange rate shocks produce long-lasting effects on prices and that there is little evidence for any changes in the nature of these price responses over time. More interestingly, Franta et al (2014) do not confirm the trend of decreasing pass-through in the Czech Republic as most of the previously published literature suggests. After Mihaljek, Klau (2008) and Shioji (2014) this is another paper that partially contradicts the common perception that pass-through is of fading nature. To some extent, Beirne, Bijsterbosch (2009) may be added to this category of papers since they also found higher pass-through levels as argued in paragraphs above.

To sum up, there are considerable differences in the estimated results due to different methodologies and different periods used in the papers. Despite that, empirical evidence suggest that pass-through in the Czech Republic is of incomplete nature. However, it becomes increasingly discutable whether the pass-through is of fading nature or not. More recent papers show that it might not be a coincidence that their results indicate higher pass-through. In fact, it becomes more probable that substantial structural break (e.g. financial crisis) may have appeared in the latest years changing the pattern of the underlying relationship. In this regard, my results should have quite unique position in either confirming or rejecting such pattern.

3 GENERAL ESTIMATION STRATEGY

In this chapter, methodology and data that will be used for estimation will be presented. As mentioned above, the consensus on the method of ERPT is scarce throughout the literature and each technique has its pros and cons. Nonetheless, we believe that the approach of McCarthy seems to be the most appropriate because the single equation method cannot cope with the issue of endogeneity.

As a consequence, the system of specifications that has been already applied to the Czech data in Babecka (2009) will be replicated here. However, our attention will be paid only to the part that deals with short-run pass-through (i.e. VAR analysis). Then, unique time-varying cointegration model developed by Bierens, Martins (2009) will be applied.[1]

My argument for such choice of methodology is policy-relevancy. In my opinion, central banks with inflation-stability mandate (e.g. CNB) are primarily interested in short-term effects of exchange rate change on the price level. When it comes to long-term perspective, the key is how stable the relationship between the variables is and how the pass-through levels change when the economy goes through different phases of performance.

3.1 Methodology

3.1.1 Vector Autoregression

In the Vector Autoregressive (VAR) framework, short-run pass-through is measured as an impulse response to a given shock. Impulse responses are being extracted with the use of Cholesky ordering that selects the order of variables in the system. The choice of ordering is of major importance because if chosen wrongly you limit the dynamics and effects of one variable to another which may not always be in line with theory or previous findings.

What is more, it is not only difficult because of aspects just mentioned but it is almost impossible to account for all possible combinations from practical point of view (e.g.

[1] Babecka (2009) also used VECM which has the advantage of coping with omission variable bias (that may appear in VAR systems as argued in section 2.3). Since the outcome of this model is long-term effect it might be interesting to include it in the analysis. On the other hand, standard version of VECM does not possess the ability to counter the possible structural-break issues that are quite likely to appear in time-series that cover the latest economic development. Thus, chosen methodlogy that incorporates VECM estimation and allows for changes in time is preferred.

chosen system has at most 6 endogeneous variables that implies 720 possibilities of different ordering).

Therefore, we decided to follow the ordering used in Babecka (2009) that corresponds to distribution chain hypothesis with variables approximating supply and demand shocks placed before the distribution chain. This ordering is consistent with McCarthy (2007) and Ca'zorzi et al (2007). There are three major differences to Babecka (2009). First, industrial production is used instead of GDP gap data because GDP gap data are provided only on quarterly basis.[2] Second, unit labour costs variable is dropped from the estimation since it is not available on monthly basis. Third, having in mind the choice of industrial production over GDP, the ordering was adjusted in a sense of Beirne, Bijsterbosch (2009) who used also industrial production as approximation of demand shocks. Beirne, Bijsterbosch (2009) argued that this 'adjusted' ordering is more natural. Since literature on ERPT with the use of industrial production instead of GDP data is rather scarce, we decided to follow this scheme in order to be consistent with previous literature.

In this light, consider the following system:

$$\Delta pm_{it}^{oil} = E_{t-1}(\Delta pm_{it}^{oil}) + \varepsilon_{it}^{supply} \tag{3.1}$$

$$\Delta s_{it} = E_{t-1}(\Delta s_{it}) + a_1\varepsilon_{it}^{supply} + \varepsilon_{it}^{s} \tag{3.2}$$

$$\Delta ip_{it} = E_{t-1}(\Delta ip_{it}) + b_1\varepsilon_{it}^{supply} + b_2\varepsilon_{it}^{s} + \varepsilon_{it}^{demand} \tag{3.3}$$

$$\Delta pm_{it} = E_{t-1}(\Delta pm_{it}) + c_1\varepsilon_{it}^{supply} + c_2\varepsilon_{it}^{s} + c_3\varepsilon_{it}^{demand} + \varepsilon_{it}^{pm} \tag{3.4}$$

$$\Delta px_{it} = E_{t-1}(\Delta px_{it}) + d_1\varepsilon_{it}^{supply} + d_2\varepsilon_{it}^{s} + d_3\varepsilon_{it}^{demand} + d_4\varepsilon_{it}^{pm} + \varepsilon_{it}^{px} \tag{3.5}$$

$$\Delta py_{it} = E_{t-1}(\Delta py_{it}) + e_1\varepsilon_{it}^{supply} + e_2\varepsilon_{it}^{s} + e_3\varepsilon_{it}^{demand} + e_4\varepsilon_{it}^{pm} + e_5\varepsilon_{it}^{px} + \varepsilon_{it}^{py} \tag{3.6}$$

$$\Delta pc_{it} = E_{t-1}(\Delta py_{it}) + f_1\varepsilon_{it}^{supply} + f_2\varepsilon_{it}^{s} + f_3\varepsilon_{it}^{demand} + f_4\varepsilon_{it}^{pm} + f_5\varepsilon_{it}^{px} + f_6\varepsilon_{it}^{py} + \varepsilon_{it}^{pc} \tag{3.7}$$

[2] There exist several methods for data transformation (e.g. quadratic method of interpolation) but such transformation creates a bit artificial data even though based on the true variable. Therefore, my replacement of GDP data by industrial production data is based on idea of having correctly specified data at the cost of approximating the variable of interest only.

where Δ is the difference operator (i.e. $\Delta Y_t = Y_t - Y_{t-12}$), pm_{it}^{oil}, s_{it}, ip_{it}, pm_{it}, px_{it}, py_{it} and pc_{it} stands for import price (oil only), exchange rate, industrial production, import price (all groups), export price, producer price and consumer price, respectively; $E_{t-1}(.)$ is the expectation of a variable based on the information set at the end of period $t-1$. $\varepsilon_{it}^{supply}$, ε_{it}^{s}, $\varepsilon_{it}^{demand}$ ε_{it}^{pm}, ε_{it}^{px}, ε_{it}^{py} andε_{it}^{pc} are the supply, exchange rate, demand, import price, export price, producer price and consumer price shocks, repspectively.[3]

Equation (3.1) says that supply shocks are identified from the dynamics of oil price change. Equation (3.2) says that exchange rate shocks are identified from the dynamics of exchange rate change after taking into account the contemporaneous effect of the supply shock. As far as demand shocks are concerned, they are identified from the dynamics of industrial production change after taking into account the contemporaneous effects of the supply and exchange rate shocks as presents equation (3.3) and so on.

According to definition of the system, one may conclude that shocks in consumer price are identified from the dynamics of consumer price change after taking into account the contemporaneous effects of shocks of all variables that are placed before the consumer price (i.e. those that are defined in (3.1) - (3.6)).

Moreover, we ought to mention two other features about the models. First, the model allows domestic consumer prices to be affected by import prices in two channels - directly and indirectly via producer prices. Second, there is no contemporaneous feedback in the model (e.g. consumer price change may affect import price change only in future periods).

Estimated VAR specifications are presented in Table 3.1. With the exception of specification 1, McCarthy (1999) argues that shocks along the distribution chain can be thought of as changes in the pricing power and markups of firms at these changes. Finally, we assume that the conditional expectations in all specifications can be replaced by linear projections of the lags of all endogenous variables included in the system.

[3]In some specifications where pm_{it}^{oil} is included as exogeneous variable, pm_{it} is replaced by pm_{it}^{n-oil} that denotes import price (all groups except oil).

Table 3.1: Estimated VAR specifications

VAR No.	Endogeneous variables						Exogeneous variables	
1	s	pm	px	py	pc			
2	pm^{oil}	s	ip	pm^{n-oil}	py	pc		
3	s	ip	pm^{n-oil}	py	pc		pm^{oil}	
4	s	ip	pm^{n-oil}	py	pc		pm^{oil}	i
5	s	ip	pm^{n-oil}	pc			pm^{oil}	i
6	s	ip	pc				pc^{EU}	
7	s	pm	pc				pc^{EU}	
8	s	pc					pc^{EU}	
9	pm^{oil}	s	pc				pc^{EU}	
10	s	pc					pc^{EU}	pm^{oil}
11	s	ip	pm	pc				

Source: Babecka (2009), Beirne, Bijsterboosch (2009), McCarthy (2007).

Notes: *s - exchange rate, pm - import prices, px - export prices, py - producer prices, pc - consumer prices, w - unit labour costs,* pm^{oil} *- import prices (oil only), ip - industrial production,* pm^{n-oil} *- import prices (all items except oil), i - interest rate,* pc^{EU} *- euro area consumer prices.*

3.1.2 Vector Error Correction Model

Since vector error correction model (VECM) is slightly more advanced than classic VAR, the focus on the theory here than in subsection 3.1.1 will be greater. Also, we believe it is important for reader to understand the issue of cointegration as it is a key for understanding the idea in the original part of the estimation.

> **Definition (co-integrating vector)** *The components of the vector x_t are said to be co-integrated of order d, b denoted $x_t \sim CI(d,b)$, if: (i) all components of x_t are $I(d)$; (ii) there exists a vector $\alpha(\neq 0)$ so that $z_t = \alpha' x_t \sim I(d-b)$, $b > 0$. The vector α is called the co-integrating vector.*

Definition above is taken from Engle, Granger (1987) and it says that components of vector x_t are said to be cointegrated of order d, b if all these components are integrated with the same order d and if there exist some vector α enabling linear combination $\alpha' x_t$ to be of order $d - b$, the vector α is called the cointegrating vector. Moreover, focusing on the case of $d = 1$, $b = 1$, that would mean that if the components of x_t were all $I(1)$, then the equilibrium error would be $I(0)$ and z_t will rarely drift far from zero (i.e. considering zero mean of z_t) and often cross the zero line (Engle, Granger, 1987). Therefore, z_t cannot wander widely and equilibrium will occasionally occur.

In this context, if non-trivial linear combination of two variables is stationary, then they are said to be cointegrated. And so, the property of cointegration assures that these two variables cannot depart from each other for some longer period of time (i.e. they share common trend). If one moves away from the other, then it either moves back or the other variable moves towards the first one. Obviously, this suggests much more powerful and stable relationship than for example high level correlation.

Definition (error correction representation) *A vector time series x_t has an error correction representation if it can be expressed as:*

$$A(B)(1-B)x_t = -\gamma z_{t-1} + u_t, \tag{3.8}$$

where B is backshift operator, u_t is a stationary multivariate disturbance, with $A(0) = I$, $A(1)$ has all elements finite, $z_\tau = \alpha' x_\tau$, and $\gamma \neq 0$.

In this multivariate representation that Engle, Granger (1987) presented, the only explanatory variable is the disequilibrium in the previous period. Considering that any set of lags of the z can be represented like that, the setting allows for any type of gradual adjustment toward a new equilibrium. This feature is the key for understanding the importance of error correction representation.

Focusing on the case of a two variable system, a typical error correction model would link the change in one variable to past equilibrium errors and to past changes in both variables.

Granger representation theorem *If the $N \times 1$ vector x_t given in:*

$$(1-B)x_t = C(B)\varepsilon_t, \tag{3.9}$$

is cointegrated with $d = 1$, $b = 1$ and with co-integrating rank r, then:

1. *$C(1)$ is of rank $N - r$.*
2. *There exists a vector ARMA representation:*

$$A(B)x_t = d(B)\varepsilon_t \tag{3.10}$$

with the properties that $A(1)$ has rank r and $d(B)$ is a scalar lag polynomial with $d(1)$finite, and $A(0) = I_N$. When $d(b) = 1$, this is a vector autoregression.

3. *There exist $N \times r$ matrices, α, γ, of a rank r such that:*

$$\alpha' C(1) = 0$$

$$C(1)\gamma = 0$$

$$A(1) = \gamma\alpha'.$$

4. *There exists an error correction representation with $z_t = \alpha' x_t$, an $r \times 1$ vector of stationary random variables:*

$$A*(B)(1-B)x_t = -\gamma z_{t-1} + d(B)\varepsilon_t \tag{3.11}$$

with $A*(0) = I_N$.

5. *The vector z_t is given by:*

$$z_t = K(B)\varepsilon_t \tag{3.12}$$

$$(1-B)z_t = -\alpha'\gamma z_{t-1} + J(B)\varepsilon_t, \tag{3.13}$$

where $K(B)$ is an $r \times N$ matrix of lag polynomials given by $\alpha' C*(B)$ with all elements of $K(1)$ finite with rank r, and $det(\alpha'\gamma) > 0$.

6. *If a finite vector autoregressive representation is possible, it will have the form given by (3.10) and (3.11) above with $d(B) = 1$ and both $A(B)$ and $A*(B)$ as matrices of finite polynomials.*

Putting it simply, Granger representation theorem says that cointegrating relationship implies error correction which means that the current movement of a variable is a function of its past deviation from the equilibrium. What is more, Engle, Granger (1987) not only proved that cointegration implies error correction but they also proved it conversely, that is error correction implies existence of cointegration. In other words, they proposed a technique how to deal with cointegration and that is by the use of vector error correction model which is justified by the Granger theorem.

