Essays on Empirical Economics

Economic Policies and their Working on the Aggregate Economy and Various Industries

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This dissertation is submitted for the degree of

Doctor of Philosophy

September 2018

To my family for their never-ending support during my studies
and for the love which give me throughout life.

The whole of science is nothing more
than a refinement of everyday thinking.

Albert Einstein

Cogito ergo sum.

René Descartes

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements.

Martin Gürtler
September 2018

Acknowledgements

At this place I would like to kindly acknowledge the people, who directly or indirectly contributed to the completion of the thesis. At first, thesis supervisor Prof. Ing. Lukáš Čechura, Ph.D. deserves great gratitude for his helpful, encouraging and friendly attitude, which provided me an indispensable support during the whole time of thesis preparation. I mainly appreciated his faith to enable me to work on my own research and to specialize in loved areas of macroeconomics and econometrics. I would also like to recognize Prof. Ing. Miroslav Svatoš, CSc., head of the Department of Economics, as he gave me a chance to be a part of the department and to gain an experience in teaching, what I really enjoyed. Many thanks go as well to other members of the Department of Economics, because they formed stimulating and pleasant environment, where it was a pleasure to work. At the same time, I must mention the students attending my courses in econometrics, when their challenging questions frequently forced me to view things differently. Outside academia, it has been a fortune and privilege for my professional life to receive a position in the Czech National Bank. To work in the Czech National Bank, one gets an opportunity to be in a close relation with everyday working of national and global economy – must to have experience for every serious macroeconomist. Within this institution, I was present at many interesting and inspiring discussions with highly educated and experienced colleagues. Regarding that, I am grateful to the colleagues from Monetary Department and from Macroeconomic Forecasting Division in particular. Lastly but the most intensively, I would like to say thank you to my family, who emphasized the role of education since my childhood and supported me in everything what I have done.

Abstract

Thesis deals with selected macroeconomic issues of the Czech economy. There are three researched areas, namely demand for money, exchange rate pass-through, and business investment behavior. All the questions are answered on the basis of results of the econometric models estimation, when both frequentist and Bayesian models are used. We strive not only for explanations on the aggregate macroeconomic level, but we want to give a microeconomic view into the researched areas. Consequently, granular data are often employed. Data samples variably cover the last two decades of the Czech economic development. Regarding the results of money demand investigation, we realize that the speculative demand plays a crucial role for the evolution of overall money demand. Transactions demand for money seems to be saturated and it does not significantly depend on the level of economic activity. Limited importance have the precautionary savings, which exhibit positive link to the business cycle. With respect to exchange rate pass-through, the thesis observes reaction of the trade balance to a change in exchange rate. In particular, it is the question if depreciated Czech koruna induces a trade balance dynamics resembling the J-curve. The answer is yes for the aggregate economy and also for some industries. Weakening of the exchange rate can be an effective policy tool in order to support the economy. We at the same time propose better practices for a future research into the J-curve phenomenon. Factors influencing the Czech business investment are researched in the last part of the thesis. The survey including 30 thousand non-financial corporations serves as a base for the research. Also in this case, the research is conducted both for the whole non-financial sector and for selected industries. The main driver of Czech business investment is foreign demand. It is followed by the working of real exchange rate and real interest rate. In some specific periods of economic development, there could also be present important effect of government investment and EU funds. Government investment crowds out business investment on the aggregate level, but it was also observed crowding in for some industries. Interaction of monetary and fiscal policy probably stands behind the crowding out.

Abstrakt

Disertační práce se zabývá vybranými oblastmi fungování české ekonomiky. Zkoumána je přitom poptávka po penězích, vliv měnového kurzu na stav výkonové bilance a chování soukromých investic. Veškeré závěry této práce jsou založeny na odhadech ekonometrických modelů, a to jak modelů frekventistické, tak i Bayesovské povahy. Cílem je vysvětlit zkoumané ekonomické jevy jak na úrovni celé agregátní ekonomiky, tak i poskytnout desagregovaný vhled do dané problematiky. V důsedku toho jsou využita data s velkým množstvím pozorování, známá také jako big data. Zkoumané období odpovídá zhruba posledním dvěma dekádám ekonomického vývoje v České republice. Na velikost poptávky po penězích má zásadní vliv spekulační poptávka. Transakční poptávka vykazuje známky saturace a její velikost nezávisí na výši důchodu. Omezený vliv má také poptávka z opatrnostního motivu, která pozitivně koreluje s vývojem hospodářského cyklu. V rámci vlivu měnového kurzu na stav výkonové bilance je zkoumán především vliv kurzového znehodnocení. Otázkou je, zda reakce výkonové bilance na kurzové znehodnocení odpovídá tzv. J křivce. Výsledky disertační práce tento typ přizpůsobení potvrzují. Měnový kurz je tak stále efektivním nástrojem měnové politiky. V disertační práci jsou rovněž identifikovány problematické oblasti dosud prováděného výzkumu J křivky a zároveň jsou navržena možná vylepšení. Chování soukromých investic je dáno do souvislosti s vývojem množiny makroekonomických proměnných. Základem pro výzkum soukromých investic jsou data ze statistického šetření mezi třiceti tisíci nefinančních podniků. Výsledky jsou prezentovány jak pro celý nefinanční sektor, tak také pro jednotlivá odvětví. Z výsledků vyplývá, že nejvýznamnější proměnnou ovlivňující vývoj soukromých investic je zahraniční poptávka. Ve významu ji pak následuje reálný měnový kurz a reálná úroková sazba. V určitých obdobích ekonomického vývoje může mít také významný vliv velikost vládních investic a objem čerpaných fondů EU. Vládní investice přitom na makroekonomické úrovni vytěsňují investice soukromé, existují však také odvětví s pozitivním vlivem vládních investic. Nejpravděpodobnější vysvětlení vytěsňovacího efektu vládních investic je interakce měnové a fiskální politiky.

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1 Introduction

1.1 Motivation

Thesis emerged as a result of our effort to provide advanced data-based analysis of the issues permeating the Czech economy. We chose the areas which have deserved less or even no attention in the last two decades and therefore, the results should be a novel information about the behavior of the Czech economy. The last two decades were also the basis for the econometric model estimation. In every aspect we strove for practical implications of the results and so we hope that they could be beneficial for the Czech economic policy. Although there were researched mainly macroeconomic questions, we frequently solved them on microeconomic basis. We believe that this approach can bring about a deeper insight into the researched areas and is also in accordance with the definition of modern macroeconomy built on the interaction of optimizing agents. As a result, we often used the dense data sets. From a methodological point of view, time series econometrics served as a common workspace for all presented analyzes. Both frequentist and Bayesian models were used.

1.2 Structure of the thesis

There are three topics analyzed in the thesis. First topic is the demand for money, or for real money balances in the Czech Republic. As it is mentioned in the section 2.1, only two studies in this area were available to this day for the Czech Republic. Moreover, both are outdated and built on unreliable data sets. We therefore propose up-to-date analysis based on a reliable data set. Although the money demand became less important due to an enlargement of inflation targeting in advanced economies, it still remains an integral part of monetary transmission. It holds for both conventional and unconventional monetary policy; see the section 2.1 and the section 2.3 respectively. It is consequently a good reason to estimate the parameters of money demand function and establish the operability of monetary policy. The second reason to not resign on research into the money demand is the fact that the money also acts as an asset. It should thus be beneficial to determine its role in the investment portfolio of Czech households and firms. In order to explain the demand for real money balances, time series of real aggregate production, interest rate, unemployment rate and real effective exchange rate were employed. Justification for the inclusion of these variables to the research is based on a theoretical model stated in the section 2.1. Linkages among the time series are then elaborated through the vector error correction model and analyzed further by the generalized impulse responses and Granger causality tests. See the chapter 3 for a complex review of the methodology used in the thesis. Results of the money-demand investigation are included in the section 4.1.

The second topic concerns the exchange rate pass-through. In other words it takes into account the influence of exchange rate depreciation (and implicitly also of its appreciation) upon the Czech trade balance. Studies of such type are also known as the J-curve investigation or as a verification of the Marshall-Lerner condition. Despite a large amount of empirical research studies on a diverse set of economies over the world, the Czech Republic has been neglected so far; see the section 2.2. It holds for both macroeconomic and microeconomic studies. Yet, knowledge about the exchange rate pass-through is important for the Czech economy. Czech Republic still remains outside the Eurozone and exchange rate can still be used as a monetary policy tool. Actually, it was really used by the Czech National Bank as an unconventional measure in the situation when the zero lower bound on nominal interest rates began to be binding; see the section 2.3 and 2.4. Because of the openness of the Czech economy, fluctuations of the exchange rate of the Czech koruna can work strongly upon the performance of Czech exports. There is therefore a permanent need to consider the usefulness of exchange rate as a stabilization policy tool, or to consider the extent to which the exchange rate fluctuations can be a source of external shocks for the economy. It could also add some information for the decision about the entrance of the Czech Republic to the Eurozone. Beside the influence of exchange rate on the trade balance, there are also regarded the consequences of domestic and foreign economic growth for the structure of Czech foreign trade. Relevancy of intertemtemporal substitution in international trade is evaluated as well. Currently prevailing methodology for the J-curve investigation is the conditional error-correction modeling and the bounds testing for cointegration, what we generally follow; see the section 3.7. But, because we found some practices of past research as inadequate, we propose a better way, at least from our view, how to identify the J-curve phenomenon from data. It also includes a new definition of the impulse response analysis; see the section 4.2.3. Results of the investigation on aggregate or macroeconomic level could be found in the section 4.2. As indicated in the motivation, we did not satisfy with the results on aggregate level. Therefore, the trade with thirteen foreign-trade partners and the trade of fifty-eight industries were entertain and the results are stated in the section 4.3. Consequently, we are able to say who benefits from a weakening of the Czech koruna and who loses from it. Finally, we also consider if the zero-lower-bound economy described in the section 2.3 and 2.4 induces a structural change in the sense of Lucas critique; see the section 4.3.