Stock, Watson (1988) adds that cointegration indicates presence of a common stochastic trend among variables.

Now, assume following model:

$$X_t = \alpha_0 + \alpha_1 X_{t-1} + \beta_0 Y_t + \beta_1 Y_{t-1} + e_t, \tag{3.14}$$

where X_t and Y_t are cointegrated and both $I(1)$ meaning there is a unit root and they are not stationary.

Next, substract X_{t-1} from both sides of equation and get:

$$\Delta X_t = \alpha_0 + \rho_1 X_{t-1} + \beta_0 Y_t + \beta_1 Y_{t-1} + e_t \tag{3.15}$$

And finally, add $\pm\beta_0 Y_{t-1}$ and get:

$$\Delta X_t = \alpha_0 + \rho_1(X_{t-1} + \gamma Y_{t-1}) + \beta_0 \Delta Y_t + e_t, \tag{3.16}$$

which is the vector error correction representation of model (3.14). In the presented case of non-stationary but cointegrated variables, the VAR may suffer from omission variable bias to which the vector error correction model is imune and therefore, more appropriate. Babecka (2009) adds that once the model contains only one cointegrated equation the error correction term provides information on the degree of equilibrium pass-through that is estimated as the inverse of the exchange rate coefficient.

Other approach than Engle, Granger (1987) is the one of Johansen (1988) who proposed a different method based on testing for the number of cointegrating relationships which then has been extended in Johansen (1996).

Assume following model that might have more than one cointegrating relationship:

$$x_{1t} = \beta_1 + \beta_2 x_{2t} + \beta_3 x_{3t} + u_t, \tag{3.17}$$

where x_{1t}, x_{2t}, x_{3t} are variables and u_t is stationary error term. In this case, the vector of cointegrating coefficients β becomes $N \times r$ cointegrating matrix:

$$\beta' = \begin{pmatrix} \beta_1^1 & \beta_2^1 & \beta_3^1 \\ \beta_1^2 & \beta_2^2 & \beta_3^2 \end{pmatrix}$$

And so the cointegrating relation for these three variables can be written as:

$$\begin{pmatrix} e_1 \\ e_2 \end{pmatrix} = \beta' x = \begin{pmatrix} \beta_1^1 & \beta_2^1 & \beta_3^1 \\ \beta_1^2 & \beta_2^2 & \beta_3^2 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}$$

with stationary product representing two error correction terms $\begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$. The vector error correction representation of model (3.17) then can be represented as:

$$\Delta x_t = \mu + \alpha\beta' x_{t-1} + \sum_{i=1}^{p} \Pi_i \Delta x_{t-i} + \varepsilon_t \tag{3.18}$$

where α is $N \times r$ matrix of adjustment coefficients (corresponding to term ρ in VECM given in (3.16)) and the product $\alpha\beta'$ is $N \times N$ matrix. By defining $\Pi_0 = \alpha\beta'$, the model can be now written as:

$$\Delta x_t = \mu + \Pi_0 x_{t-1} + \sum_{i=1}^{p} \Pi_i \Delta x_{t-i} + \varepsilon_t. \tag{3.19}$$

And finally, the Johansen procedure tests the rank of Π_0 (i.e. it tests how many eigenvalues of Π_0 are statistically significant) which equals to the number of cointegrating vectors β.

In this light, all specifications are tested for cointegration.

3.1.3 Time-Varying Cointegration

The methodology described in subsections 3.1.1 and 3.1.2 has been heavily used in exchange rate pass through estimations in recent decades but it still has some shortcomings as neither of them can tackle the issue of structural breaks that are so distinct in recent development of modern economics. As mentioned in section 2.2, there are several techniques how to allow for adjustments in time but the one that attracted our attention the most is the extension of standard Johansen procedure proposed by Bierens, Martins (2009).[4]

In the standard Johansen procedure, the cointegrating vector is assumed to be constant over time. However, this assumption may be quite restrictive and so to gain some flexibility it would be logic to allow the cointegrating vector to vary which may be easily said than done. Hansen (2003) tried to address this issue by generalization of reduced-rank methods to cointegration under sudden regime shifts with known number of break points. However, Bierens, Martins (2009) argue that the cointegrating vector may be subject to a smooth and gradual change over time rather than to sudden shifts and so the structural change is associated with smooth time variations of the cointegrating vector.

That is also confirmed by Sekine (2006) who states that time-varying coefficient model generally suggests gradual changes in pass-through coefficients rather than structural break-type parameter shifts. Author addresses such outcome to underlying structural change that possibly took place gradually over time (e.g. globalization) or because it took some time for structural change to be incorporated in behavioural changes (e.g. even though the shift in regime has been done overnight, the acceptance of such regime by economic subjects might be reflected gradually as the new policy regime appears more and more credible).

In this context, Bierens, Martins (2009) develop a technique where ECM is specified with a cointegrating vector indexed by time and this vector is then approximated by linear combination of orthogonal Cheybshev time polynomials. Chebyshev time polynomials $P_{i,T}(t)$ are defined by

$$P_{0,T}(t) = 1,\ P_{i,T}(t) = \sqrt{2}cos(i\pi(t-0.5)/T),\ t = 1, 2, ..., T,\ i = 1, 2, 3, ... \tag{3.20}$$

where T is number of observations and i is integer.[5]

The resulting ECM has then time invariant coefficients which allows for usual maximum-likelihood estimation and it is also possible to define a long-run statistic that tests for standard cointegration.

In detail, consider following time-varying VECM(p) with Gaussian errors without intercepts and time trends:

[4] Other solutions has been addressed in papers like Hansen (1992), Quintos and Phillips (1993) or Maddala and Kim (1998) for single-equation models. In the case of system of equations, see Seo (1998) or Hansen and Johansen (1999) who propose fluctuation tests for parameter constancy in cointegrated VAR's.

[5] If interested in more thorough theoretical background of Chebyshev polynomials, see Hamming (1973). In case of wander about the usage of polynomials in applied econometrics, see Bierens (1997) who used them in his unit root test against nonlinear trend stationarity.

$$\Delta Y_t = \Pi_t^{'} Y_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta Y_{t-j} + \varepsilon_t,\ t = 1, ..., T, \tag{3.21}$$

where $Y_t \epsilon R^k$, $\varepsilon_t \sim i.i.d.\, N_k\ [0, \Omega]$, $\Pi_t^{'} = \alpha\beta_t^{'}$ with $rank(\Pi_t^{'}) = r < k$ where α is fixed $k \times r$ matrix and $\beta_t^{'}$'s are time-varying $k \times r$ matrices of cointegrating vectors, Ω and the Γ_j's are fixed $k \times k$ matrices and T is the number of observations.

Now, substituting $\Pi_t^{'} = \alpha\beta_t^{'} = \alpha \left(\sum_{i=0}^{m} \xi_i P_{i,T}(t)\right)^{'}$ in (3.21) yields:

$$\Delta Y_t = \alpha \left(\sum_{i=0}^{m} \xi_i P_{i,T}(t)\right)^{'} Y_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta Y_{t-j} + \varepsilon_t, \tag{3.22}$$

where m is order of Chebyshev polynomials. For some $k \times r$ matrices ξ_i, which can be written more conviently as:

$$\Delta Y_t = \alpha\xi^{'} Y_{t-1}^{(m)} + \Gamma X_t + \varepsilon_t, \tag{3.23}$$

where $\xi^{'} = \left(\xi_0^{'}, \xi_1^{'}, ..., \xi_m^{'}\right)$ is an $r \times (m+1)\, k$ matrix of rank r, $Y_{t-1}^{(m)}$ is defined by:

$$Y_{t-1}^{(m)} = \left(Y_{t-1}^{'}, P_{1,T}(t) Y_{t-1}^{'}, P_{2,T}(t) Y_{t-1}^{'}, ..., P_{m,T}(t) Y_{t-1}^{'}\right)^{'} \tag{3.24}$$

and:

$$X_t = \left(\Delta Y_{t-1}^{'}, ..., \Delta Y_{t-p+1}^{'}\right)^{'}. \tag{3.25}$$

In that case as Bierens, Martins (2009) argue, the null hypothesis of time-invariant cointegration corresponds to $\xi^{'} = \left(\beta^{'}, O_{r,k.m}\right)$, where β is the $k \times r$ matrix of time-invariant cointegrating vectors, so that then $\xi^{'} Y_{t-1}^{(m)} = \beta^{'} Y_{t-1}^{(0)}$, with:

$$Y_{t-1}^{(0)} = Y_{t-1}.$$

Consequently, Bierens, Martins (2009) suggest to test the null hypothesis via a likelihood ratio test $LR^{tvc} = -2\left[\widehat{l_T}(r, 0) - \widehat{l_T}(r, m)\right]$, where $\widehat{l_T}(r, 0)$ is the log-likelihood of the VECM(p) defined in (3.23) in the case $m = 0$, so that $Y_{t-1}^{(m)} = Y_{t-1}$, and $\widehat{l_T}(r, m)$ is the log-likelihood of the VECM(p) defined in (3.23) in the case where $Y_{t-1}^{(m)}$ is given by (3.24), where in both cases r represent the cointegration rank.[6]

On the other hand, this original method of capturing smooth transitions on the cointegrating vector has one limiting aspect. In detail, that would be chi-square distribution $\left(\chi_{mkr}^2\right)$ which is taken as null distribution for the likelihood ratio test applied in order to distinguish Johansen's standard cointegration from Bierens-Martins time-varying alternative.

[6]If interested in more details about the method, its derivation, proofs, etc., see Bierens, Martins (2009) or Bierens, Martins (2009A).

Degrees of freedom that are given by multiple mkr are not allowed to be zero as either part of the multiple cannot be zero. Moreover, for a given pair (k, r), the distribution becomes less skewed as m increases.

Despite that, we consider the method to be a viable option for estimation of the time-varying aspect of exchange rate pass-through as it may shed some light on the behaviour of cointegrating relationship and its stability over time.

3.2 Data Analysis

All specifications described in Table 3.1 are estimated against five consumper price indices: aggregate CPI (PC), tradables only (PC-TT), food only (PC-TF), other tradables excluding food and beverages (PC-TO) and non-tradables excluding regulated prices (PC-NT).

3-month Prague InterBank Offered Rate, Czech aggregate CPI and aggregate CPI for EU are taken from Eurostat. Nominal effective exchange rate[7], producer prices and industrial production index come from International Financial Statistics published by IMF. Import prices, export prices and sub-components of these price indices are obtained from the Czech Statistical Office (CZSO). Other consumer price indices and its sub-components come from ARAD database operated by the Czech National Bank (CNB).

The original period starts at 1998:1 and ends at 2013:8 that is 188 observations.[8] Except from interest rates, the original series are expressed in indices equal to 100 for the base year 2005. It should be also noted that in the case of PC-TT, PC-TF, PC-TO, PC-NT and import prices (all items except oil) the data are not adjusted for methodological changes, unfortunately. Furthermore, export and import prices are based on revised external trade structure of the year 2010, data for industrial production was extracted already with seasonal adjustment. Descriptive statistics of original series are presented in Table 3.2. Also, log-transformation has been performed.

As far as time-varying cointegration model is concerned, the underlying relationship between nominal effective exchange rate and aggregate CPI will be the core for estimation. For the purposes of comparison, analysis based on bilateral exchange rate of the Czech koruna against euro (CZK/EUR) and the US dollar (CZK/USD) will be considered too. This is especially due to the fact that bilateral exchange rate data covers a period of 1998:1-2014:1. Meaning that the effects of recent foreign exchange interventions executed by CNB will be also present in the estimation. Summary statistics may be found in Table 3.3.

As stated above, nominal effective exchange rate comes from International Financial Statistics and the period that data set covers 1998:1-2013:8. The other three variables (CPI,

[7]Nominal effective exchange rate used in the estimation is defined according to IMF definition of NEER.

[8]In the case when import prices (all items except oil) are used, one observation is missing (1998:1) restricting the estimated data set to 187 observations.

Table 3.2: Descriptive statistics of data used for VAR estimation

	Mean	Median	Min	Max	Stand. dev.	Skewness	Kurtosis	Observations
PC	102.85	100.65	84.10	122.50	11.07	0.143	1.840	188
PC-TT	103.22	102.30	98.36	112.74	3.674	0.767	2.478	188
PC-TF	107.44	100.58	92.01	138.96	13.15	0.758	2.269	188
PC-TO	99.88	99.27	83.88	112.00	9.26	-0.200	1.671	188
PC-NT	98.37	100.80	69.78	117.92	14.50	-0.365	1.827	188
s	101.72	101.19	74.80	129.36	15.51	-0.078	1.614	188
px	98.74	98.75	91.70	105.90	3.062	0.188	2.658	188
pm	99.81	99.50	88.60	114.20	4.819	0.634	3.821	188
ip	98.58	99.85	61.50	134.50	18.47	-0.089	1.849	188
py	100.62	100.39	84.27	117.87	10.28	0.087	1.751	188
pm^{oil}	99.49	97.95	29.10	175.00	37.17	0.206	2.337	188
pm^{n-oil}	99.80	99.22	88.38	115.48	6.43	0.497	2.654	187
pc^{EU}	101.01	100.76	86.29	117.61	9.46	0.086	1.780	188
i	3.662	2.545	0.460	16.590	3.313	2.272	8.317	188

Source: CZSO, ARAD database (CNB), Eurostat, IFS (IMF).

Notes: *PC - aggregate CPI, PC-TT - consumer prices for tradables, PC-TF - consumer prices for traded food only, PC-TO - consumer prices for other tradables, PC-NT - consumer prices for non-tradables,, s - exchange rate, pm - import prices, px - export prices, py - producer prices, pc - consumer prices,* pm^{oil} *- import prices (oil only), ip - industrial production,* pm^{n-oil} *- import prices (all items except oil), i - interest rate,* pc^{EU} *- euro area consumer prices.* Data included are before log-transformation.

CZK/EUR and CZK/USD) were obtained from Eurostat with complete data set of 1998:1-2014:1 making 193 observations in total.

Table 3.3: Descriptive statistics of data used for TVC estimation

	Mean	Median	Min	Max	Stand. dev.	Skewness	Kurtosis	Observations
CPI	103.34	101.50	84.10	122.50	11.33	0.122	1.803	193
NEER	101.72	101.19	74.80	129.36	15.51	-0.078	1.614	188
CZK/EUR	29.71	28.72	23.53	38.46	4.200	0.377	1.840	193
CZK/USD	25.54	23.10	14.92	41.20	7.371	0.567	1.933	193

Source: Eurostat, IFS (IMF).

Notes: *CPI - aggregate consumer price index, NEER - nominal effective exchange rate, CZK/EUR - bilateral exchange rate of Czech koruna against euro, CZK/USD - bilateral exchange rate of Czech koruna against US dollar.* Data included are before log-transformation.

3.2.1 Stationarity

Each time series has been checked for stationarity[9] and to this purpose three tests were applied: Augmented Dickey-Fuller (ADF), Kwiatkowski-Phillips-Schmidt-Shin (KPSS) and Phillips-Perron (PP) test.[10] It is worth mentioning that ADF and PP tests are asymptotically equivalent and usually yield similar results too (though they may differ substantially in some finite samples) but PP is considered to be generally more comprehensive especially

[9] We expect that the reader's knowledge regarding the property of stationarity lies fairly beyond basic level. If not see Cipra (2008).

[10] If interested in theoretical background of ADF, KPSS or PP test, see Dickey, Fuller (1979), Kwiatkowski et al (1992) or Phillips, Perron (1988), respectively.

because it incorporates an automatic correction to the Dickey-Fuller procedure allowing for autocorrelated residuals. On the other hand, both tests are sometimes being critized because of lower power of the test when the process is stationary but with a root close to the non-stationary boundary.

KPSS test varies quite substantially from the ADF- and PP-type of tests. In terms of practical testing, it is crucial not to mix the null hypotheses as they are completely opposite to each other (i.e. ADF- and PP-type of tests test unit root presence under null hypothesis whereas KPSS has under null hypothesis stationarity).

Getting back to ADF test, we chose 14 as a maximal lag lenght according to Schwert (1989) rule of a thumb[11]. Also, only a constant in the tests is included, we did not include linear trend specification since we did not find any strong argument in the ERPT theory for such choice and so (if non-stationary) we expect this data to be rather of stochastic than deterministic-trend process.[12]

VAR

The results are presented in Table 3.4. Majority of time series seems to be non-stationary in levels which is supported by all three tests. However, there are 4 cases when evidence is rather mixed. Import and export prices seem to be non-stationary, but the null hypothesis of ADF test (i.e. unit root presence) is not refused with $p-$level very close to the refusal boundary (e.g. 0.1>p>0.05). Similair issue appears when stationarity is checked with PP test. As stated above, this is the exact room for criticism of low power of ADF- and PP-type of tests when the root seems to be close to non-stationary boundary. What it means is that mentioned price indices may be stationary but with a root very close to 1 (but not equal to 1!). Checking ACFs and PACFs at both cases confirm that. What is more, KPSS test does not refuse stationarity at both cases which only increases the doubt about ADF and PP results.

Another example of mixed results is the case of price index for non-tradables. PP refuses unit root with extremely high significance level whereas both KPSS and ADF do not share such outcome. Moreover, $p-$level with ADF test is again very close to the non-stationary

[11] That is defined by:

$$p_{max} = \left[12 \cdot \left(\frac{T}{100}\right)^{\frac{1}{4}}\right],$$

where [...] denotes integer and T represents number of observations. Then, having in mind t-statistics of the last lag we chose the most appropriate one according to Schwarz (SIC) and Akaike Information Criteria (AIC).

[12] This act is of major importance since these two processes require totally different treatment to induce stationarity. If the standard method of first differencing is applied to trend-stationary series, it would get rid of the non-stationarity but only at the expense of introduction of MA(1) structure into error term. On a different note, if detrending is used on a series with stochastic trend, the non-stationarity property shall remain.

Table 3.4: Testing for unit root

	ADF		KPSS		PP	
	level	△	level	△	level	△
PC	0.7749	0.0000	1.6442	0.0421	0.8110	0.0001
PC-TT	0.8801	0.0000	1.2783	0.5000	0.9256	0.0001
PC-TF	0.9950	0.0000	1.5191	0.0928	0.9972	0.0001
PC-TO	0.8793	0.0000	1.6248	0.1330	0.9989	0.0001
PC-NT	0.0929	0.0000	1.6188	0.0663	0.0000	0.0001
s	0.4426	0.0000	1.5906	0.0992	0.4565	0.0001
px	0.0988	0.0000	0.4265	0.0459	0.0850	0.0001
pm	0.0725	0.0000	0.3140	0.0519	0.2153	0.0001
ip	0.8265	0.0000	1.4515	0.1789	0.8154	0.0001
py	0.7027	0.0000	1.6225	0.2388	0.8360	0.0001
pm^{oil}	0.4499	0.0000	1.3192	0.0410	0.7127	0.0001
pm^{n-oil}	0.5311	0.0000	1.2490	0.1040	0.5080	0.0001
pc^{EU}	0.8371	0.0000	1.6658	0.0393	0.9414	0.0001
i	0.0002	-	1.1241	-	0.0000	-

Source: Author's calculations.

Notes: *PC - aggregate CPI, PC-TT - consumer prices for tradables, PC-TF - consumer prices for food only, PC-TO - consumer prices for other tradables, PC-NT - consumer prices for non-tradables, s - exchange rate, pm - import prices, px - export prices, py - producer prices,* pm^{oil} *- import prices (oil only), ip - industrial production,* pm^{n-oil} *- import prices (all items except oil), i - interest rate,* pc^{EU} *- euro area consumer prices.* In ADF and PP columns there are presented p-values with lags chosen due to AIC and SIC. However, in KPSS column is presented LM-statistic which has to be compared with 0.739, 0.463 and 0.347 representing 1, 5 and 10 per cent significance, respectively.

boundary increasing the controversality of results. Nontheless, after checking the graph and correlogram of this series we consider it to be somehow non-stationary.

Having in mind previous studies, interest rate is usually included in levels (partially) disregarding the property of stationarity/non-stationarity. Test results indicate stationarity of interest rate despite a bit controversial outcome of KPSS test. In this light, we shall include interest rate in levels. On the other hand, in order to induce stationarity in most of the series we applied year-on-year differences and Table 3.4 contains the results of the new tests.[13] Unfortunately, differencing the data to make them stationary means loosing the long-term information.

Most of the series is stationary now, only one mixed result occurs in the case of price index for other tradables where KPSS does not refuse the null-hypothesis of stationarity.

Nevertheless, inclusion of some non-stationary variables in the model is possible if the whole model passes the stability test which is essential.

[13] We decided to use year-on-year (y-o-y) changes instead of month-on-month (m-o-m) changes in the price level for various reasons. In general, data obtained by m-o-m transformation are more volatile and are usually associated with seasonality. Moreover, m-o-m changes are typically not monitored by economic agents such as households or unions. More importantly, central banks set their inflation targets in y-o-y changes in the price level. See Babecky et al (2009).

Time-Varying Cointegration

All time-series turned out to be non-stationary which allows one to proceed with cointegration analysis. Outcome of all tests may be found in Table 3.5.

Table 3.5: Testing for unit root

	ADF	KPSS	PP
CPI	0.6815	1.6874	0.7649
NEER	0.4426	1.5906	0.4565
EUR/CZK	0.4352	1.5990	0.3421
USD/CZK	0.6721	1.4537	0.6683

Source: Author's calculations.

Notes: *CPI - aggregate consumer price index, NEER - nominal effective exchange rate, EUR/CZK - bilateral exchange rate of Czech koruna against euro, USD/CZK - bilateral exchange rate of Czech koruna against US dollar*. In ADF and PP columns there are presented p-values with lags chosen due to AIC and SIC. However, in KPSS column is presented LM-statistic which has to be compared with 0.739, 0.463 and 0.347 representing 1, 5 and 10 per cent significance, respectively.

3.2.2 Cointegrating relationships

All specifications have been tested for cointegration by the use of Johansen's unrestricted cointegration rank test. That can be used in two modes - it either concentrates on the trace or maximum eigenvalue of the given matrix. In both cases, the null hypothesis says that there are at most r cointegrating relationships and the test is carried out against alternative that there are $r+1$ cointegrating relationships.[14] Thus, the outcome is the number of cointegrating relationships in tested specifications that cannot be rejected on 5 per cent significance level.

It should be noted that outcomes of the test are very sensitive to inital assumptions. As argued in previous subsection, we expect no deterministic trend in data and we include constant in testing. Moreover, Johansen's test assumes no exogeneous shocks.

VAR

With regard to the assumption of Johansen's test, exogenous variables have been dropped from specifications 3-10 while testing for cointegration. The lag length was selected according to information criteria (i.e. AIC and SIC) and we also checked stability of given setting by examining whether all inverse roots lie in the unit circle. Then, we used one lag less in Johansen's test. That is due to the fact that possible VECM would be specified for first differences. The results are presented in Table 3.6.

Unfortunately, some tests bring controversy even for the same price index (i.e. trace and maximum eigenvalue modes give different number of cointegrating relationships).[15]

[14] If interested in more about Johansen's unrestricted cointegration rank test, see Johansen (1996).

[15] Lüthkepohl et al (2000) suggests that trace tests tend to have more distorted sizes whereas their power is in some situations superior to that of maximum eigenvalue.

Therefore, we have decided to try other lags suggested by different criteria (e.g. HIC, final prediction error, sequential modified LR test statistic, etc.) and then repeat the test.

Table 3.6: Cointegrating relationships given by Johansen cointegration test

VAR No.	PC		PC-TT		PC-TF		PC-TO		PC-NT	
	trace	max λ	trace	max λ	trace	max λ	trace	max λ	trace	max λ
1	2	2	1	1	1	1	2	2	1	1
2	2	2	2	2	2	2	3	3	2	2
3	1	1	1	1	1	1	2	2	1	1
4	1	1	1	1	1	1	2	2	1	1
5	1	1	0	0	1	1	1	1	1	1
6	1	1	1	1	1	1	1	0	2	2
7	1	1	0	0	0	0	1	1	3	1
8	1	1	0	0	0	0	0	0	2	2
9	1	1	0	0	0	0	1	1	3	1
10	1	1	0	0	0	0	0	0	0	0
11	1	1	0	0	1	1	1	1	1	1

Source: Author's calculations.

Notes: *PC - aggregate CPI, PC-TT - consumer prices for tradables, PC-TF - consumer prices for food only, PC-TO - consumer prices for other tradables, PC-NT - consumer prices for non-tradables, trace/max λ - Johansen's unrestricted cointegration rank test based on trace/maximum eigenvalue.* Specifications 7 with price index for tradables, 6 with price index for other tradables and numbers 7 and 9 with price index for non-tradables were the most problematic when deciding on the number of cointegrating relationships.

Unlike Babecka (2009), the results presented in table 3.6 are a bit mixed. No specification can be labelled as 'completely' cointegrated because the results vary when different consumer price indices are used.

Specification number 2 reveals no cointegrating relationships. As far as the rest is concerned, it really matters what consumer price index is used for testing. Specifications 3-6 and 11 seem to be the most frequent ones to incorporate exactly one cointegrating relationship. In terms of others, the number of cointegrating relationships varies substantially from 0 to 3.

Nevertheless, the presence of cointegrating relationships suggest possible omission variable bias in VAR models. To some extent, this problem is adressed in the latter part of the estimation.

Time-Varying Cointegration

In the case of NEER-CPI relationship and EUR/CZK-CPI, both SIC and HIC suggested to include 1 lag in the VAR which implies 0 lags for Johansen's cointegration test. As far as the relationship USD/CZK-CPI is concerned, the lag suggestion differs (i.e. HIC suggests 2 lags whereas SIC 1 lag). We decided to include 2 lags since lag exclusion test did not refuse the second lag.

In all three cases Johansen's test finds exactly one cointegrating relationship between the examined variables on 5 per cent significance level and test results may be found in Table

7.9 in Appendix A. Moreover, imposed restricitions on the intercept parameters hold which means that outcomes of the cointegration tests are valid. Summary of these tests is shown in Table 7.10 in Appendix A. The standardized cointegrated vectors found are presented in Table 3.7.

Table 3.7: Standardized cointegrated vectors

	NEER	EUR/CZK	USD/CZK
CPI	$(-0.8776; 1)$	$(1; 0.7512)$	$(0.4562; 1)$

Source: Author's calculations.

Notes: *CPI - aggregate consumer price index, NEER - nominal effective exchange rate, EUR/CZK - bilateral exchange rate of Czech koruna against euro, USD/CZK - bilateral exchange rate of Czech koruna against US dollar*. In the cases of NEER and USD/CZK, the first dimension in the paranthesis represents the respective exchange rate part of the vector that is standardized due to CPI dimension. In terms of EUR/CZK, the second dimension represents the CPI dimension that is standardized due to exchange rate dimension of the vector.