Last researched topic covers the field of business investment behavior. Actually, we are searching for the link of business investment to its possible macroeconomic covariates. No similar study can be found for the Czech Republic. The discussion about business investment in the Czech Republic was thus rather ideological until this moment, when it lacked any data evidence. We took this research shortage seriously. As a result, we offer the investigation based on the survey among 30 thousand Czech non-financial corporations. Regarding macroeconomic covariates, we assessed the role of foreign demand, interest rate, economic sentiment, real effective exchange rate, government investment and the EU funds. Reasoning behind the decision to include a particular variable is mentioned in the section 2.5. Based on the results, which you will find in the section 4.4, we are able to classify the covariates according to their empirical importance. It could be helpful for the construction of models serving for economic analysis and forecasting. Measuring the effect of interest rate and real exchange rate on business investment, we can evaluate a power of monetary policy to support or dampen the firm sector of the economy. We can also say if the government investment crowds out business investment, as economic theory instructs. Finally, the conclusion could be made about the extent the private firms use the EU funds to finance their own investment projects. All are crucial questions which have remained unanswered so far. In order to accomplish the analysis, Bayesian VAR models are used; see the section 3.8.

1.3 Goal and particular research questions

The goal of the thesis is to present the results of investigation into the selected areas of the Czech economy. Namely, the demand for money, the exchange rate pass-through to the trade balance, and the business investment behavior are the topics under the study. While the topics have macroeconomic substance, we mostly strive for their solution on the microeconomic level – specifically on the level of individual industries. There is therefore a strong appeal to the heterogeneity in the economy and to the distributional aspects (wealth effects) of economic policy. Consequently, the results should be much more descriptive than is usual for macroeconomic studies and should contain more information for policy-decision makers.

The overall goal can be split into the 12 specific questions that the thesis aims to answer:

1. What factors determine the demand for money? What is the relative importance of transactions and speculative demand for money?

2. Does the behavior of money demand depend on its particular definition through the monetary aggregate?

3. Does the precautionary savings go in line or against the business cycle?

4. Does the trade balance adjustment to exchange-rate depreciation correspond to the J-curve? Does the adjustment vary with the expectations of private agents?

5. Who benefits from exchange-rate depreciation and who loses?

6. Is the exchange rate still effective tool of monetary policy?

7. What are the consequences of domestic and foreign economic growth for the structure of Czech foreign trade?

8. Is there a space for the working of intertemporal substitution in the current setting of international trade and international monetary system?

9. What stands behind the decision about new business investment? How the Czech industries differ in their reaction to different economic shocks?

10. Could the government investment crowd out private investment?

11. Does the monetary policy have a power over the business investment via the interest rate and the exchange rate?

12. Does the uncertainty play increasing role in the decision about a new investment?

2 Literature review

2.1 Demand for money and savings

Demand for money, or for the real money balances, is integral part of monetary theory. Yet its role in current setting of monetary policy diminished due to a broad acceptance of money endogeneity and to the enlargement of inflation targeting regime. Upon the money endogeneity, money supply adjusts to the demand and therefore contradicts the neoclassical theory based on Say's law. Nowadays, the commercial banks are crucial in the creation of a new money as they provide a credit. Modern money balances are credit based. As a consequence, the central banks have a little power over the money stock in the economies of today. Therefore, the central banks decided to leave the monetary targeting and began to target the agents' expectations – and indirectly also to target the demand for credit and so the demand for money. Through the continuous modification of market expectations, central bank strives to achieve the inflation target (main goal of central banks in most of advance economies) and to promote an intended rate of economic growth. It depends on its credibility, how it will be successful.

The above resulted to the situation, when the money demand studies have been replaced by econometric estimations of the central-bank reaction function or by the search for its optimal parameters. See Galí (2008) and Woodford (2003) for the exposition of New Keynesian theory providing a framework for the state-of-the-art monetary policy. Nevertheless, importance of the money demand was not totally eliminated by a switch to the inflation targeting regime – it remains a part of monetary transmission (for both conventional and unconventional monetary policy[1]). For instance, operability of the open market operations places some constraints on the parameters of money demand function.

In the case of the Czech Republic, no empirical work regarding the demand for money has emerged since 2000. From preceding articles the two can be mentioned, namely Arlt et al. (2001) and Hanousek and Tůma (1995). Paradoxically, the period of these investigations is the most problematic. Arlt et al. (2001) use the data from 1994 to 2000, Hanousek and Tůma (1995) from 1991 to 1994. It can be expected that the parameter instability

[1]See the section 2.3.

is very real, because the Czech economy witnessed many structural changes in this period.[2] The structural changes were induced by the transformation process from a central-planned to market-oriented economy. The first half of 1990s is the most contentious (including currency separation in 1993, among others), when the effect of getting acquainted with an environment of market economy was strong. Notice that both Arlt et al. (2001) and Hanousek and Tůma (1995) were aware of this threat.

Deriving theoretical assumptions for the research, we depart from the quantity theory of money represented by the quantity equation

$$M \times V = P \times Y \tag{2.1}$$

where M stands for the money supply, V is the income velocity of money, P is the aggregate price index and Y represents the real production or income. The Y also forms a proxy for the number of transactions in the economy.[3] Equation (2.1) acts as a cornerstone of neoclassical macroeconomics, when it introduces the money into the exchange of goods and services; money acts as a medium of exchange and the unit of account (numéraire).[4] Upon the assumptions of neoclassical theory – consisting of the perfectly competitive and complete markets – money are neutral and an increase in the money stock amounts to one-for-one increase in the aggregate price level. The previous holds to the extent that the economy attains the market-clearing general equilibrium and the money velocity is constant. Situation where nominal and real variables are determined separately is also known as the classical dichotomy. To bring the equation (2.1) close to the purpose of the research, it can be formulated as the demand for real money balances.[5]

$$\frac{M}{P} = k \times Y \tag{2.2}$$

where k is the Cambridge coefficient[6], inverse to the income velocity. Consequently,

$$V = \frac{P \times Y}{M} = \frac{1}{k} \tag{2.3}$$

Quantity theorists considered both k and V the constant quantities in the short term and their size gave to the link of institutional factors, such as

[2] In this respect see also the section 2.2 of the thesis.

[3] Actually, it is proportional to the number of all transactions as it contains only the transactions with final-good production.

[4] Regardless the money are exogenous or endogenous, the equation 2.1 remains important macroeconomic identity.

[5] We assume the equilibrium on money market, so $M = M_S = M_D$.

[6] This formulation of the quantity theory of money goes in the tradition of economists from the University of Cambridge.

payment methods. Cambridge coefficient directly expresses the willingness of economic agents to hold a specific amount of real money balances in relation to their level of income. As other factors affecting the demand for money were not explicitly taken into account by the quantity theorists of money, their inquiries contributed mainly to the transactions demand for money. Interest rate as an opportunity cost of holding liquidity was regard only implicitly, mostly within the coefficient k.[7] Keynes (1936) was the first, who incorporated the interest rate (henceforward denoted as i) into the demand for money. Keynes function of the demand for real money balances takes the form

$$\frac{M}{P} = f(Y, i) \tag{2.4}$$

where

$$\frac{\partial f}{\partial Y} > 0, \qquad \frac{\partial f}{\partial i} < 0$$

Keynes theory stands on the motives for holding money, or motives for liquidity preference. These motives are transaction motive, precautionary motive, and speculative motive. Transaction and precautionary motives are related to the transactions demand for money and they are proportional to the level of income. The higher is the income level of an agent, the more money balances are demanded to satisfy the transaction and precautionary needs. On the other hand, speculative demand considers uncertainty about the future development of interest rates, or asset prices. Increase (observed or expected) in the interest rate and a consecutive decrease in asset prices foster the demand for interest-taking assets at the expense of the demand for liquidity – there is a payoff for the risk taking. How strong the negative effect of interest-rate increase will be depends on the distribution of risk aversion over the agents in the economy. In this way, Keynes laid down the foundations of portfolio balance approach to money. Within that, money are regarded as a one type of asset, not just a mean of transactions. Portfolio balance approach was developed further by Tobin (1958). As the name of Tobin's article "Liquidity Preference as Behavior Towards Risk" suggests, money from the speculative motive are demanded by a risk-averse agent to reduce portfolio riskiness.

In Keynesian theory the interest rate plays a key role, because it provides a link between the monetary and real economy. Beside the neoclassical economists, Keynesians assume a high elasticity of money demand to the interest rate. Moreover, if prices and wages are sticky, money supply is not

[7] It does not apply for an early version of the quantity theory of money from Irving Fisher, which was only the transaction identity.

neutral and it can promote changes in the money velocity and real production.

Let assume that the Keynesian function is separable across the liquidity preference motives

$$\frac{M}{P} = L_1(Y) + L_2(i) \tag{2.5}$$

where L_1 represents transactions demand (both from the transaction and precautionary motive) and L_2 represents speculative demand. According to the Baumol (1952) and Tobin (1956), equation (2.5) can be extended in a following way

$$\frac{M}{P} = L_1(Y, i) + L_2(i) \tag{2.6}$$

with

$$\frac{\partial L_1}{\partial Y} > 0, \qquad \frac{\partial L_1}{\partial i} < 0, \qquad \frac{\partial L_2}{\partial i} < 0$$

because both Baumol (1952) and Tobin (1956) highlight the importance of opportunity (shoe-leather) costs of holding money. If the interest rates are high, it is optimal to hold smaller amount of liquidity, and greater amount of interest-bearing assets, per a unit of time and to undergo a large number of transactions per a given period of time. We will go a little bit further in our analysis and amend the equation (2.6) by the unemployment rate (denoted as u) and the real effective exchange rate (denoted as q),

$$\frac{M}{P} = L_1(Y, i, u) + L_2(i, q) \tag{2.7}$$

with

$$\frac{\partial L_1}{\partial Y} > 0, \qquad \frac{\partial L_1}{\partial i} < 0, \qquad \frac{\partial L_1}{\partial u} > 0, \qquad \frac{\partial L_2}{\partial i} < 0, \qquad \frac{\partial L_2}{\partial q} > 0$$

Including unemployment rate as a determinant of the transactions demand for real money balances, we want to accent other side of precautionary savings. Along with the level of income, these precautionary savings potentially also depend on the business cycle. The higher the unemployment rate is, the higher is the uncertainty about prospective employment and the level of profits. Therefore, it could be expected that a rise in the rate of unemployment would cause a greater demand for liquidity. In other words, demand for precautionary savings is likely countercyclical; according to this intuitive reasoning. Regarding the real effective exchange rate, its position in the model is to provide a space for the effect of international diversification.

When the real effective exchange rate appreciates (increase in q[8]), domestic currency becomes more attractive relative to the effective foreign currency and its share in a portfolio of assets should increase. Notice that the foreign currency is not a perfect substitute to the domestic currency within speculative demand due to the foreign-exchange risk – it is likely that there will be a final conversion to the domestic currency.

2.2 J-curve phenomenon

The Marshall-Lerner condition and J-curve phenomenon are issues frequently discussed among academicians and policy decision makers, and are just as often the subject of empirical testing. The Marshall-Lerner condition follows from the work of Marshall (1923), Lerner (1944), Robinson (1937) and Machlup (1939) and tells that if foreign trade elasticities are sufficiently large, then exchange rate depreciation or devaluation contributes to trade balance improvement. More concretely, a sum of the absolute values of export demand elasticity and import demand elasticity, both with respect to prices, must exceed one. It therefore implies an econometric approach, known as the elasticity approach, based on an estimation of the foreign demand function for domestic exports and the domestic demand function for foreign imports and subsequent computation of elasticities.

This was the first empirical effort to establish a relationship between trade balance and exchange rate; today we can say it is the classic one. For a detailed demonstration see Goldstein and Khan (1985), Orcutt (1950), Stern, Francis and Schumacher (1976), Sawyer and Sprinkle (1997), Fullerton, Sawyer and Sprinkle (1999), Bahmani-Oskooee, Harvey and Hegerty (2013), Sawyer and Sprinkle (1996), Houthakker and Magee (1969), Khan (1974), Rose (1991) and Warner and Kreinin (1983), among others. Many of these works estimate not only price elasticities but also income elasticities. The importance of income elasticities was emphasized by Johnson (1958), who showed that if trade is initially balanced in a two-country model, prices are constant and income growth is the same in both countries, then the trade balance between them can still change over time if their respective income elasticities of demand for the other's exports differ, as Houthakker and Magee (1969) summarized.

One of the basic principles of international economics and finance, based on the above and many other empirical research studies, states that in many

[8] In this thesis the effective exchange rate is computed as a number of units of effective foreign currency per the unit of domestic currency. On the other hand, bilateral exchange rates are expressed as units of domestic currency per a unit of foreign currency.

cases the Marshall-Lerner condition is fulfilled only in the long run, which leads into the possibility that exchange rate depreciation (devaluation) has a short-run negative effect to trade balance. Such a dynamic view of the Marshall-Lerner condition is known as the J-curve phenomenon or effect; the name derives from the post-devaluation pattern of behavior of the trade balance.

The J-curve effect was first observed by Magee (1973), when studying the 1971 devaluation of the U.S. dollar. As a justification, he spoke of lags which follow from fixed-volume or fixed-time contracts in international trade, i.e. not readily adjustable to new conditions. Therefore, after depreciation (devaluation), the price effect initially dominates the volume effect (if hedging is not applied), and thus the trade balance, expressed in money balances, deteriorates in the first instance. In the limit situation, when theoretically all firms in the country hedged themselves against the foreign-exchange risk and forward contracts perfectly fit in the time structure to trade contracts, the short-run deterioration of trade balance does not realize and just positive effect remains. Additionally, at least some exported goods must be priced in different currency than goods imported.[9]

Junz and Rhomberg (1973) elaborate foreign trade lags in great detail, with a final distinction among lags arising from the recognition of a changed competitive situation (this delay is prolonged by language and distance obstacles to the spread of information), decision to change real variables (time to new bargaining), replacement of inventories and materials, production (the producer has to become convinced that the profit opportunity is permanent, or at least long-lasting), and delivery time.

The Marshall-Lerner condition is theoretically derived from the trade balance model, which shows that the M-L condition is a special case of the Bikerdike-Robinson-Metzler condition for infinite supply elasticities[10] and initially balanced trade (the case when exports equal imports); for a more informative exposition see Stern (1973). On the other hand, the J-curve phenomenon has an empirical origin. The B-R-M condition has theoretical importance, but for the identification problem (too many elasticities to determine), the M-L condition is instead used, despite simplifications, in the empirical area. The position of the M-L condition as a necessary and sufficient condition for trade balance improvement is also weakened in the situation where exports exceed imports (only necessary) or, on the contrary,

[9]Upon the symmetric currency pricing in international trade, the J-curve is even justifiable by the different rate of price stickiness in export and import prices. For the discussion of pricing in the international trade and its relationship to the J-curve phenomenon refer to Ahtiala (1983).

[10]In the current setting of the global economy this is readily fulfilled.

where imports exceed exports (only sufficient).

The time-through development of the trade balance after an exchange rate change depends on many different factors; perhaps the most important are the size and structure of the economy (mainly the difference between small open economies and large closed economies), the exchange rate regime (some studies compare the Bretton Woods era with the subsequent floating era, e.g. already mentioned Warner and Kreinin (1983)), participation in any type of integration unit (for example, the EU or eurozone in the case of European states) and, until the 80s or 90s, the degree of capital mobility could have also played some role. Of course barriers to trade, whether of a tariff or non-tariff nature, are also important, although not too relevant nowadays after the rounds of GATT/WTO negotiations.

The fact that it is very difficult to state which factors are important indicates the diverse and in some instances confusing results of previous research. These results depend not only on that for which economy the investigation is done, but also on the method applied or data used. On the data side, three possibilities are offered: aggregate, bilateral or sectoral (industry) data. Applied methods are now clearly dominated by cointegration, or error-correction based models, which overcome the disadvantages of the classical linear regression model in the sense that they are able to distinguish between the short and long run, and are therefore better for investigating the J-curve phenomenon. Before the cointegration revolution, an aggregation data method had been used in this respect.

Among the papers engaged in the investigation of the J-curve phenomenon, we can quote Bahmani-Oskooee and Goswami (2003), who used quarterly bilateral data for Japan and its nine trading partners to demonstrate the problem of aggregation, i.e. when aggregate data are used, there is no evidence of the J-curve, whereas when bilateral data are employed, evidence for some trading partners is found. The authors stated that this problem can be due to the fact that exchange rate depreciation (devaluation) has a positive effect on the trade balance with some trading partners, but may be offset by a negative impact on trade with other trading partners, as there exist the variations in nature of the trade over countries.[11] Albeit the disaggregation is getting more popular currently, if one needs to accomplish the analysis on aggregate trade flows (likely for the economic policy purposes) the aggregation is a necessary step. Analysis on bilateral country level data or industry level data might then serve as a tool to provide a solution of puzzles arising from aggregate analysis.

[11] With respect to that, the choice of proper proxies for effective exchange rate and foreign income seems most challenging in the aggregate studies.

Table 2.1: J-curve around the world: North and Latin America

NORTH AMERICA
Bahmani-Oskooee and Fariditavana (2016) RESEARCH GRASP: Trade of the U.S. with its six most important trading partners (the same as in Rose and Yellen (1989)); quarterly data arising from the period 1971-2013 was engaged. METHODOLOGY: Both linear and nonlinear ARDL approach to cointegration. RESULTS: Rather mixed for linear ARDL (J-curve concluded for just three countries), but more supportive for nonlinear ARDL (due to the existence of nonlinearities).
Bahmani-Oskooee, Goswami and Talukdar (2008) RESEARCH GRASP: The trade of Canada vis-à-vis her 20 major trading partners; the research includes data with quarterly frequency enclosing the period of 1973-2001. METHODOLOGY: Bounds testing for cointegration and error-correction modeling. RESULTS: Support for the J-curve in 11 out of 20 cases.
LATIN AMERICA
Bahmani-Oskooee, Halicioglu and Hegerty (2016) RESEARCH GRASP: Bilateral trade of Mexico with 13 trading partners; estimated period: 1980-2014; the quarterly data was used. METHODOLOGY: Linear and non-linear ARDL, and bounds testing. RESULTS: Supporting the J-curve phenomenon for 10 out of 13 partners and find out positive effect of peso devaluation (with possible asymmetries).
Costamagna (2014) RESEARCH GRASP: Trade of Argentina and Brazil vis-à-vis the rest of the world during the years 1990-2010 (with quarterly frequency). METHODOLOGY: Vector error correction modeling and generalized impulse response analysis. RESULTS: Pattern of estimated IR functions does not go in line with the J-curve hypothesis, but alongside the estimated long-run parameters the devaluation can lead into a competitive gain. Results also highlight the influence of different exchange-rate regimes and the dependence on studied subperiod.