It should be mentioned that Bierens, Martins (2009) developed also a test that can be considered to some extent as robust check for estimated cointegrating vectors. In a nutshell, it is based on testing of the significance of the dimensions of given vectors. Some vectors that were not rejected on 5 per cent significance level were found which means they might be also cointegrating for given relationships (e.g. vector equal to $(-1; 1)$ for NEER-CPI relationship). The power of this test remains, however, unknown.

As a consequence, one may double-check outcome of previous tests by testing whether these new linear combinations are stationary by the use of ADF, KPSS and PP test. Many vectors have been tested in this regard and no other vectors (than those in Table 3.7) have been confirmed as cointegrating for given relationships (i.e. linear combinations seem to be non-stationary). A brief summary on the outcomes of this testing may be found in Table 7.8 in Appendix A.

4 RESULTS

This chapter presents firstly time-invariant results and then results that are allowed to vary over time. Taking into account the number of VAR models estimated, only one model will be presented in detail so the reader has a notion for what the models were tested, etc. The detail results for all other models are provided in Appendix B (separate).

Moreover, the section on time-invariant results of VAR's is divided into another five sub-sections in order to distinguish among the results given by different price groups that form the examined indices. If not stated otherwise, previous short-term results used for comparison are those presented in Babecka (2009).

Nevertheless, as being discussed in sub-section 3.2.2, there is non-negligible number of cointegrating relationships in the VAR specifications which points to possible omission variable bias in VAR models. Also, as VARs are estimated on differenced data, part of the long-term information has been lost. These two facts should be taken into consideration while presenting short-term results.

4.1 Short-Term Results

Given the initial setting of 11 specifications and 5 price indices examined, the total of 55 VAR models have been estimated. In order to establish the pass-through effect by the use of these models correctly, the model has to be stable and its residuals should not be autocorrelated, heteroscedastic or follow other distribution than normal.

However, there is one important aspect that contradicts this statement. There will definitely be some autocorrelation in residuals since the data was transformed due to y-o-y differences and by definition this implies autocorrelation around 12th lag.

Moreover, if the assumptions of homoscedasticity and normality are invalid this does not necessarily mean that these models are wrong. That is because the aspect of homoscedasticity affects standard errors and not the actual value of the estimate. As far as non-normality is concerned, it would mean that computed t-statistics are not valid and there might be omission variable bias as argued in 3.2.2.

In my humble opinion, since the primary concern is about actual value of the estimate, neglecting unfulfilled assumptions of homoscedasticity or normality might be considered as acceptable while presenting the results. Needless to say, we are still aware what these unfulfilled assumptions mean and what limitations they imply.

4.1.1 Illustrative Case

As a detail analysis to be presented we chose specification 8 with aggregate CPI which is defined in Table 3.1. It focuses on the underlying relationship between exchange rate and aggregate CPI allowing only foreign price level to be included in the system as exogenous variable.

First of all, one must define the lag structure of the VAR model. Eventhough there are several information criteria (e.g. AIC, HQIC, SIC, etc.) to choose the lag length from and it is common practice to use them, the choice simply based on the criteria is not always the most appropriate since the outcome of them is affected by several factors (e.g. number of observations, etc.) and they do not take into account lag structure significance.

Therefore, we have decided to include only one lag at first. Then, correlogram of the residuals has been checked and substantial correlation remained there. So we added second lag and most of the correlation in the residuals disappeared but some effect still remains. Figure 7.2 in Appendix A shows the correlogram of VAR(2). Also, we checked the lag exclusion test with 2 lags and both of them could not be rejected on 5 per cent significance level as presented in Table 7.2 in Appendix A.

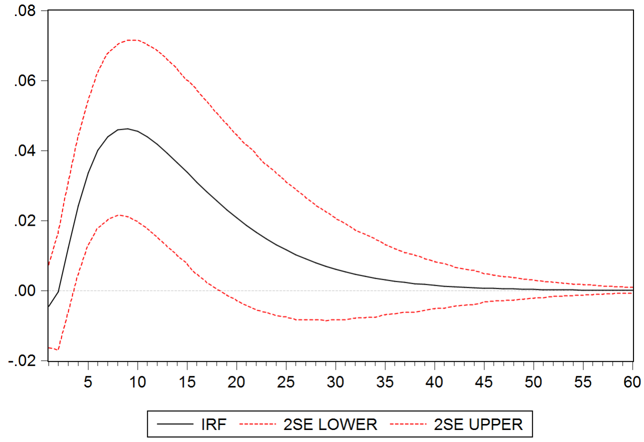
Having in mind usual step-wise procedure, there is no need to include more lags since they do not improve residuals that much (i.e. marginal effect is the highest for 2nd lag inclusion) and they become insignificant when more of them is included. As far as information criteria are concerned, HIC confirms 2 lags as the most appropriate whereas AIC and SIC suggest 3 and 1, respectively. Table 7.1 in Appendix A shows the lag selection criteria computed for 8 lags.

Then, the stability of chosen VAR model has to be checked by testing whether all the inverse roots of the characteristic polynomial lie within the unit circle. Figure 7.1 in Appendix A confirms that they do with modulus of the closest one to the unit-boundary around 0.8. That means the system of variables is stationary and this VAR(2) is stable. If the model was unstable it would not be possible to use it. Thus, such finding is of major importance.

On the other hand, it should be noted that residuals of this VAR(2) are found to be non-normal and heteroscedastic as expected. Tables 7.3 and 7.4 in Appendix A show the detail test results for normality and homoscedasticity, respectively.

Finally, Figure 4.1 shows the impulse response of aggregate CPI to 1 per cent change in the exchange rate. The peak is achieved around 8th or 9th period with maximum pass-through of 4.6 per cent and then it slowly decreases towards 0. When it comes to accumulated response plotted in Figure 4.2, it seems that the total effect that is transmitted to aggregate CPI accounts for about 70 per cent and it is reached roughly after 2 years. On the other hand, one should be aware of huge confidence bands with which these results are being presented.

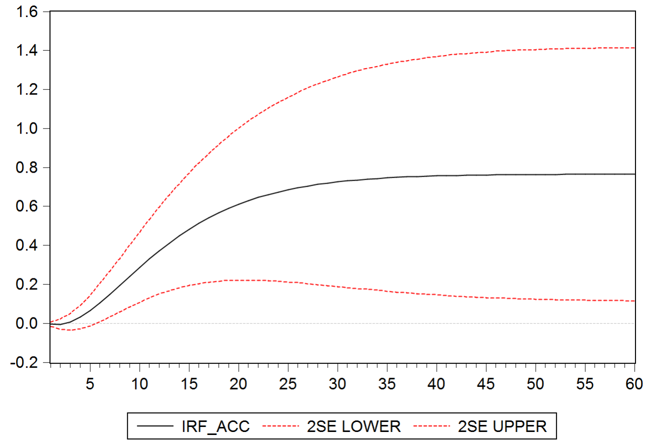
Figure 4.1: Impulse response of PC to 1% exchange rate shock



Source: Author's calculations.

Notes: *PC - aggregate CPI, exchange rate - NEER - nominal effective exchange rate, 2SE (LOWER/UPPER) - 2 asymptotic standard errors (lower band, upper band).* The period (moths) is plotted on the horizontal axis. Impulse response is based on Cholesky ordering as discussed in subsection 3.1.1. Also, the effect on NEER is multiplied by -1 so that results can be easily compared to other papers. The reasoning behind this is that the NEER is defined in a such way that when it increases it means it appreciates whereas when usual bilateral exchange rate (e.g. CZK/EUR) increases it means it depreciates. Also, the shock in this case represent exchange rate depreciation.

Figure 4.2: Accumulated response of PC to a 1% exchange rate change



Source: Author's calculations.

Notes: *PC - aggregate CPI, exchange rate - NEER - nominal effective exchange rate, SE (LOWER/UPPER) - asymptotic standard errors (lower band, upper band).* The period (moths) is plotted on the horizontal axis. Impulse response is based on Cholesky ordering as discussed in subsection 3.1.1. Also, the effect on NEER is multiplied by -1 so that results can be easily compared to Babecka (2009). The reasoning behind this is that the NEER is defined in a such way that when it increases it means it appreciates whereas when typical bilateral exchange rate (e.g. CZK/EUR) increases it means it depreciates.

To sum up, results above are quite different to previous findings suggesting that the dynamics of ERPT slowed down substantially whereas the total effect to be transmitted increased. Whether or not this outcome is confirmed for all specifications and different price indexes used will be discussed more in next subsection since this was only illustrative case.

4.1.2 Summary of VAR models

Getting back to models presented in next sub-sections, the procedure was exactly the same as presented in subsection 4.1.1. In all cases the lag order selected is 2 with reasoning given above.

Also, each model was tested for stability and the inverse roots of characteristic polynomials in all of them were found to lie within the unit circle as can be extracted from Table 7.5. That means every model passed the VAR stability test which is again extremely important.

As far as normality is concerned, with few exceptions the residuals are not normal which comes mainly from rejected testing for normal kurtosis (i.e. if the distribution is not mesocurtic, then it is either leptocurtic or platycurtic). However, if focused solely on testing for skeweness in 38 out of 50 models the residuals are found to be normal (i.e. not skewed). In these cases, the effect of having different kurtosis than normal overweights the effect of the residuals not being skewed. Table 7.6 in Appendix A summarizes main conclusions of normality tests.

In terms of homoscedasticity, residuals are found to be heteroscedastic. Only exceptions are specifications 8 and 10 where several models are found to have homoscedastic residuals.

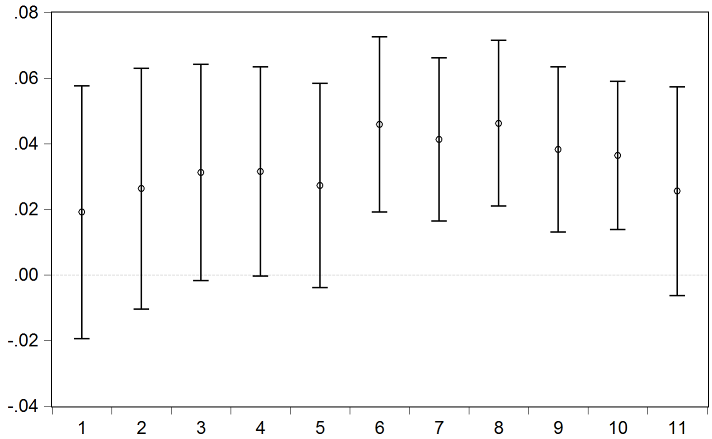
More problematic could be correlation in the residuals. However, as deeper analysis of correlograms suggests statistically significant correlation in residuals is (with rare exceptions) only around 12th lag which is quite logic considering how the differences are defined (i.e. y-o-y differences).

As argued above, primary concern in this estimation is about the actual value of the response and not about properties that require valid assumptions of normality and homoscedasticity. Though possibly not ideal, chosen models are considered as appropriate for ERPT analysis.

Aggregate CPI

Figure 4.3 shows the peak impulse responses of aggregated CPI to a 1% exchange rate shock. It seems that the peak impulse response declined from 6-7 to 3 per cent on average. What is more, the timing of the peak occurs sometimes between 8 to 11 months after the initial change in exchange rate which is quite different from findings of Babecka (2009) who finds the peak occuring around 2 months after the change.

Figure 4.3: Peak impulse response of PC to a 1 per cent exchange rate shock



Source: Author's calculations.

Notes: *PC - aggregate CPI*. The numbers from 1 to 11 on the horizontal axis denote the specification number as defined in Table 3.1. The peak impulse response timing is not the same for all specifications. Generally, it occurs sometimes in between 8 and 11 months after the initial change in exchange rate.

This suggests that the dynamics of the pass-through effect on aggregate CPI slowed down and prolongated its duration substantially. That is confirmed by Table 4.1 where the accumulated responses for 6, 12, 18, 24 and 60 months are presented. The total effect to be transmitted after two years is on average about 50-60 per cent of the initial change as opposed to 25 per cent estimated in Babecka (2009).

However, Beirne, Bijsterbosch (2009) estimated the effect to aggregate CPI to be 43 per cent. Considering that Beirne, Bijsterbosch (2009) cover period of 1995-2008 (3 years longer than Babecka (2009)), the difference in result might suggest that during the 'extra' period the pass-through increased. In this light, the results we got could be to some extent considered as in line with previous findings. That is also confirmed by Franta et al (2014) who suggest NEER-CPI pass-through in the Czech Republic increased in late 2000s.