Table 2.2: J-curve around the world: East Asia

EAST ASIA
Bahmani-Oskooee and Zhang (2014) RESEARCH GRASP: Commodity trade of Korea with the rest of the world (including 148 industries); the authors explored annual data over the period 1971-2011. METHODOLOGY: Bounds testing approach to cointegration and error-correction modeling. RESULTS: Some type of the J-curve was recorded in 58 industries. However, the long run favorable effect of devaluation or depreciation was evidenced only in 26 mostly small industries (against the aggregate studies which found an evidence of the ML condition).
Wang, Lin and Yang (2012) RESEARCH GRASP: China and her 18 major trading partners, since August 2005 to September 2009 (the period after an exchange rate policy reform in July 2005); data are collected by months. METHODOLOGY: Panel-data oriented investigation, encompassing unit-root and cointegration testing, with final construction of panel ECM. Methodologically, it therefore provides an original contribution. RESULTS: The article discusses the policy of undervalued currency paved by the Chinese government. On average, the evidence for the J-curve was found (interpreted purely on short-run coefficients). From the long-run perspective, there exists a significant relationship with expected sign between the exchange rate and trade balance just for the trade of China and her three partners (namely the U.S., the U.K. and Japan).
Bahmani-Oskooee and Goswami (2003) RESEARCH GRASP: Japan versus her major trading partners (nine in total) using quarterly data over 1973-1998 period. METHODOLOGY: Error-correction (in the form of ARDL) modeling applied both on the aggregate and bilateral trade flows. RESULTS: If the aggregate data was employed, there appears no significant improvement in the trade balance for the long run. On bilateral basis, the J-curve arises in two cases, Germany and Italy (inferred purely from short-run parameters). Even though the authors do not interpret the results in that direction, combining the short-run and long-run parameters the J-curve is apparent also for the United States and Canada.

Table 2.3: J-curve around the world: South and South-East Asia

SOUTH AND SOUTH-EAST ASIA
Kyophilavong, Shahbaz and Uddin (2013) RESEARCH GRASP: The trade of Laos with the rest of the world; period under review: 1993-2010; the usage of yearly data which was converted to quarterly frequency. METHODOLOGY: ARDL and bounds testing for cointegration; Johansen approach with generalized impulse-response and FEVD analysis. RESULTS: Existence of the J-curve on the aggregate level.
Lal and Lowinger (2002) RESEARCH GRASP: Five South Asian countries (Bangladesh, India, Nepal, Pakistan, and Sri Lanka) and their trade with the rest of the world; the data with quarterly frequency since 1985 to 1998 were used (the period after adoption of market oriented reforms and increased openness of the economies). METHODOLOGY: VECM and Johansen test for cointegration with the IR analysis. Instead of the usual real effective exchange rate the nominal version of that was employed. RESULTS: A depreciation can lead to an improvement in the trade balance in all countries under review. Equally, the short-run adjustment of trade balance behaves along the J-curve for all countries.
Bahmani-Oskooee, Goswami and Talukdar (2005) RESEARCH GRASP: Australia and its trading with 23 major partners during the years 1973-2001; the data was collected quarterly. METHODOLOGY: Bounds testing and ARDL approach to cointegration. RESULTS: J-curve concluded for only three countries (Denmark, Korea, New Zealand). The long-run effects of Australian dollar's depreciation are broadly insignificant.

Table 2.4: J-curve around the world: Middle East

MIDDLE EAST
Halicioglu (2007, 2008) Research grasp: Turkey vis-à-vis the rest of the world and also vis-à-vis her major trading partners. Period under interest covers 1985-2005, with quarterly frequency (Halicioglu, 2008), and 1960-2000, with annual frequency (Halicioglu, 2007). Methodology: Bounds testing for cointegration and error-correction modeling in the form of ARDL (Halicioglu, 2008), and vector error correction modeling and generalized impulse-response analysis (Halicioglu, 2007). Results: The Turkish data contradict the existence of the J-curve. While Marshall-Lerner condition achieves a fulfillment in the long run (with relatively low long-run multipliers on bilateral level), the short-run dynamics does not bring the required pattern. If the combined inference, including both short- and long-run parameters, is applied the J-curve might be concluded for the trade with the U.S. and the U.K.
Jamilov (2013) Research grasp: The trade of Azerbaijan and its biggest partner of eurozone (including 17 countries) during the years 2006-2009 (monthly data). Methodology: Johansen approach to cointegration, the estimation of VECM, and IR analysis. Demand functions for export and import are studied separately. Oil-related export was excluded from the investigation. Results: Strong evidence for the J-curve, and the price and volume effects as well. Sensitivity analysis reveals that the exports are driven by exchange-rate fluctuations in a greater extent than imports.

Table 2.5: J-curve around the world: Europe

EUROPE
Ketenci and Uz (2011) RESEARCH GRASP: The trade of EU-15 vis-à-vis major trading partners (eight in total) and selected integration units (among others NAFTA, EFTA and ASEAN); the research covers the period 1980-2007 on the quarterly basis. METHODOLOGY: Error correction modeling with the aid of bounds test and ARDL applied separately to the export and import demand equations. RESULTS: In the long run, according to the presented results, the relative prices seem to be unimportant compared to a level of domestic and foreign income. The support for the J-curve dynamics is limited.
Hacker and Hatemi-J (2003) RESEARCH GRASP: Five small North European economies: Belgium, Denmark, Norway, Sweden and the Netherlands, and their trade with the rest of the world (both on quarterly and monthly basis) and also with their major trading partner Germany (on monthly basis). The investigated period ranges from 1970s to 2000. METHODOLOGY: Analysis with the aid of vector error correction models and generalized impulse-response functions. RESULTS: Mostly supportive with respect to the J-curve phenomenon. Some difficulties pertaining the quarterly data against monthly data are discussed.
Bahmani-Oskooee, Economidou and Goswami (2006) RESEARCH GRASP: Trading of the United Kingdom and her twenty major trading partners since 1973 up to 2001, with observations by quarters. METHODOLOGY: ARDL and bounds testing approach to cointegration. RESULTS: There does not exist any specific form of the adjustment in trade balance, which would resemble the J-curve. Regarding long-run multipliers, the positive effect of a weak currency was observable for six countries.

Table 2.6: J-curve around the world: OECD countries and Africa

OECD COUNTRIES
Boyd, Caporale and Smith (2001) RESEARCH GRASP: Aggregate trade flows of eight major OECD countries with the rest of the world; the reference period ranges from 1975 to 1996 (with quarterly frequency). METHODOLOGY: Johansen's system estimation, together with generalized impulse response functions, and consecutive application of restrictions (finally leading to the usual ARDL specification). Trace and eigenvalue test is used for cointegration testing. RESULTS: Provides an evidence to broadly usage of the one-cointegration-vector and weakly-exogenous-variables assumption in the J-curve literature. Regarding trade balance dynamics, the results speak persuasively for the ML condition in the long run but they lack this clarity for the short-run adjustments (J-curve).
AFRICA
Schaling and Kabundi (2014) RESEARCH GRASP: South Africa vis-à-vis the rest of the world. The quarterly data ranging from 1994 to 2011 were used. METHODOLOGY: VECM, Johansen test for cointegration and IR analysis. RESULTS: Following a real depreciation of the Rand, there is an initial deterioration of the trade balance with subsequent improvement in the long run. Consequently, the J-curve was confirmed.

Rose and Yellen (1989) is perhaps the most cited paper dealing with bilateral data (along with the aggregate data), and is probably the first paper to strictly reject the J-curve phenomenon; based on the example of the U.S. and its major trading partners – countries of the Group of Seven. Indeed, the authors did not find any reliable link between the trade balance and the real exchange rate. By them, this non-conventional finding goes partially due to a failure of past research to deal with a simultaneity bias.[12]

In Tables 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6, we give an another list of articles engaged in the J-curve investigation. We tried to encompass almost each region of the world economy. For more detailed survey see for example Bahmani-Oskooee and Ratha (2004) and Bahmani-Oskooee and Hegerty (2010). While one reads these articles, despite their diversity in methods, data (including measurement errors) and countries employed, he/she gains a feel that the empirical research collectively supports the thesis about the J-curve phenomenon, rather than to conclusively reject it.[13] The agreement is considerable on the fulfillment of the Marshall-Lerner condition in the long run but it is sparser on the short-run adjustment imitating the letter J. The measurement errors likely play a significant role therein, as they are surfaced more within first-differentiated variables than variables in levels.[14]

Even though there exists an extensive body of research papers on the J-curve phenomenon or Marshall-Lerner condition, until now the Czech Republic has been neglected. To our knowledge there are just two articles, one from Bahmani-Oskooee and Kutan (2009) and the second from Hacker and Hatemi-J (2004), which include the Czech Republic. However, the attention paid to Czech trade balance behavior in the Bahmani-Oskooee and Kutan (2009) is rather marginal[15]; in addition, the authors analyze monthly data for the period January 1993 – June 2005.

In our view, this choice is extremely problematic, because in this period the Czech Republic experienced many structural changes, from price liberalization (actually around 80 percent of prices had been released in the

[12]The simultaneity bias might be investigated deeply through the maximum-likelihood estimation of the whole system of equations. But, according to the recent results, the simultaneity does not pose a problem in this area of interest. The practices used by Rose and Yellen are discussed in Bahmani-Oskooee and Brooks (1999), who found an evidence for the same countries, at least for the long-run effect.

[13]That view is clearly subjective, but it is a hard work to summarize objectively the results, for example through the meta-analysis (with a quantification of publication bias), mainly because of the diversity in methodologies.

[14]Although we do not apply it, the band-pass filtering of estimated IR functions may partly reduce the impact of measurement errors.