Table 4.1: Accumulated response of PC to a 1 per cent exchange rate shock

Var No.	6 months	12 months	18 months	24 months	60 months
1	0.0009	0.1000	0.2109	0.3074	0.4782
2	0.0308	0.1778	0.2891	0.3078	0.2051
3	0.0476	0.2222	0.3760	0.4540	0.4610
4	0.0528	0.2312	0.3811	0.4519	0.4549
5	0.0426	0.1981	0.3272	0.3897	0.3871
6	**0.1052**	**0.3701**	**0.5622**	**0.6663**	0.9224
7	0.0991	**0.3316**	**0.4712**	**0.5157**	0.4073
8	**0.1053**	**0.3726**	**0.5670**	**0.6740**	**0.7651**
9	0.0740	**0.2901**	**0.4154**	**0.4442**	0.3111
10	0.0719	**0.2824**	**0.4363**	**0.5230**	**0.6061**
11	0.0501	0.1972	0.292	0.3002	0.1250

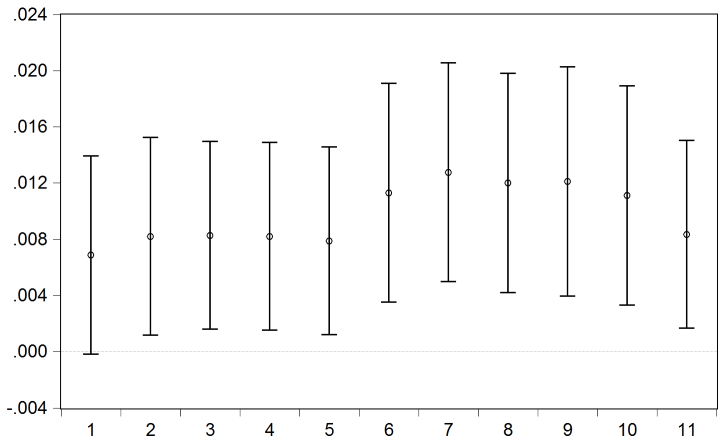
Source: Author's calculations.

Notes: *PC - aggregate CPI*. Only highlighted numbers were found significantly different from 0.

Tradables

In terms of total tradables, the situation depicted on Figure 4.4 is much different. The effect to be transmitted is only 1 per cent on average at its peak which occurs around 4th or 5th month. This suggest that the dynamics is substantially faster than in aggregate CPI case though it is not as fast as concluded in Babecka (2009). Her effect was about 8 per cent on average with peak around 2nd month.

Figure 4.4: Peak impulse response of PC-TT to a 1 per cent exchange rate shock



Source: Author's calculations.

Notes: *PC-TT - consumer prices for tradables.* The numbers from 1 to 11 on the horizontal axis denote the specification number as defined in Table 3.1. The peak impulse response timing is not the same for all specifications. Generally, it occurs around 4th or 5th month after the initial change in exchange rate.

When focused on accumulated effect, the most of it is transmitted in the first 12 months reaching roughly 6-7 per cent on average as opposed to previous 25 per cent. Detail effects estimated may be found in Table 4.2.

Therefore, it appears again that the dynamics of the pass-through slowed down and it takes more time to transmit the total effect into the price index. On the other hand, the pass-through to consumer prices for tradables is found to be much lower than in the case of aggregate CPI. These results go against our expectations. In our humble opinion, the logic is of course that prices of traded goods are the ones mostly affected by changes in exchange rate. Therefore, the pass-through should be higher in case of tradables than in the case of non-tradables. Whether or not this pattern is the same for other price indices for tradable items is shown in next subsections.

Table 4.2: Accumulated response of PC-TT to a 1 per cent exchange rate shock

Var No.	6 months	12 months	18 months	24 months	60 months
1	0.0153	0.0420	0.0540	0.0608	0.0714
2	0.0188	0.0509	0.0591	0.0589	0.0656
3	0.0224	0.0520	0.0606	0.0617	0.0673
4	0.0228	0.0493	0.0551	0.0551	0.0593
5	0.0206	0.0473	0.0558	0.0576	**0.0558**
6	**0.0368**	**0.0694**	**0.0825**	**0.0879**	**0.0924**
7	**0.0404**	**0.0691**	**0.0773**	**0.0795**	**0.0803**
8	**0.0376**	**0.0702**	**0.0817**	**0.0858**	**0.0880**
9	0.0354	**0.0668**	**0.0744**	**0.0759**	**0.0755**
10	0.0325	**0.0594**	**0.0675**	**0.0700**	**0.0710**
11	0.0242	**0.0546**	**0.0680**	**0.0727**	**0.0734**

Source: Author's calculations.

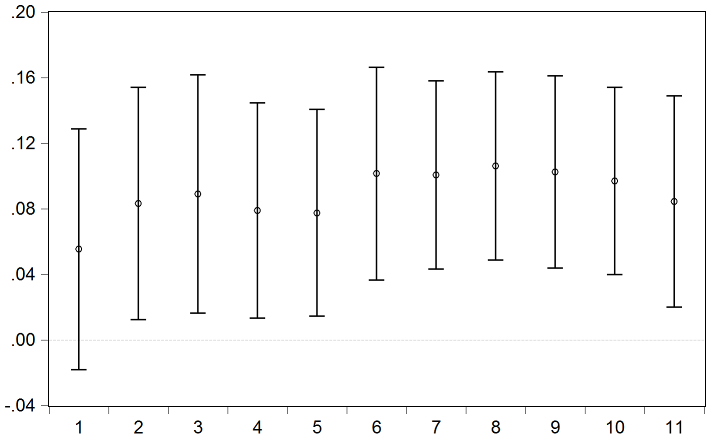
Notes: *PC-TT - consumer prices for tradables*. Only highlighted numbers were found significantly different from 0.

Tradables (Food Only)

Peak impulse responses when consumer prices for traded food are used occur around 9th or 10th month after the initial change and reach maximum of 9 per cent on average. That is exactly in line with previous estimation even though the peak occurs around 2nd month there. Figure 4.5 presents estimated short-term peak impulse responses.

However, extremely different is the total amount of the effect to be transmitted. Table 4.3 suggests that after its peak the effect decreases unbelievably slowly which makes the total effect growing constantly. It appears that after 12-18 months the effect is fully transmitted to the price index as opposed to Babecka (2009) estimation reaching 25 per cent. Therefore, on one hand the increased amount to be transmitted into the price level better corresponds to our expectations about tradable items than in the previous case. On the other, however, finding of complete pass-through to food prices is quite surprising.

Figure 4.5: Peak impulse response of PC-TF to a 1 per cent exchange rate shock



Source: Author's calculations.

Notes: *PC-TF - consumer prices for traded food only*. The numbers from 1 to 11 on the horizontal axis denote the specification number as defined in Table 3.1. The peak impulse response timing is not the same for all specifications. Generally, it occurs sometimes during 9th and 10th month after the initial change in exchange rate.

Table 4.3: Accumulated response of PC-TF to a 1 per cent exchange rate shock

Var No.	6 months	12 months	18 months	24 months	60 months
1	0.0647	0.3740	0.6676	0.8855	1.2858
2	0.1671	**0.6415**	**1.0148**	1.1412	1.0292
3	0.2023	**0.7109**	**1.1442**	**1.3652**	1.5043
4	0.1962	**0.6511**	**0.9985**	**1.1470**	1.2214
5	0.1802	**0.6269**	**0.9844**	**1.1467**	1.0695
6	**0.2425**	**0.8306**	**1.2780**	**1.4790**	1.6007
7	**0.2363**	**0.8177**	**1.2354**	**1.4268**	1.2082
8	**0.2336**	**0.8496**	**1.3321**	**1.5790**	**1.7182**
9	**0.2182**	**0.8090**	**1.2347**	**1.4347**	**1.2429**
10	**0.2131**	**0.7777**	**1.2230**	**1.4903**	**1.7596**
11	0.1897	**0.6746**	**1.0693**	**1.2219**	0.8690

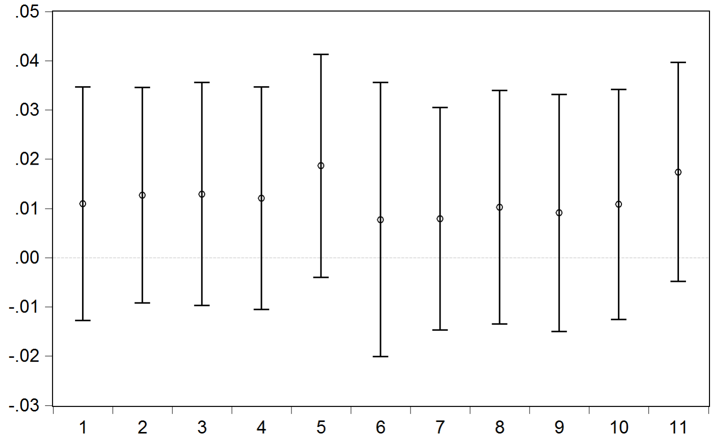
Source: Author's calculations.

Notes: *PC-TF - consumer prices for traded food only*. Only highlighted numbers were found significantly different from 0.

Other Tradables (All Except Food)

When it comes to other tradables (all items except food), the peak size of 1 per cent on average is quite similar to the case of total tradables. On the other hand, results are not significantly different from 0 as it is shown in Figure 4.6. Babecka (2009) estimates the peak to be around 10 per cent occuring in 3rd month.

Figure 4.6: Peak impulse response of PC-TO to a 1 per cent exchange rate shock



Source: Author's calculations.

Notes: *PC-TO - consumer prices for other tradables (all items execept food).* The numbers from 1 to 11 on the horizontal axis denote the specification number as defined in Table 3.1. The peak impulse response timing is not the same for all specifications. Generally, it occurs sometimes in between 11 and 13 months after the initial change in exchange rate.

Accumulated responses are not significant as well but for completeness they may be found in Table 4.4.

Table 4.4: Accumulated response of PC-TO to a 1 per cent exchange rate shock

Var No.	6 months	12 months	18 months	24 months	60 months
1	0.0128	0.0721	0.1324	0.1825	0.3810
2	0.0268	0.0986	0.1559	0.1897	0.3327
3	0.0260	0.0986	0.1600	0.1761	0.2548
4	0.0243	0.0922	0.1486	0.1761	0.2530
5	0.0317	0.1293	0.2376	0.3251	0.4966
6	0.0157	0.0584	0.1020	0.1351	0.1576
7	0.0044	0.0453	0.0905	0.0905	0.2171
8	0.0125	0.0662	0.1263	0.1773	0.2986
9	0.0138	0.0653	0.1449	0.1531	0.2444
10	0.0163	0.0754	0.1377	0.1885	0.3032
11	0.0298	0.1204	0.2230	0.3097	0.5168

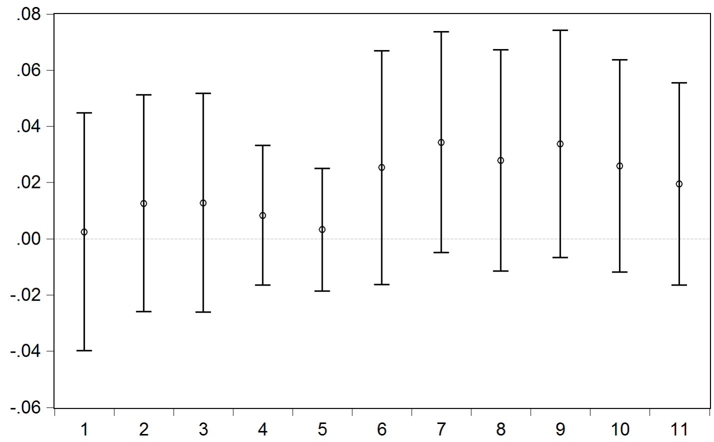
Source: Author's calculations.

Notes: *PC-TO - consumer prices for other tradables (all items except food).* Only highlighted numbers were found significantly different from 0.

Non-tradables

In the case of non-tradables the peak is estimated to be around 2 per cent which is in line with Babecka (2009). However, the results are also statistically insignificant. That applies to the case of peak impulse response as well as to the case of accumulated responses. Nevertheless, peak impulse responses are depicted in Figure 4.7 whereas accumulated responses are presented in Table 4.5.

Figure 4.7: Peak impulse response of PC-NT to a 1 per cent exchange rate shock



Source: Author's calculations.

Notes: *PC-TO - consumer prices for other tradables (all items execept food).* The numbers from 1 to 11 on the horizontal axis denote the specification number as defined in Table 3.1. The peak impulse response timing is not the same for all specifications. Generally, it occurs sometimes in between 11 and 13 months after the initial change in exchange rate.

Table 4.5: Accumulated response of PC-NT to a 1 per cent exchange rate shock

Var No.	6 months	12 months	18 months	24 months	60 months
1	-0.0163	-0.0198	-0.0060	0.0061	0.0613
2	-0.0053	0.0448	0.1163	0.1567	0.1577
3	0.0081	0.0663	0.1391	0.1849	0.2005
4	0.0083	0.0473	0.0907	0.1052	0.0690
5	-0.0102	-0.0015	0.0175	0.0312	0.0422
6	0.0495	0.1925	0.3341	0.4445	0.6569
7	0.0750	0.2712	0.4651	0.6234	1.0148
8	0.0481	0.2030	0.3624	0.4927	0.7945
9	0.0560	0.2445	0.4349	0.5869	0.9289
10	0.0475	0.1942	0.3390	0.4540	0.7156
11	0.0021	0.0448	0.1103	0.1754	0.3184

Source: Author's calculations.

Notes: *PC-NT - consumer prices for non-tradables.* Only highlighted numbers were found significantly different from 0.

4.2 Time-Varying Results

While estimating the time-varying ERPT, unique EasyReg software has been used.[1]

4.2.1 NEER-CPI

If number of Chebyshev time polynomials included is higher than 1, the null hypothesis of Bierens-Martins test described in subsection 3.1.3 is firmly rejected suggesting the nature

[1] EasyReg software is a freeware. Therefore, if interested, see http://econ.la.psu.edu/~hbierens/EASYREG.HTM.

of the NEER-CPI relationship varies over time. Results may be found in Table 4.6. Note that if more Chebyshev polynomials are added the more firmly the null hypothesis is rejected.