[15]Apart from the Czech Republic, the authors also study Cyprus, Hungary, Poland, Slovakia, Bulgaria, Croatia, Romania, Turkey, Russia and Ukraine.

year 1991, but consequences in a higher inflation persisted), currency separation, tax reform (both also contributed to inflation), privatization and the introduction of external convertibility of the Czech currency in 1995, through 1997's currency crisis with a consecutive recession and transition from a fixed to floating exchange rate regime, up to inflation targeting installation in January 1998. Thanks to the time inconsistency of structural characteristics of the Czech economy in this period, we unfortunately cannot attribute too much relevance to the results of Bahmani-Oskooee and Kutan (2009) in the case of the Czech Republic. In fact, the situation is similar in the latter work of Hacker and Hatemi-J (2004), who engaged monthly data over the August 1993 – July 2002, despite they were more selective and concentrated on three countries.[16] Keeping the above in the mind, the Hacker and Hatemi-J (2004) results might be interpreted as rather supportive and Bahmani-Oskooee and Kutan (2009) ones as rather non-supportive for the J-curve hypothesis.

But the fact that the Czech Republic has not paid attention does not mean that research into trade balance behavior following exchange rate changes is not important. The opposite is true for two reasons. Firstly, the Czech Republic committed itself to joining the eurozone upon entering the European Union, and thus the question of when or if ever to give up the exchange rate as a stabilization policy tool is very important[17]; especially in the context of recent experience with the euro crisis. An analysis of the performance or efficiency of the exchange rate as an economic policy instrument can help to answer this question. Secondly, from 2013 the Czech National Bank (CNB) has begun using the exchange rate as a policy tool, in situation when it was not possible to continue to cut interest rates. The CNB's main reason for devaluation was to prevent a deflationary spiral and thus an analysis of the impact of foreign exchange interventions on the economy is desirable. The efficiency of these foreign exchange interventions, meaning their impact on the market rate, is another question, and in that regard see Geršl (2004, 2006), who studies foreign exchange interventions of the Czech National Bank.

2.3 Unconventional monetary policy

After the recent crisis, or even during this, many central banks decided to apply unconventional measures in order to stabilize the economy. These mea-

[16]Outside the Czech Republic, Hungary and Poland are considered as well. Albeit the authors present the results of aggregate study, much of their interest is devoted to the trade between the countries and Germany (their most important trading partner).

[17]In the case of Sweden, it is possible to see that this obligation can be bypassed for a relatively long time.

sures have come into effect due to a liquidity trap that renders conventional channels inoperable, and equally because of persisting disinflation driven by an insufficient demand and engulfing a range of advanced economies.[18] Quantitative easing, qualitative or credit easing, forward guidance and foreign exchange interventions are considered possible solutions to the zero-lower-bound (ZLB) problem on short-run nominal interest rates.[19]

Reifschneider and Williams (2000) found that under a standard Taylor (1993) monetary policy rule and a two percent inflation target, monetary policy would only be constrained by the ZLB in five percent of the time, and that the constraint would be binding for only one year. The threat of a low inflation target is widely recognized; see for instance Blanchard et al. (2014). Conversely, Benhabib, Schmitt-Grohé and Uribe (2001) implicitly identified the ZLB policy as a passive (low-inflation and low-interest-rate) steady state which exists alongside the proactive Taylor policy (an active steady state) and, what is more interesting, both equilibriums are connected by a robust saddle-path dynamics.[20] Unlike the passive steady state, which is globally stable, the active steady state only possesses local stability and, furthermore, in the neighborhood of an active steady state, it is possible to locate infinitely many equilibrium paths leading to the passive steady state. In relation to the previous, Benhabib, Schmitt-Grohé and Uribe (2001, p. 46) aptly state that " ... *all that is needed for the economy to fall into the liquidity trap is that people expect the economy to slide into a deflationary phase.*". Due to global stability the liquidity trap can be relatively long-standing.

Apparently, contemporary experience gives more weight to the latter opinion from Benhabib et al. (2001). The outcomes of Reifschneider and Williams (2000), on the contrary, generally represent a viewpoint typical for the pre-crisis era, when the liquidity trap was taken as a highly unlikely

[18]We do not consider an emergency liquidity provision to be an unconventional monetary policy tool. On the contrary, this role is assigned to the central bank within its lender-of-last-resort mandate and thus fits in the usual set of monetary policy instruments, through which it generates financial sector stability. Unconventionality is therefore related to impotence of classical monetary transmission mainly based on targeting short-term rates.

[19]An extreme method of solving policy ineffectiveness could also be a temporary or permanent change of monetary policy regime. Frequently offered alternatives to conventional inflation targeting are price-level targeting (Svensson, 1999; Evans, 2012) and nominal-GDP targeting (Taylor, 1985).

[20]The active steady state corresponds to the active interest rate feedback rule, i.e. the rule which induces a change in the nominal interest rate that responds to a change in inflation with more than one-for-one (Benhabib et al. (2001) use agents with perfect foresight). For the passive steady state, the interest rate reaction is less than one-for-one. The existence of indeterminacy and multiple equilibria itself follows directly from the usage of an active monetary policy.

event without any practical relevance. Factors constituting the main reasons for an undervaluation of the risk of ZLB are discussed in Chung et al. (2012). It also follows that the size of the risk was partially reduced due to the period over which econometric models were estimated. The tranquil "Great Moderation" is an example, and it only suffices to take into account a larger sample so the estimation of the risk becomes more accurate. Similarly, Keynes (1936), or Hicks (1937) within the IS-LM model, originally deemed the ZLB on nominal interest rates as a purely theoretical and limit situation of an ineffective monetary policy, and therefore they did not seek a way out. Naturally, outside monetary policy the fiscal expansion is at disposal, but that is another story.

Quantitative easing (QE) was greatly exploited, especially in the most advanced economies. The Federal Reserve (FED), Bank of England (BOE), European Central Bank (ECB) and Bank of Japan (BOJ) are the most significant examples of institutions that use QE in their monetary policy. For concrete information about operating procedures in the mentioned countries see Fawley and Neely (2013).

The balance sheet expansion of a central bank (above the level consistent with a zero policy rate), known as quantitative easing, consists in an extension of asset maturity and is effective primarily in the case of general liquidity distress in the banking sector.[21] An excess of liquidity can cause a mismatch between an increase in the money base (an outside money injection) and a change in the money supply, because of an unwillingness of financial intermediaries to further distribute surplus funds. When conducting large-scale purchases of assets with a longer-term maturity (government bonds have empirically had the greatest importance), the aim of central bankers is to directly influence real long-term interest rates, and ultimately the performance of the real economy, through the asset-price channel. If money differs in its characteristics from bonds, or potentially other financial assets, then growth in the money stock can, through the rebalancing an investor's portfolio, support the aforementioned. Moreover, thanks to price stickiness, the temporary wealth increase promotes further spending on consumption and housing. In the strict sense, the efficacy loss of monetary policy which is caught in a liquidity trap stems from the public perception of money as a perfect substitute for bonds; see Krugman (1998), for example. It is necessary to emphasize here that bonds, as financial securities, differ from one another. Hence, if money forms a perfect or nearly-perfect substitute for very short-term bonds, the same need not be, and a priori is not, true for bonds with longer-term maturities. In practice, quantitative easing actually represents open market

[21] As was the case in the economies listed above.

interventions whose target is the volume of banking reserves rather than the size of the overnight interest rate (the price of reserves).[22]

In comparison with quantitative easing, qualitative easing is more selective and oriented toward influencing the structure of assets (towards less liquid and more risky) held by central banks on the balance sheet, keeping the volume of the balance sheet constant. On the other side, as a consequence of that, financial market institutions enjoy improvement in their balance sheets. Sometimes credit easing is perceived differently as a combination of both quantitative and qualitative easing, because it leads to growth in the size of the central bank's balance sheet while decreasing average liquidity and/or increasing the average riskiness of its asset portfolio.[23] In point of fact, quantitative and qualitative easing both comprise an easing of credit, in the literal sense of the word, because they facilitate a reduction in the risk premium in the banking sector and hence affect the cost and availability of loans. This is why the sectoral character of credit easing is primarily highlighted when it is targeted mainly at non-functional segments of the market.

Under the condition of imperfect asset substitutability, a change in the composition of assets held by the central bank can considerably impinge the relative supply on the financial market, with a potential cut in the term premium, ultimately resulting in flatter yield curves. An additional effect arising from qualitative easing may be an improvement in the creditworthiness of some private agents, see Bernanke and Gertler (1995). So far we have discussed quantitative and qualitative easing in relation to the capital market or, in other words, when a central bank purchases assets and provides liquidity. This was typical for the FED and the BOE. On the other hand, the monetary authority might also offer reserves directly via a discount window, as was the case with the ECB and the BOJ. However, the effects, consisting of a reduction in specific real rates and greater economic growth, remain the same. What we have not yet said explicitly is that, in a situation where some obstacles hinder the smooth functioning of the financial market, the operations listed above cause it, or its parts, to work better.[24] An in-depth description of quantitative and qualitative easing is provided by Bernanke and Reinhart (2004).

Both quantitative and qualitative easing are frequently combined with forward guidance to further increase the easing of monetary conditions. Forward guidance is directed to the expectations of market participants and is

[22] The way of conducting this policy is thus fairly conventional. Only its focus and scope are unconventional.

[23] Quantitative easing preserves average liquidity and riskiness unchanged. This is achieved thanks to the range (in terms of volume) of operations carried out.

[24] Or even starts working again.

a basic communication strategy of central banks in economies with rational expectations (forward-looking). The supreme importance of expectations management was stressed by Krugman (1998), as well as Eggertsson and Woodford (2003, 2004).

Krugman (1998) looks at the liquidity trap as a kind of credibility problem. Based on him, a monetary expansion that the market expects to be sustained will always work, whatever structural problems the economy might have. The idea stands on the money neutrality proposition and on the fact that this proposition is not generally state-dependent. But in this case, the credibility problem has an inverse nature to that usually perceived for a central bank trying to anchor a price level or inflation. In a liquidity trap environment, the central bank must credibly promise to be irresponsible in the future, in the sense of targeting a higher price level or its path.[25] Eggertsson and Woodford (2004) even consider any monetary policy action, including quantitative and qualitative easing, to be absolutely ineffective if it does not change the attitude of private agents towards a prospective interest rate policy. Paradoxically, the more credible the initial commitment, the more difficult it is to get the public to support a new commitment. Specially, in the context of ZLB, the communication has the form of a commitment to lower interest rates for a longer period than previously expected; known as the lower-for-longer solution.[26] Accordingly, it acts through the signaling channel and consequently, through the Fisher effect, affects current and future short-term interest rates. Forward guidance can be date- or state-dependent, if its duration is related to a calendar date or to economic conditions, respectively.[27]

The success of the lower-for-longer strategy relies on the credibility of the monetary authority, and therefore it is often necessary to demonstrate resolution through real action; this relates to the previously mentioned connection of forward guidance with other policies. Alongside the cited articles, we arrive at a conclusion about the mutual conditionality of real-action policies and bank communication for overall success. It should be noted that dozens of the policies discussed above were initially only experiments within

[25] In the situation of zero nominal interest rates, inflation target forms a lower bound for negative ex-ante real interest rates.

[26] Actually, some economists, see Eggertsson and Woodford (2003) for the example, suggest that interest rates should be kept lower for a longer period than the state of the economy necessitates, with the aim of better shaping expectations and also creating an ample cushion for monetary ease in the future. An additional suggestion about how to avoid a further liquidity trap is to increase the inflation target; see Blanchard et al. (2014).

[27] Due to uncertainties in the economy, a date-dependent commitment can be time-inconsistent; see Kydland and Prescott (1977) and Barro and Gordon (1983a, b). A state-dependent commitment is optimal in the eyes of Eggertsson and Woodford (2004).

theoretical models until economic development had prepared conditions for their practical usage. A large portion of these articles, today forming the theoretical basis for ZLB considerations, were stimulated by the situation of Japan in the 1990s and early 2000s. However, the currently prevailing stylized facts encourage further research, of course. Moreover, thanks to the fact that a relatively large number of economies have stayed at the ZLB for an extended period, it is also possible to initiate econometrically oriented studies assessing the consequences of unconventional monetary policies; see for example Bernanke, Reinhart and Sack (2004), or Hamilton and Wu (2012).

2.4 Czech exchange-rate commitment

The Czech National Bank (CNB) has chosen the exchange rate as a monetary policy instrument under the binding conditions of ZLB, which in the Czech Republic took place from autumn 2012; see Figure 2.1. The two-week repo rate, the policy rate used by the CNB, has gradually converged to the zero level since 2008. That decline was a consequence of drops in aggregate demand[28], both domestic and foreign, with a follow-up recession and disinflation. Despite all efforts, the economy remained depressed[29], and according to the CNB's projection model, see Franta et al. (2014), the equilibrium nominal interest rate needed to be hypothetically negative in the spring of 2013. Even under the unrealistic assumption of negative interest rates, the output gap was predicted to be negative till the end of 2015 (Franta et al., 2014). Finally, observed inflation during the year 2013 was approaching the lower limit of the tolerance band, and there was a danger of prospective deflation in 2014. Thus, the need for a further monetary easing did not disappear.

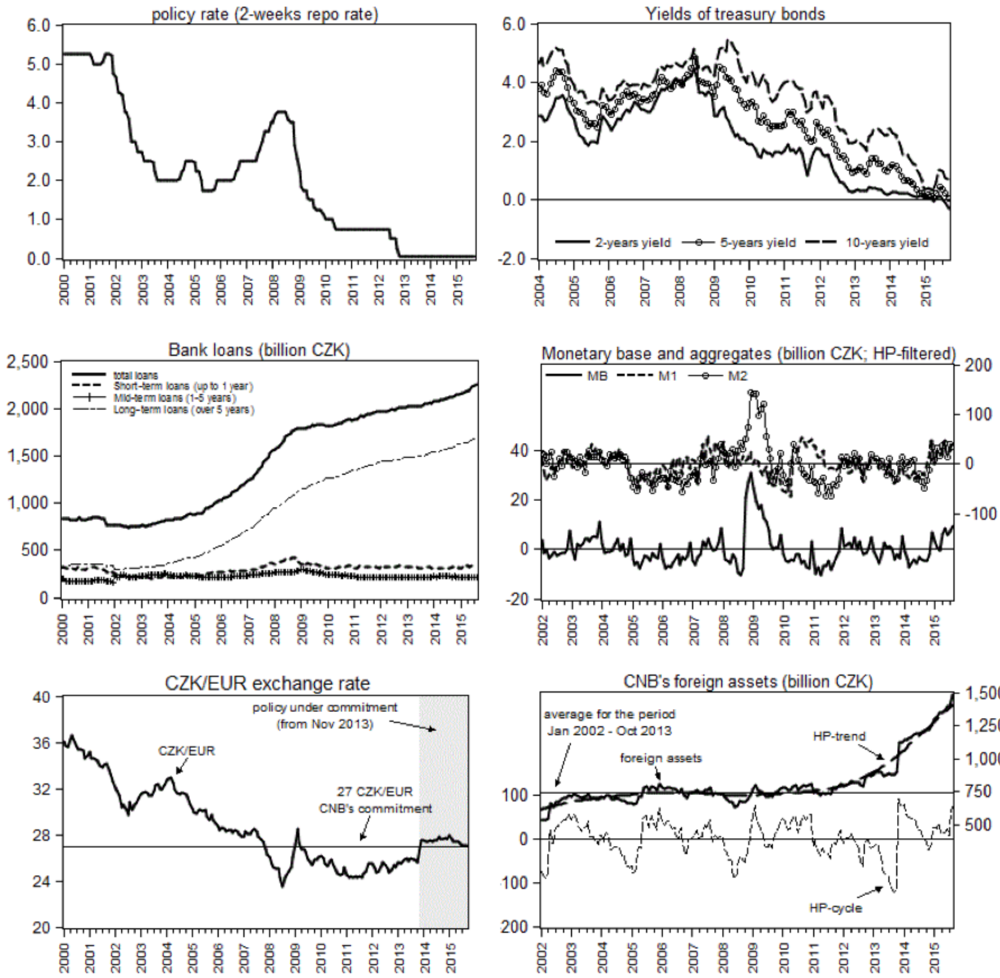
Based on the unfavorable outlook, the Czech National Bank publicly committed itself in November 2013 to not let the exchange rate of the Czech koruna to the euro go below the value of 27.[30] A pledge to hold interest rates lower until inflation pressures were sufficient supplemented the one-side exchange-rate commitment. The lower-for-longer communication has been effective since the fall of 2012. In autumn 2012, the CNB also announced that it was prepared to use unconventional measures if necessary. The option of using the exchange rate in an open economy, with the intention of supporting economic growth under a liquidity trap, was advocated in McCallum (2000) and Svensson (2001).

[28] The demand downturns were naturally related to the financial and European debt crises and the global economic uncertainty arising from them.

[29] With the exception of the years 2010 and 2011, when a partial recovery was observed.

[30] If interested in the CNB's decision, refer also to Franta et al. (2014).

Figure 2.1: Financial conditions in the Czech economy



Source: Czech National Bank.

Svensson (2001) proposal relies greatly on the ability of a central bank to efficiently manipulate market expectations. Within his approach, a central bank uses both real-action policies and a commitment regarding future monetary policy. He proposed a foolproof way of escaping from a liquidity trap, which consists in the introduction of a price-level target path corresponding to a small positive long-run inflation target, and jump-starting the economy via a devaluation of the currency and a temporary exchange-rate peg. A price-level target serves well for anchoring nominal variables.[31] Svensson (2001) designates the price-level target path as follows[32]

$$\hat{p}_t = \hat{p}_{t_0} + \hat{\pi}(t - t_0), \qquad t \geq t_0 \tag{2.8}$$

with the initial price-level target $\hat{p}_{t_0}$ exceeding the current price level p_{t_0},

$$\hat{p}_{t_0} > p_{t_0} \tag{2.9}$$

and a positive target for the inflation, which also constitutes the slope of (2.8), that is

$$\hat{\pi} > 0 \tag{2.10}$$

If the central bank's inflation target is fully credible, it is now necessary to reach the same for the initial price-level target. One way of attaining this is with the aid of the exchange rate s_t. In fact, the Czech National Bank applied a one-side nominal exchange-rate peg, so[33]

$$s_t \geq \bar{s}, \qquad t \geq t_0 \tag{2.11}$$

The key to success of the foolproof way is the size of the initial exchange-rate devaluation, which must be so large that the real exchange rate q_t overshoots its equilibrium value q,

$$q_{t_0} \equiv p^*_{t_0} + s_{t_0} - p_{t_0} > q \tag{2.12}$$

where p^*_t is the average foreign price level. Assuming a widely low-inflation environment, we logically, based on equations (2.11) and (2.12), arrive at

$$s_t \geq \bar{s} > q \tag{2.13}$$

[31] See Svensson (1999) for a comparison with famous inflation targeting.

[32] All variables are expressed in logs; see Svensson (2001) for a full description of the model.