Table 4.6: Bierens-Martins test for NEER-CPI case

No. of Chebyshev time polynomials	Test statistic	10 per cent signficance level	5 per cent significance level	$\chi^2(df)$
m=1	4.32	4.61	5.99	2
m=2	11.29	7.78	9.49	4
m=3	15.05	10.64	12.59	6
m=4	22.97	13.36	15.51	8
m=5	26.84	15.99	18.31	10
m=6	37.06	18.55	21.03	12
m=7	48.39	21.06	23.68	14
m=8	53.41	23.54	26.30	16

Source: Author's calculations.

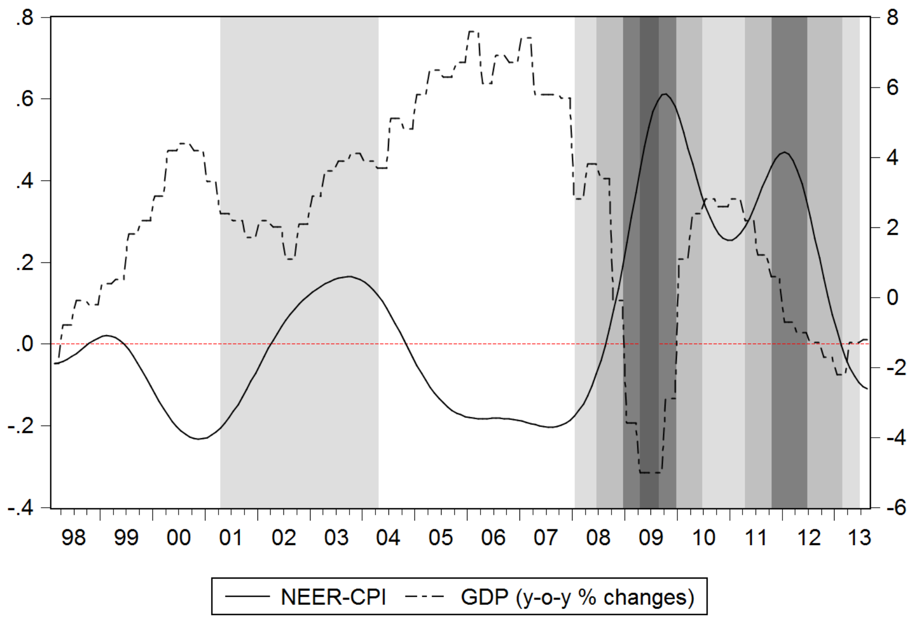
Notes: *df - degrees of freedom*. Putting it simply, the null hypothesis says that cointegrating vector is time-invariant whereas the alternative hypothesis suggest that some or all of the components of the cointegrating vector are linear combinations of m Cheybshev time polynomials.

Both time-varying dimensions of the NEER-CPI cointegrating vector were modelled and standardized so that one may focus solely on the behavior between the two variables (the same has been also done with the two latter cases). That is shown at Figure 4.8. The software used did not allow one to compute standard errors.[2] From the look on the given Figure 4.8 it is quite clear that the standard errors would be large. Moreover, since we deal with long-term concept it appears that the estimator suffer from lack of data and might be responsible for huge volatility in the NEER-CPI relationship.

Therefore, in order not to overemphasize the results it appears that the resulting pass-through fluctuates somewhere around 0 (in positive values) for most of the period. However, there is some interesting pattern that might be extracted. It seems that the pass-through tend to increase in less stable environment which is represented graphically by shaded areas in Figure 4.8. The effect of less stable environment is even more distinctive when focused on the period of recent financial crisis. Huge external negative demand shock hit the Czech economy the hardest at the end of 2008 which is also the time when the pass-through levels started to increase heavily and peaked somewhere around mid-2009. Then, the y-o-y GDP changes experienced return to positive numbers with peak on the verge of 2011 and pass-through inversely copied this development. However, as the year 2012 approached and Europe's banking system started to become unsustainable the y-o-y GDP changes started to plummit once more and consequently, pass-through started to increase with peak at early 2012. After that, y-o-y GDP changes did not vary that much and so pass-through levels continued their movement back.

[2] If time-varying methodology is being used, it is quite complicated to compute standard errors due to t-statistics that also vary. This is valid even more for absolutely new and unique method that is used here.

Figure 4.8: NEER-CPI long-term pass-through



Source: Author's calculations, Eurostat.

Notes: *NEER - nominal effective exchange rate, CPI - aggregate consumer price index, GDP (y-o-y % change) - year-on-year % GDP change (against the same quarter in previous year).* Shaded areas correspond to periods of certain macroeconomic slowdown and in case of darker areas even to macroeconomic downfalls. Left axis correspond to NEER-CPI relationship whereas right axis to GDP (y-o-y % changes). On horizontal axis the whole time period is presented. NEER-CPI curve corresponds to NEER dimension that is standardized due to CPI dimension in the cointegrating vector and the curve represents the long-term pass-through.

To some extent, the pattern that my results suggest may be considered as in line with Franta et al (2014) who found that NEER-CPI pass-through increased in late 2000s. Especially, around years 2008 and 2009 where the increase was the most apparent. Therefore, this striking evidence which has not been presented in many papers contradicts previous findings. It must be noted that previous papers did not cover the most interesting period from economic point of view - recent financial crisis. In this light, my thesis may become quite useful to monetary-policy authorities in the Czech Republic as it reveals possible change in pattern of NEER-CPI behavior when macroeconomic stability is uncertain.

Moreover, the claim that during macroeconomically less stable periods pass-through rises may be also confirmed in Sekine (2006) who finds that during oil crises at late 1970s and early 1980s the volatility and pass-through in 6 major industrialized countries has been substantially higher than in periods before or after. Then, there are two papers Shioji (2012) and Shioji (2014) by the same author. In both the author focuses on the case of pass-through in Japan. In the earlier one, he did not come to conclusions similar to mine (i.e. pass-through to domestic prices continued to decrease despite the recent financial crisis). In the latter one, however, he strongly argues that the pattern changed in favour of pass-through 'revival'. In other words, pass-through in Japan significantly increased in the latest years. There is one more very interesting aspect for comparison between the Czech Republic and Japan in the latest times but that will be discussed more in next section.

Even though we generally agree with Sekine (2006) and Bierens-Martins (2009) who suggest that pass-through is subject to gradual changes rather than to structural-break-type parameter shifts, we must also admit that the change in pass-through associated with recent financial crisis (considering its size, entire impact and unpredictability) could be considered as structural-break-type shift (as assumed by split sample estimations). As a consequence, it might be interesting to re-estimate the pass-through over the whole period with split samples given the special circumstances.

4.2.2 EUR/CZK-CPI

Weights of all currencies in the creation of NEER heavily depends on international trade. In the case of the Czech Republic, it is obvious that since roughly 70 per cent of total traded goods are traded with EU economies (Germany mostly) the weight of euro in the creation of NEER is substantially large. In this light, the relationship between bilateral exchange rate EUR/CZK exchange rate and CPI should be quite similar to the previous case.

Table 4.7 shows that time-varying nature of EUR/CZK-CPI relationship is also confirmed. Having in mind 5 per cent significance level, if number of Chebyshev polynomials included in the estimation is higher than 1 then null hypothesis of Bierens-Martins test is strongly rejected.

Table 4.7: Bierens-Martins test for EUR/CZK-CPI case

No. of Chebyshev time polynomials	Test statistic	10 per cent signficance level	5 per cent significance level	$\chi^2(df)$
m=1	5.39	4.61	5.99	2
m=2	11.32	7.78	9.49	4
m=3	11.92	10.64	12.59	6
m=4	25.55	13.36	15.51	8
m=5	28.89	15.99	18.31	10
m=6	49.63	18.55	21.03	12
m=7	56.02	21.06	23.68	14
m=8	72.08	23.54	26.30	16

Source: Author's calculations.

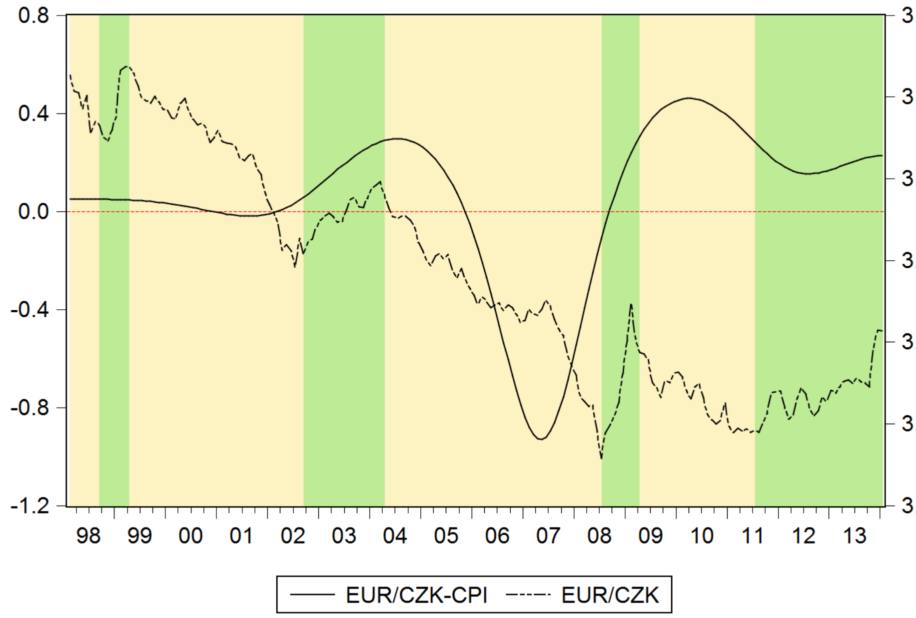
Notes: *df - degrees of freedom*. Putting it simply, the null hypothesis says that cointegrating vector is time-invariant whereas the alternative hypothesis suggest that some or all of the components of the cointegrating vector are linear combinations of m Cheybshev time polynomials.

Figure 4.9 shows the behavior of EUR/CZK-CPI relationship and the development of bilateral EUR/CZK exchange rate. Needless to say, for the reasons given above the impression of the estimated curve should not be overemphasized. As far as the pattern is concerned, it is to some extent similar to NEER-CPI case. Pass-through fluctuates somewhere in positive values close to 0 and in time of macroeconomically less stable periods it tends to rise, especially around 2009. After that it declined with bottom around mid-2012 and as the end of 2013 approached the curve started to rise slighlty again. On the other hand, extreme downfall in the relationship between the years 2006 and mid-2008 remains unexplained.[3] The Czech koruna continously appreciated to euro from the beginning of 2004 till mid-2008 and CNB (2008) claims that this appreciation was unnaturally strong (especially in the latter part of this period) with respect to development in the rest of the Czech economy. Even though it lies fairly behind the schope of this thesis, it would be interesting to see how would the results change after controlling for this unnaturally strong trend.

The other interesting aspect that could be extracted is possible asymmetry in reaction of pass-through to appreciation or depreciation. In general, prices are believed to be more rigid to downward movement and so the appreciation that creates pressure for prices to decrease have actually smaller absolute effect (due to rigidness) than depreciation which causes price increase rather easily. On the other hand, there are only a few papers studying this phenomenon in the Czech Republic. For instance, Mihaljek, Klau (2008) did not find any statistically significant results for asymmetric effects of pass-through. From the look on Figure 4.9, it appears that the reaction to strong appreciation during 2004 and mid-2008 is most probably smaller in absolute in comparison to much shorter period of sharp depreciation that happened on the edge between years 2008 and 2009 suggesting possible asymmetry. Needless to say, much further analysis is needed and that is left for the future.

[3] Though we were not able to come up with any reasons why pass-through should be negative, some papers also find that after employing time-varying methodology pass-through enters negative numbers in some periods. For instance, see the case of France in Sekine (2006).

Figure 4.9: EUR/CZK-CPI long-term pass-through



Source: Author's calculations, Eurostat.

Notes: *EUR/CZK bilateral exchange rate, CPI - aggregate consumer price index.* Green areas correspond to periods of depreciation of EUR/CZK (6-month-average starting in each quarter has been compared to previous 6-month-average given the room for either appreciation or deprication that would be lasting longer than 1 month) whereas yellow areas to appreciation. Left axis correspond to EUR/CZK-CPI relationship and right axis to logged EUR/CZK bilateral exchange rate. On horizontal axis the whole time period is presented. EUR/CZK-CPI curve corresponds to EUR/CZK dimension that is standardized due to CPI dimension in the cointegrating vecto rand the curve represents the long-term pass-through.

4.2.3 USD/CZK-CPI

In the latest case concerning relationship between bilateral exchange rate USD/CZK and aggregate CPI, the time-varying nature is confirmed even if only 1 Chebyshev polynomial is included. Table 4.8 provides the summary of the test.

Table 4.8: Bierens-Martins test for USD/CZK-CPI case

No. of Chebyshev time polynomials	Test statistic	10 per cent signficance level	5 per cent significance level	$\chi^2(df)$
m=1	11.03	4.61	5.99	2
m=2	16.69	7.78	9.49	4
m=3	29.65	10.64	12.59	6
m=4	36.53	13.36	15.51	8
m=5	48.89	15.99	18.31	10
m=6	49.39	18.55	21.03	12
m=7	56.12	21.06	23.68	14
m=8	72.29	23.54	26.30	16

Source: Author's calculations.