[33] Svensson (2001) formulates the exchange-rate peg in a linear form, which significantly eliminates the difficulties in a model solution. We use a non-linear peg, because it better describes the situation in the Czech economy. At the same time, we do not strive here for any exact mathematical solution; rather, the discussion is based on intuition, and therefore our approach is justifiable.

Accordingly, the exchange-rate floor has to be set above the steady-state value of the real exchange rate. The credibility for this one-side peg is easily attainable, because the central bank can intervene against currency appreciation to an unlimited extent by issuing additional money.

The first-round observable effect of exchange rate devaluation is an increase in the CPI due to a virtually immediate rise in consumer-good import prices.[34] With a delay, an increase in the price of imported production factors causes the price of domestic goods to rise as well. Because the weight of imported goods in a consumer basket is high for an open economy, the aforementioned acts fairly quickly. At the same time, real exchange-rate depreciation leads to an improvement in the trade balance (if the Marshall-Lerner condition is met). The excess of the exchange rate over its equilibrium value urges economic agents to expect future appreciation and, to the extent that interest rate parity is valid, also expect lower real interest rates. As Figure 2.1 in the upper-right corner demonstrates, this situation indeed occurred in the Czech Republic. Simultaneously, as the lower-left corner of the same figure indicates, the 27 CZK/EUR one-side peg has been above the steady-state level of the real exchange rate for at least the last seven or eight years. However, unlike Svensson (2001) linear exchange-rate peg, the central bank in our case need not increase the interest rate to maintain a peg. Conversely, that is counterproductive if an exchange-rate commitment is combined with the lower-for-longer strategy. Both ultimately result in higher inflation expectations.

Unlike Svensson (2001), McCallum (2000) rests on the portfolio balance channel. Fundamentally, the one-side exchange-rate peg contains fragments of both quantitative and qualitative easing. It might actually lead at limit to an unlimited increase in the central bank's balance sheet or entirely change the structure of the balance sheet towards foreign assets. As we stated in the section 2.3, the pass-through of these measures significantly depends on the rate of substitutability between different assets. Gürtler (2015) investigated asset substitutability for the Czech economy and concluded that the elasticity of substitution for domestic assets (value of 0.2) is considerably lower than that between domestic and foreign assets (value of 2.1).[35] This fact clearly speaks to the concentration of exchange-rate monetary policy on the expectations channel, rather than the classical foreign exchange interventions

[34] This ideally operates under the conditions of frictionless foreign-trade contracts and an economy without financial instruments, serving as a hedge against foreign-exchange risk. Because the real economy is not such a place, the first-round effect may be dampened, but surely does not vanish completely.

[35] Here we shall emphasize that the estimation was undertaken over the period, which does not correspond to an unconventional monetary policy.

themselves, in the Czech Republic. Looking at the lower-right corner of Figure 2.1, one can see that the Czech National Bank utilized both, even though some FX interventions were not publicly announced. However, usually the central bank simply met the requirements of market participants.

Additionally, a decision in favor of the exchange rate was also determined by a long-lasting general liquidity surplus on the Czech money market.[36] As you can see from Figure 2.1, during the financial crisis and the European debt crisis the volume of loans provided has remained constant (short- and mid-term loans) or even increased (long-term loans). Therefore the picture does not reveal any cash insufficiency among banks. Actually, liquidity distress as a first-round effect of the Lehman Brothers collapse was warded off by the CNB; this is also observable from a hump-shaped development of the outside money and broad monetary aggregate, both expressed as a deviation from the equilibrium path. Nevertheless, the increase in the base money is by no means linked to quantitative easing, which the Czech National Bank has not used.

2.5 Business investment

Investment is the most volatile component of aggregate demand. That proposition is accepted among economists for a long time, probably since the introduction of Keynes' General Theory. As a consequence, there are many factors which could potentially influence the decision about new investment. These factors can be divided into two groups. At first, new investment is planned according to the expectations about the future. For private firm those expectations regard primarily prospective demand for its production, which in the same time determine an expected marginal efficiency of invested capital. Beside expectations regarding future demand, it also depends on their probability distribution. Although the mean of this distribution is in the most of advanced economies measured by economic confidence indicators, its second and higher moments remain unmeasurable. The problem is that the importance of these higher moments has recently increased, because of a general upsurge of uncertainty. This uncertainty is related to the political events, terrorist attacks, financial crises and increased volatility on commodity markets. Naturally, many other sources of uncertainty can be listed as well. Therefore, some part of fluctuations in investment can still be explained just by a metaphysical "animal spirit". This is not an encouraging statement,

[36] If commercial banks would be willing to distribute surplus funds arising from FX interventions, the low rate of substitutability between domestic assets might strengthen the exchange-rate channel by a reduction in real rates.

but there is fortunately a larger part of development in investment which has a systematic nature. For a general exposition of uncertainty see Bloom (2014).

The observable and easily definable variables which exert a significant influence on investment form the other group of factors. Interest rate is likely the most famous one, when almost every textbook on economics mentions its negative link to the investment. The negative relation between real interest rate and volume of investment is based on the assumption, that at least a part of investment is financed through the debt. Increase in interest rate then leads into higher financing costs and smaller demand for investment. That the effect of cost of capital[37] on investment need not be so straightforward empirically is highlighted by Shapiro (1986), who attempted to give it a stronger theoretical basis and explain the nature and causes of situations when the data are non-supportive. Less interest rate sensitivity of investment was found, for example, in Sharpe and Suarez (2014), who analyzed the data from a survey of CFOs of U.S. non-financial corporations.[38]

As the Czech economy is frequently classified as a small open economy, many of its macroeconomic indicators, and so overall output, depend on the economic and political development abroad. One of these indicators could also be investment. Dependency of private investment on the changes of output is in line with the accelerator theory, which predicts changes in the capital stock in order to sustain or reach the required capital-output ratio; see Clark (1917), or Chenery (1952) and Koyck (1954). That the predictions of the accelerator theory are still relevant is documented by a vast amount of studies. One of the most recent is the study of European Central Bank (2017), arguing for the output growth as a main driver of business investment in the EU and U.S. economy. Of course, there are exceptions, such as Italy and Portugal with a high share of non-performing loans and over-leveraged private sector, defending a place for other variables. Similar results also follow from the study of Barkbu et al. (2015).

Strong correlation between output growth and investment is puzzling for Serven and Solimano (1992), who emphasize that a substantial part of fluctuations in production appears to be transitory and therefore should not affect investment. They see the reason in investors' myopic expectations or short planning horizons. Regarding this issue, one must take into account the difference between business-cycle investment and structural investment.

[37] Cost of capital is not formed just by the interest rate. Price of capital goods and depreciation rate play a role as well.

[38] The results are somewhat biased by the year when the survey was conducted (year 2012), as it falls into the period of Great Recession recovery and extraordinary low interest rates.

Whereas the structural investment relates to long-run trends in the economy, demographics or technical innovations can serve as an example, and so they have long planning horizon, the horizon of business-cycle investment is really shorter. Expansionary phase of the business cycle then brings up the investment, simply because of a larger amount of orders on the production.[39]

That the disinvestment is costly or unfeasible is a central motive for the theory of irreversible investment; see Arrow (1968). Under the certainty, the irreversible investment imposes a wedge between the marginal revenue and the cost of capital. The wedge has a tendency to increase during a boom and to decrease during a recession. As the boom lasts longer than recession, the discounted sum of the wedges over the entire business cycle should be positive. It gives a support for the output-investment correlation.

Irreversible investment is negatively affected by uncertainty; in that respect see Bernanke (1983), McDonald and Siegel (1986), Pindyck (1988 and 1991), Bertola and Caballero (1994), Abel and Eberly (1994 and 1996), Bachmann and Bayer (2013), and Binding and Dibiasi (2017). If the future is largely uncertain, option to wait for a while rather than to invest immediately has a larger utility value for the firm. Waiting for an assurance that the investment will be profitable and the firm will not suffer with an excess capital leads into a delay of business investment behind the economy output. The delay is actually observed in most of advanced economies.

In many cases, researchers also examine the role of firm-specific variables. Under the study, among others, are cash flow, liquidity, equity prices and leverage. The link of business investment to financial factors on the panel of manufacturing firms for Belgium, France, Germany, and the United Kingdom was researched by Bond et al. (2003). They realized that cash flow and profits appear to be both statistically and quantitatively more significant in the United Kingdom, than in the three continental European countries – as a result of presumably more severe financial constraints on investment in the more market oriented U.K. financial system. Importance of financial constraints, including credit rationing under imperfect-information markets, was emphasized in Stiglitz and Weiss (1981). Asymmetric information impose a risk premium over the cost of external finance (bond, equity, or bank credit) and so favor the internal funds (retained profits). Consequently, investment of constrained firms depends more on cash flow; see Fazzari et al. (1988a, b), Calomiris and Hubbard (1989), and Hubbard (1998). Kaplan and Zingales (1997, 2000) pointed out that excess sensitivity of investment to cash flow need not be an indication of the financial frictions. That the investment-cash

[39] Assuming that there is a constant capital-labor ratio in the production for the short run.

flow sensitivity is nonmonotonic in firm characteristics was also confirmed by Hovakimian (2009).

Actually, the most complex measure including the expected flow of current and future profits and regarding firm's fundamentals is Tobin's Q; see Tobin (1969) and Brainard and Tobin (1968). Tobin's marginal Q expresses an increase in the intrinsic value of the firm due to a new investment and relates it to the firm's replacement cost. Tobin's Q exceeding the value of one then encourages the firm to invest. As the marginal Q is unobservable quantity, it is frequently replaced by average Q measured as the market to book value ratio; see Hayashi (1982). High correlation of expected flow of current and future profits and Tobin's Q could be a reason why most authors conclude the statistical insignificancy for one of these, when tested in one equation model[40]; see Abel and Eberly (2012) and Cummins et al. (2006)[41]. Moreover, strong correlation of firm specific variables with the overall economic activity (aggregate demand) defends the usage of these indicators in macroeconomic oriented investigations.[42] By coincidence, there is simultaneously arising study of Babecká Kucharčuková and Pašaličová (2017), who explore the influence of firm specific variables for a sample of Czech companies.