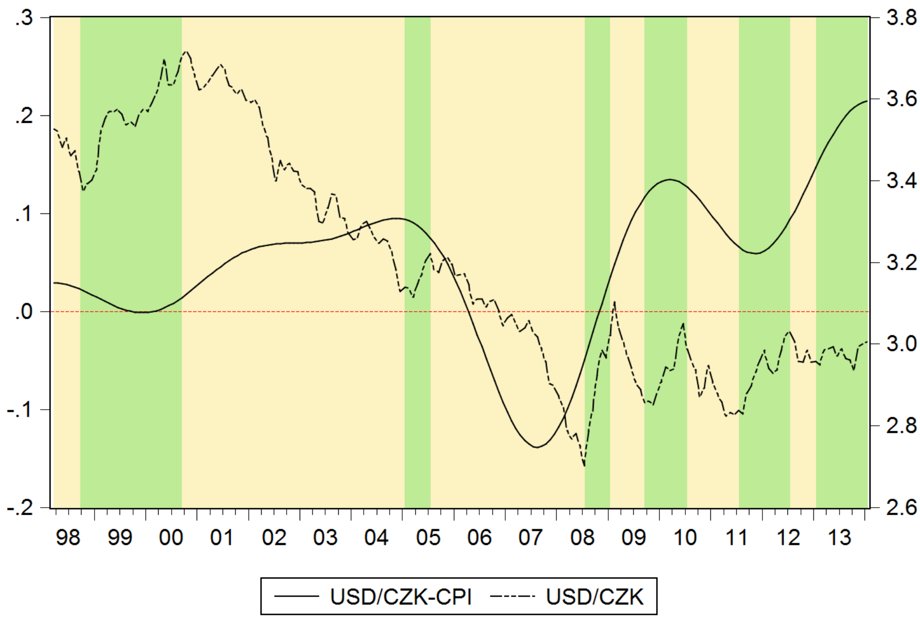
Notes: *df - degrees of freedom*. Putting it simply, the null hypothesis says that cointegrating vector is time-invariant whereas the alternative hypothesis suggest that some or all of the components of the cointegrating vector are linear combinations of m Cheybshev time polynomials.

The behavior of USD/CZK-CPI relationship and the development of bilateral USD/CZK exchange rate is depicted in Figure 4.10. The pattern of the behavior is almost identical to EUR/CZK-CPI case (neglecting actual values of the estimate). In the first half of the period the pass-through moves somewhere in positive values very close to 0 which lasts until early 2006 where the curve suddenly drops. In mid-2008 it gets back sharply peaking around end of 2009. After that it declines with bottom around early 2012 (as in previous two cases) and then it gets back to 2009-value and reaches maximum on the verge of 2014.

In this light, the premise that is being presented here concerning macroeconomically less stable periods is confirmed also in this case (while the movement in years 2006 and 2007 remains unexplained).

From the look on Figure 4.10, it is hard to somehow generalize the effects of appreciation or depreciation on the pass-through levels. As stated above, only deeper analysis may shed some light on possible asymmetry in the behavior.

Figure 4.10: USD/CZK-CPI long-term pass-through



Source: Author's calculations, Eurostat.

Notes: *USD/CZK - bilateral exchange rate, CPI - aggregate consumer price index.* Green areas correspond to periods of depreciation of USD/CZK (6-month-average starting in each quarter has been compared to previous 6-month-average given the room for either appreciation or deprication that would be lasting longer than 1 month) whereas yellow areas to appreciation. Left axis correspond to USD/CZKD-CPI relationship and right axis to logged USD/CZK bilateral exchange rate. On horizontal axis the whole time period is presented. USD/CZK-CPI curve corresponds to USD/CZK dimension that is standardized due to CPI dimension in the cointegrating vector and the curve represents the long-term pass-through.

5 CONCLUDING REMARKS

In the last chapter, possible implications of changed pattern of pass-through are breifly being discussed at first. Then, executive summary concluding the whole paper is presented.

5.1 'New' Monetary Policy Approach?

Case of Japan

As mentioned above, Shioji (2014) finds that pass-through in Japan increased in the latest years with no clear reasons for such increase. For some part, it is adressed in Shioji, Uchino (2011) who argue that change in structure of production costs may be the leading cause. We add another which is suggested by results presented here and that is macroeconomically less stable environment.

The reason why the case of Japan is mostly interesting for comparison with the Czech Republic is the reaction that monetary policy authorities used to counter-attack the problems of potential deflation.

In Japan, issues with deflation appeared almost two decades ago in time when Asian crisis appeared and it has remained as one of the most struggling areas for Japan ever since. In early 2000s, Japan continued somehow its way out of the deflation period towards brisk mornings but after 2008 the things took dramatic turn. Japan was severely hit as most of other industrialized economies and if the problem with deflation disappeared in mid-2000s (at least in minds of Japanese policymakers) it came back probably with even more disasterous effect (combined with the need for structural reforms, tsunami in 2011, etc.) as a vulture of financial crisis.

Another aspect that needs to be taken into consideration is that many industrialized economies found themselves at zero lower bound position due to the crisis. This means that monetary-policy authorities cannot go with interest lower than at current state (although for example the Taylor rule would suggest it) which calls for other tools to emerge in policymaker's hands. Quantitative easing, commitement to lower interest rate for longer period of time or foreign exchange interventions are some of those tools that many CBs used with regard to zero lower bound situation.

Consequently, newly mandated governor of Bank of Japan (BOJ) Haruhiko Kuroda declared a war to deflation and depreciation of Japanese yen oughted to be his 'white knight' in reaching the 2 per cent inflation target. Indeed, the speed of the yen's downfall was remarkable. The USD/JPY exchange rate jumped from 78 in September 2012 to 94 in February 2003 accounting in total for unbelievable 21 per cent decline in value. During the same period, euro strenghtened its position against yen by 26 per cent while the South-Korean Won by 24. After a rebound in mid-2003, it weakened once more in early 2014 attacking value of 104 in terms of USD/JPY.

What is, however, extremely important in estimating the final effect of depreciation on the price level is the effect on private-sector's inflation expectations. Only after this analysis, the final effect on price level can be estimated. Based on *Opinion Survey* conducted by BOJ presented in Shioji (2014A), frequently purchased items (such as food and gasoline for most part) seem to have dominant role in the creation of inflation expectations in Japanese private sector while the role of BOJ's monetary policy is tiny.

In this light, Shioji (2014A) estimates that if the exchange rate itself depreciates by about 3.631 logarithmic points in response to the exchange rate shock, the CPI increases by about 0.165 logarithmic points. So for instance, if the depreciation was about 0.25 logarithmic points, then the aggregate CPI should increase by 0.0114 log points. Findings in Shioji (2014A) suggest the depreciation of yen (as it was experienced in latest two years) would account for about a half of the effect that would be needed for hitting the inflation target of 2 per cent. Whether or not this effect is sustainable and to what extent it could be labelled as effective in terms of Japan we leave for others to discuss. The main message from our part is that due to change in pattern (suggesting higher pass-through) monetary policymakers have a 'new' tool to defy the deflationary situation with zero lower bound at their diposal.[1]

Implications for the Czech Republic

In early November 2013, CNB declared currency interventions that will lead to depreciation of koruna from initial EUR/CZK value around 25.7 to targeted value somewhere around 27. In time of finishing of this thesis, the EUR/CZK exchange rate fluctuated mostly around value 27.5 which in turn accounts for roughly 7 per cent depreciation. In terms of USD/CZK it was more or less similar from average values around 18.8 to 20 which is again roughly 7 per cent.

[1] In order not to be mistaken, we are well aware of the fact that every monetary policy decision as extreme as this one comes at certain costs and they are obviously not negligible. There is always trade-off and it heavily depends on the given point of view. Moreover, such movement may negatively encourage the temptation of other economies to do the same and the worst situation resulting from this 'new' monetary policy approach could be currency wars. Note: the term 'new' is used in a sense that of course it was possible to intervene in similar manner in years before but now (as the results suggest) it has become much more effective than in years before.

As stated above, from the look on Figures 4.9 and 4.10 it is obvious that at the end of the year 2013 the long-term pass-through continued to rise and in the time of interventions it accounted for 0.22 and 0.21 in EUR/CZK-CPI and USD/CZK-CPI case, respectively.[2] Considering 7 per cent depreciation, the total effect transmitted to consumer price level should be around 1.5 per cent increase. Combined with rising prices for energy and health care payments at the customer's side, CNB's goal of hitting the 2 per cent inflation target (and thus avoiding deflation) is more likely to be achieved now.

However, this implication is very limited and included only for illustrative purposes since the time-varying results we got cannot be strictly taken (having in mind unknown and possibly quite huge confidence band). Moreover, we should mention two other things jeopardizing this illustration. First, even though short-term pass-through VAR estimation is not available for bilateral exchange rates EUR/CZK and USD/CZK, VAR results using NEER (i.e. 40-60 per cent accummulated response to CPI after 18 months) suggest that this 7 per cent depreciation would cause most probably even bigger increase in the price level. Second, subsection 4.1.2 shows that NEER pass-through to tradables price index (food only) increased extremely. In a sense of Shioji (2014A) where frequently purchased goods (like food) have dominant role in inflationary expectations, the growing importance of food prices might have non-negligible implications for overall pass-through levels. This could be also mentioned with regard to the link between expected, perceived and actual inflation. In a consequence, only further research enable us to decide how influential these implications really are.

5.2 Executive Summary

In this thesis, we studied the exchange rate pass-through phenomenon in the Czech Republic over 1998:1-2014:1 period. The main goal was to update the study of Babecka (2009) and extend the analysis by employing unique time-varying methodology which uses Chebyshev time-polynomials as a proxy for Johansen's cointegration vector that is in this sense allowed to vary over time.

The motivation for writing this thesis can be viewed from two policy-relevant perspectives. First, although the official date for adoption of euro has not yet been announced the policymakers should constantly pay close attention to underlying relationship between prices and exchange rate. This claim is even more valid with regard to catching up process (especially in the first part of the examined period) which incorporated continuous pressures on real exchange rate appreciation. In this light, finding the balance between the mandate of CNB monetary policy (price stability) and creation of macroeconomic environment that

[2] NEER-CPI case is not included in this part because the period did not cover the 2013 interventions. In our humble opinion, if the period covered also the 2013 interventions, the results would look quite different at the very end of the examined period (i.e. more similar to EUR/CZK-CPI and USD/CZK-CPI cases).

positively motivates producers to export their goods via favourate exchange rate development is key. Second, complete impacts of recent financial crisis and its links on the behavior of macroeconomic variables remains to be ciphered for economists, to some extent. Therefore, in order to better understand macroeconomically less stable periods and consequences they tend to imply, it seems viable for economists to re-open the discussion about exchange rates and their role in monetary transmission. This is supported also by the most recent empirical findings suggesting exchange rate regained some of its rather historical importance when it comes to transmission of the effect to prices.

As our results indicate, short-term pass-through slowed down substantially and is characterized by less agressive peak as opposed to previous findings. At the same time, however, the effect prolongated its duration which of course increases the total amount to be transmitted. The peak generally occurs somewhere between 4 to 11 months after the initial shock. The vast majority of the accumulated effect is then transmitted in first 12 to 18 months.

Estimation using 3 out of 5 price indices (considered in total for the analysis) provides significant results. In case of aggregate CPI, the peak impulse response accounts roughly for 3-4 per cent whereas 40-60 per cent is transmitted in total after 18 months. As one would expect, the reaction of price index for all tradable goods is much faster peaking somewhere around 4th or 5th month after the initial change. What one would not expect is the maximum size of peak impulse which is only 1 per cent with 6-7 per cent transmitted after 12 months in total. This goes clearly against our expectations and one may hardly find any explantion for such result. The logic is of course that prices of traded goods are the ones mostly affected by changes in exchange rate. Favourably, this logic appeared to be valid when price index for tradable food items is used. Maximum impulse response accounts on average for 9 per cent appearing around 9th month. Suprisingly, total amount to be transmitted after 18 months moves towards 100 per cent suggesting the nature of pass-through to food prices is of complete nature. To some extent, huge differences in estimated effects may be attributed to wide confidence bands and consequently, need to be taken into account while comparing the results.

From empirical point of view, our short-term results indicate that overall pass-through in the Czech Republic increased which goes against much of the papers published before. On the other hand, the findings published in the last 1-2 years support our outcomes suggesting a possible change in the pattern. In this light, our time-varying results points to period 2008-2014 to be the leading cause. It seems that during macroeconomically less stable periods the pass-through in the Czech Republic tend to increase. This new pattern in the behavior is confirmed regardless the type of exchange rate (nominal effective, bilateral EUR/CZK or USD/CZK) used for estimation which provides slightly wider support for our conclusions.

Therefore, consequences implied by our results may have non-negligible impact on the decision-making of monetary policy authorities in situation of zero lower bound. This statement is even more relevant if we put together outcomes suggested by this thesis and the very latest (and to some extent even surprising) unconventional measures employed by CNB. By those are meant of course the November' currency interventions that devalued the Czech koruna by roughly 7 per cent in its relationship against euro and the US dollar. CNB claims the reason for these interventions was the imminent threat of deflation. Having in mind our results, this measure seems to become much more effective in the latest years than in the rest of the period. To some extent, this justifies the choice of CNB for 'new' monetary policy approach as well as its timing, given the circumstances.

As mentioned before, the link between perceived, expected and actual inflation plays also a significant role while presenting implications of our results. Even though not much attention has been payed to this role, the case of Japan where prices of frequently purchased items (such as food and oil) pretty much predetermine the value of actual inflation (via expectations of private sector) may be a good example. In this sense, short-term results of substantially higher pass-through in the Czech Republic when price index for tradable food items is used might put exchange rate to a position of even more effective tool for the Czech monetary policy compared to estimation based solely on aggregate CPI.

On a different note, this paper and its conclusions incorporate many limitations and need to be treated with respect to such conditions. At the same time, it opens room for further research. Although there are many ways how one can extend this analysis, we see potentially four major directions. First, disaggregate data. The use of disaggregate data seems to have non-negligible impacts on final results and may actually explain the logic behind certain signals that bigger picture based on aggregate data estimation simply cannot provide. That applies mainly to the reasons why pass-through increased in the latest years. Second, the impact of recent financial crisis on the structure of the economy is simply too great. One can hardly guess to what extent the crisis is gone (and therefore the period of macroeconomically less stable environment would be over) and to what extent the heritage of the crisis will remain present. In this light, the future methodology chosen must reflect on these huge structural changes and learn how to cope with them or even to create new framework for the estimation. Following up on that, the estimation of pass-through in the framework of dynamic stochastic general equilibrium model might be a viable solution. Third, even though it has not been proven to our knowledge yet, one could pay closer look to possible asymmetries in the reaction of prices to exchange rate changes within the Czech monetary transmission. Fourth, whether findings suggested by this thesis will be confirmed by studies for other countries as well remains yet to be seen. Within cross-country studies, one could focus on the link between exchange rate regime and final pass-trough as it may also shed some light on the monetary transmission.

6 BIBLIOGRAPHY

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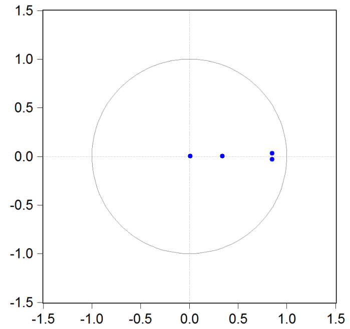
Note: For some links it is needed google.scholar access via Charles University login: http://ri.ms/Scholar.

7 APPENDIX A

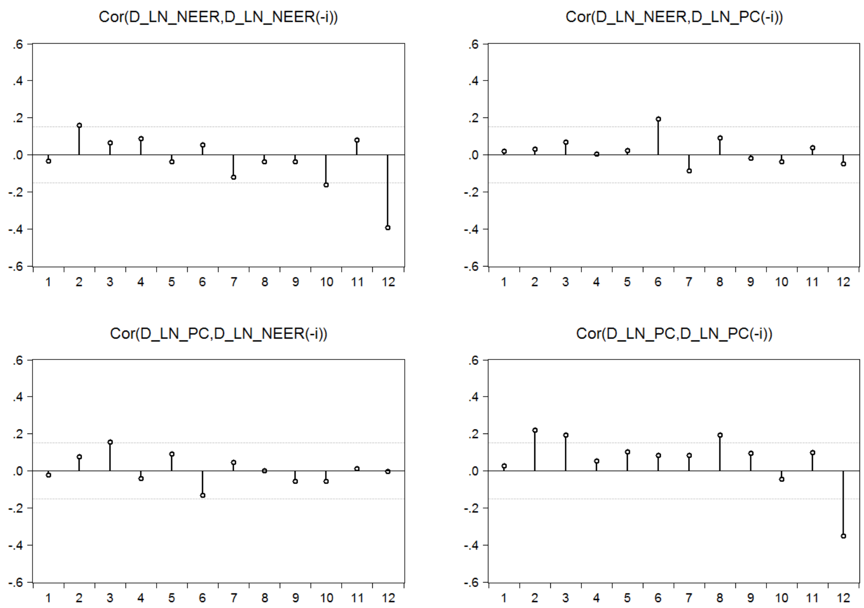
VAR: Detail Case

Figure 7.1: VAR stability



Source: Author's calculations.

Figure 7.2: Correlogram of residuals



Source: Author's calculations.

Notes: PC - aggregate CPI, NEER - nominal effective exchange rate. Graphs show autcorrelations up to 12th lag. Two gray horizontal lines represent standard errors bounds.

Table 7.1: Lag selection criteria

Lag	AIC	SIC	HIC
0	-9.120	-9.046	-9.090
1	-12.947	-12.798*	-12.886
2	-12.997	-12.774	-12.906*
3	-13.019*	-12.721	-12.899
4	-13.010	-12.639	-12.860
5	-12.991	-12.545	-12.810
6	-12.957	-12.436	-12.746
7	-12.948	-12.353	-12.706
8	-12.939	-12.270	-12.668

Source: Author's calculations.

Notes: AIC, SIC, HIC - Akaike, Schwarz, Hannan-Quinn information criterion, respectively. * indicates lag order selected by the criterion.

Table 7.2: Lag exclusion test

	S	PC	Joint
Lag 1	200.774	181.732	380.459
	(0.0000)	(0.0000)	(0.0000)
Lag 2	9.394	6.119	14.683
	(0.0091)	(0.0469)	(0.0054)
df	2	2	4

Source: Author's calculations.

Notes: s - exchange rate, PC - aggregate CPI, df - degrees of freedom. Figures in rows Lag represent χ^2 test statistics for lag exclusion with respective p-values in (.) in rows underneath.

Table 7.3: Normality of residuals in VAR model

Component	Skewness	χ^2	df	p-value
1	-0.0311	0.0281	1	0.8669
2	0.5652	9.2651	1	0.0023
Joint		9.2932	2	0.0096

Component	Kurtosis	χ^2	df	p-value
1	3.1866	0.2525	1	0.6153
2	7.1395	124.23	1	0.0000
Joint		124.49	2	0.0000

Component		Jarque-Bera	df	p-value
1		0.2806	2	0.8691
2		133.50	2	0.0000
Joint		133.78	4	0.0000

Source: Author's calculations.

Notes: df - degrees of freedom.

Table 7.4: Homoscedasticity of residuals in VAR model

χ^2	df	p-value
47.232	30	0.0236

Source: Author's calculations.

Notes: df - degrees of freedom.

VAR: Summary

Table 7.5: Summary: VAR stability

VAR No.	PC	PC-TT	PC-TF	PC-TO	PC-NT
1	0.9384	0.9280	0.9438	0.9497	0.9332
2	0.9438	0.9477	0.9452	0.9508	0.9533
3	0.9147	0.9250	0.9235	0.9562	0.9508
4	0.9156	0.9225	0.9193	0.9671	0.9219
5	0.9312	0.8803	0.9297	0.9494	0.8814
6	0.9769	0.9746	0.9658	0.9764	0.9818
7	0.9271	0.9045	0.9354	0.9659	0.9495
8	0.8534	0.8402	0.8784	0.9422	0.9437
9	0.9297	0.9139	0.9353	0.9650	0.9441
10	0.8745	0.8180	0.8642	0.9418	0.9448
11	0.9308	0.9097	0.9296	0.9457	0.9279

Source: Author's calculations.

Notes: PC - aggregate CPI, PC-TT - consumer prices for tradables, PC-TF - consumer prices for food only, PC-TO - consumer prices for other tradables, PC-NT - consumer prices for non-tradables. Figures represent the modulus of the root closest to the unit circle boundary. If the number would be higher than 1, it means that VAR is not stationary.

Table 7.6: Summary: Normality of residuals in VAR models

VAR No.	PC	PC-TT	PC-TF	PC-TO	PC-NT
1	0.0000*	0.3803	0.0044*	0.0000*	0.0000*
2	0.0000	0.0025	0.0020	0.0000	0.0000*
3	0.0000*	0.0350*	0.0030*	0.0000*	0.0000*
4	0.0000*	0.0512	0.0035*	0.0000*	0.0000*
5	0.0000	0.8045	0.0245*	0.0000*	0.0000*
6	0.0000	0.2962	0.0079*	0.0000*	0.0000*
7	0.0000	0.0001*	0.0001*	0.0000*	0.0000*
8	0.0000	0.0809	0.0039*	0.0000*	0.0000*
9	0.0000	0.0002*	0.0000*	0.0000*	0.0000*
10	0.0000	0.0271*	0.0010*	0.0000*	0.0000*
11	0.0000	0.0001*	0.0001*	0.0000*	0.0000

Source: Author's calculations.

Notes: PC - aggregate CPI, PC-TT - consumer prices for tradables, PC-TF - consumer prices for food only, PC-TO - consumer prices for other tradables, PC-NT - consumer prices for non-tradables. Figures in the table represent p-values of Jarque-Bera VAR residual normality test (orthogonalization: Cholesky). In cases denoted by * the rejection of normality on jointly basis comes from having different kurtosis than normal (i.e. platycurtic or leptocurtic). At the same time residuals in these models were not found to be skewed.

Table 7.7: Summary: Homoscedasticity of residuals in VAR models

VAR No.	PC	PC-TT	PC-TF	PC-TO	PC-NT
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0020	0.0002	0.0011	0.0019	0.0005
4	0.0025	0.0003	0.0022	0.0009	0.0013
5	0.0000	0.0002	0.0012	0.0018	0.0004
6	0.0001	0.0007	0.0027	0.0019	0.0008
7	0.0003	0.0011	0.0109	0.0024	0.0001
8	0.0236	0.1184	0.1583	0.1817	0.0095
9	0.0005	0.0028	0.0028	0.0043	0.0001
10	0.0420	0.1650	0.2867	0.2945	0.0791
11	0.0000	0.0000	0.0002	0.0045	0.0000

Source: Author's calculations.

Notes: PC - aggregate CPI, PC-TT - consumer prices for tradables, PC-TF - consumer prices for food only, PC-TO - consumer prices for other tradables, PC-NT - consumer prices for non-tradables. Figures in the table represent p-values of VAR residual heteroscedasticity tests with no cross terms (only levels and squares).

TVC: Summary

Table 7.8: Double-checking on validity of other 'possibly-cointegrating' vectors

NEER-CPI	ADF	KPSS	PP
$(-1; 1)$	0.2305	1.0961	0.1914
$(-0.5; 1)$	0.8483	1.2013	0.8162
$(-0.8776; 0.75)$	0.2986	1.3321	0.2456
$(-0.8776; 0.5)$	0.4171	1.4515	0.3442

CZK/EUR-CPI	ADF	KPSS	PP
$(0.75; 0.7512)$	0.1911	0.7328	0.2535
$(0.5; 0.7512)$	0.6684	0.8239	0.7795
$(1; 0.5)$	0.3436	1.4466	0.2913
$(1; 1)$	0.1913	0.7377	0.2532

CZK/USD-CPI	ADF	KPSS	PP
$(0.75; 1)$	0.4015	0.9354	0.4561
$(0.25; 1)$	0.6724	1.0946	0.7462
$(0.4562; 0.5)$	0.4605	1.1014	0.5022
$(0.4562; 0.75)$	0.3280	0.6674	0.3983

Source: Author's calculations.

Notes: CPI - aggregate consumer price index, NEER - nominal effective exchange rate, CZK/EUR - bilateral exchange rate of Czech koruna against euro, CZK/USD - bilateral exchange rate of Czech koruna against US dollar. In ADF and PP columns there are presented p-values with lags chosen due to AIC and SIC. However, in KPSS column is presented LM-statistic which has to be compared with 0.739, 0.463 and 0.347 representing 1, 5 and 10 per cent significance, respectively.

Table 7.9: Johansen's cointegration test for TVC models

Max. Eigen.	NEER-CPI	CZK/EUR-CPI	CZK/USD-CPI
0	24.1	30.1	21.0
1	4.6	3.6	4.1

Trace	NEER-CPI	CZK/EUR-CPI	CZK/USD-CPI
0	28.7	33.7	25.2
1	4.6	3.6	4.1

Source: Author's calculations.

Notes: CPI - aggregate consumer price index, NEER - nominal effective exchange rate, CZK/EUR - bilateral exchange rate of Czech koruna against euro, CZK/USD - bilateral exchange rate of Czech koruna against US dollar. Numbers in the left column represent the number of cointegrating relationships tested in each test (i.e. Max. Eigenvalue or Trace test). Test outcomes are t-statistics and has to be compared with relevant borders of 20, 10 and 5 per cent significance level. For no cointegrating relationships (r=0) in Max. Eigenvalue Test: 11.6, 13.8 and 15.8 for 20, 10 and 5 per cent significance, respectively. For no cointegrating relationships (r=0) in Trace Test: 15.4, 18.0 and 20.2 for 20, 10 and 5 per cent significance, respectively. For 1 cointegrating relationship (r=1) in both tests: 5.9, 7.6 and 9.1 for 20, 10 and 5 per cent significance, respectively.

Table 7.10: Validity of Johansen's test

	NEER-CPI	CZK/EUR-CPI	CZK/USD-CPI
Test statistic	3.82	3.10	3.24

Source: Author's calculations.

Notes: CPI - aggregated consumer price index, NEER - nominal effective exchange rate, CZK/EUR - bilateral exchange rate of Czech koruna against euro, CZK/USD - bilateral exchange rate of Czech koruna against US dollar. Table concludes the outcomes of the LR test of the null hypothesis that the imposed restricitions on the intercept parameters in Johansen's test hold. Asymptotic null distribution: $\chi^2(1)$. Test stastic has to be compared with 2.71 and 3.84 which correspond to 10 and 5 per cent signficance, respectively. If the null hypothesis is rejected at 5 per cent significance level, the test results regarding the number of cointegrating vectors are invalid.

8 APPENDIX B

There is a CD enclosed to this thesis which contains empirical data, workfiles for Eviews (where all specified VAR models are saved) and detailed outcomes of estimation and various testing.

- Folder 1: Data and Eviews workfiles
  - Folder A: Data
    - Folder A: VAR
    - Folder B: TVC
  - Folder B: Eviews workfiles
    - Folder A: VAR
    - Folder B: TVC
- Folder 2: VAR (testing and estimation)
  - Folder A: Preliminary testing
    - Folder A: Stationarity
    - Folder B: Cointegrating relationships
  - Folder B: Results and after-testing
- Folder 3: TVC (testing and estimation)
  - Folder A: Preliminary testing
  - Folder B: Results and after-testing