Current and future profitability, and so investment, of the firms can also be affected by the evolution of real exchange rate. Campa and Goldberg (1999) provide an evidence for manufacturing industries in the United States, Japan, the United Kingdom, and Canada. According to their results, the direction of working of exchange rate on the investment evolves with the changing export and imported-input orientation of producers. The positive effects of a home currency depreciation on investment are increasing in an industry's export share and decreasing in its imported input share. The role also plays the demand elasticities on domestic and foreign markets with both final production and production factors. In relation to that, exchange rate tends to have weak or relatively insignificant effects on investment rate in high-markup sectors; there is likely the direct transmission of exchange rate movement to the prices of final production. Inverse then holds for low-markup industries.

Another issue frequently discussed inside textbooks is the crowding-out effect of public investment. According to the crowding out, greater invest-

[40]It is well known consequence of multicollinearity in econometric models.

[41]Both papers speak for the existence of measurement errors in average Q based on the capital market information and for a bias in the respective valuation of firm's intrinsic value.

[42]Ones that seek to give the private investment into a relation with macroeconomic covariates.

ment activity of the government spills into increase in interest rate and in final instance into decrease in interest-sensitive private investment. The increase in interest rate is due to a higher demand for loanable funds. More theoretically, this financial crowding out would be strengthened further in the world of Ricardian agents, where increased public debt is considered as a future tax burden.[43] But there is yet another reason for increase in interest rate, namely the interaction of monetary and fiscal policy. While higher government investment actually represents the fiscal expansion, it is often accompanied by a reaction of monetary policy targeting policy rate with respect to the inflation target.

In the literature, crowding out is also justified by the productivity of government investment.[44] Upon productivity of government investment, private investment are postponed until government investment is put into service to exploit the synergy. Waiting for the synergy effect implies crowding out in the short run, whereas in the long run there is observed the crowding in; see Erenburg and Wohar (1995). Nevertheless, the previous will hold for less developed economies with insufficient infrastructure, rather than for more advanced economies. Therefore, it is more reasonable to expect that the short-run negative effect binds to the financial crowding-out and that the productivity of government investment induces a crowding-in in the long run. Similar results are reached by Blanchard and Perotti (2002) and Aschauer (1989) for the United States and by Mitra (2006) for India.

Xu and Yan (2014) highlight the allocation aspect of government investment, when they find crowding out in the investment to private goods (through state-owned companies) but crowding in for the investment in public goods (infrastructure, education, health, etc.).[45] In advanced market economies, governments mostly invest into infrastructural projects (such as highways) and contract private firms to provide their completion. This applies in particular to construction industry. Satisfying higher demand, construction industry expands its production capacity and therefore invests.

In the Czech Republic, there is one sector of the economy, where the consequences of public investment are studied for a long time – it is agriculture. Agriculture is specific with a high share of capital subsidies. Some are co-financed from European Union (EU) and some use just national funds. From the perspective of national accounts these subsidies are a part of government investment. Enlargement of the capital subsidies naturally imposes a loss

[43]The working of crowding out assumes the debt financing of public investment.

[44]In the sense that government investment leads into an increase in total factor productivity.

[45]The research was conducted for the specific economy as China is, where many enterprises are state-owned and the government controls lending rate and the credit rationing.

in the motivation of agricultural enterprises to invest own funds. Almost 50 % correlation between investment in agriculture and capital subsidies was found out by Svoboda et al. (2016) for the Czech Republic. As majority of that type of studies evaluates the efficiency of capital subsidies, they rather entertain the influences on enterprise's performance indicators (such as profitability, labor productivity, indebtedness, etc.). In fact, there is a rare evidence which could speak in favor of the capital subsidies. For the case of the Czech Republic, see Špička et al. (2017) or Náglová and Gürtler (2016).

That the drawing of EU funds influences the volume of government investment, and also economic growth as a whole, is widely known and it is pronounced especially in Central European countries (Czech Republic, Slovakia, Poland and Hungary). What was not known is the impact of drawing EU funds on private investment, which was uncovered recently; see CNB's Inflation Report IV/2016. In particular, it is the case of the funds targeted to improve innovation activity, which are mainly drawn by manufacturing.

3 Methodology

3.1 General perspective

As the thesis deals predominantly with macroeconomic phenomenons, methodological approach must take into account some specifics which the macroeconomy has. To say it in a rather technical manner, the macroeconomy is dynamic stochastic general equilibrium system. The fact the macroeconomy tends to converge to the general equilibrium[1] means that the variables mutually interact and we can expect a reaction of the whole system when one variable deviates from the equilibrium path. Because the macroeconomy is under the continuous influence of diverse external shocks, its future outcome cannot be predicted with certainty – it has a probabilistic or stochastic nature. Finally, forecast of the macroeconomic outcome is simplified with the existence of persistences, leads and lags, which determine the dynamic structure of the economy.

There are two possible types of models admiring this structure of the economy. Firstly, strongly theory-based DSGE models and secondly, empirical VAR models. Although DSGE models serve good as an economic laboratory and perform well in forecasting, they in the same time have a rigid structure to fully describe the data. DSGE models are therefore inconvenient at the very first stages of data analysis. On the other hand, vector autoregressive (VAR) models are sufficiently flexible to describe the data, as they do not pose any restrictions[2] on estimated parameters and the system as well. Of course, the main disadvantage of VAR models is their vulnerability with respect to the Lucas (1976) critique and so the estimated parameters are not immune to the policy change.

Because we investigate areas of the Czech economy not properly analyzed until this moment, we use VAR models as a baseline methodology. DSGE analysis can then be conducted on the ground of results presented in this dissertation.

[1] We a priory assume the existence of such stationary point.

[2] In its most basic form.

3.2 Vector autoregression

Let $\mathbf{x}_t$ be a random vector from n-dimensional Euclidean space and let the sequence of these vectors ordered in time forms a multivariate time series $\{\mathbf{x}_t\}_{t=1}^{\infty}$. Assume further that this sequence has the following properties

$$\mathbb{E}(\mathbf{x}_t) = \mathbf{0} \quad \text{for all } t \tag{3.1}$$

$$\mathbb{E}(\mathbf{x}_t\mathbf{x}_{t-\tau}^T) = \begin{cases} \Omega_x & \text{for } \tau = 0 \\ \Xi_\tau & \text{for } \tau \neq 0 \end{cases} \tag{3.2}$$

where Ω_x is finite positive definite matrix, whose values do not depend on t; the values of matrix Ξ_τ depend on the distance between τ and t, but not on t itself. Upon these assumptions the sequence can be described by stationary vector autoregression (VAR), generally of order p (Sims, 1980),

$$\mathbf{x}_t = \Phi_1\mathbf{x}_{t-1} + \Phi_2\mathbf{x}_{t-2} + \Phi_3\mathbf{x}_{t-3} + \ldots + \Phi_p\mathbf{x}_{t-p} + \varepsilon_t \tag{3.3}$$

where ε_t is the multivariate white noise, so

$$\mathbb{E}(\varepsilon_t) = \mathbf{0} \quad \text{for all } t \tag{3.4}$$

$$\mathbb{E}(\varepsilon_t\varepsilon_{t-\tau}^T) = \begin{cases} \Omega_\varepsilon & \text{for } \tau = 0 \\ \mathbf{0} & \text{for } \tau \neq 0 \end{cases} \tag{3.5}$$

where Ω_ε is positive definite covariance matrix with no dependence on t.

Due to the stability of VAR, equation (3.3) can be inverted to Wold representation, or VMA(∞)

$$\mathbf{x}_t = \varepsilon_t + \mathbf{C}_1\varepsilon_{t-1} + \mathbf{C}_2\varepsilon_{t-2} + \mathbf{C}_3\varepsilon_{t-3} + \ldots = \sum_{j=0}^{\infty}\mathbf{C}_j\varepsilon_{t-j} \tag{3.6}$$

and so $\mathbf{x}_t$ can be expressed as the linear combination of mutually uncorrelated random variables ε_t. Parametric matrices $\mathbf{C}_j$ are derived as

$$\mathbf{C}_j = \Phi_1\mathbf{C}_{j-1} + \Phi_2\mathbf{C}_{j-2} + \Phi_3\mathbf{C}_{j-3} + \ldots + \Phi_p\mathbf{C}_{j-p}\ , \qquad j = 1, 2, \ \ldots \tag{3.7}$$

where $\mathbf{C}_0 = \mathbf{I}_{n\times n}$ and $\mathbf{C}_j = \mathbf{0}$ for $j < 0$.

3.3 Impulse responses

Difficulty with the vector ε_t is its non-diagonal covariance matrix Ω_ε, as there is not possible to unambiguously assign an economic content to each shock (signal extraction problem). In order to derive structural innovations, it is necessary to identify structural form of VAR (3.3). For the identification we use the Cholesky factorization of matrix Ω_ε.[3] Therefore, let $\mathbf{A}_0$ be a lower triangular matrix arising from Cholesky factorization of Ω_ε in the form

$$\Omega_\varepsilon = \mathbf{A}_0\mathbf{D}\mathbf{A}_0^T \tag{3.8}$$

With the usage of $\mathbf{A}_0$, vector of structural innovations $\mathbf{u}_t$ will be acquired from ε_t through

$$\varepsilon_t = \mathbf{A}_0\mathbf{u}_t \tag{3.9}$$

and for this vector it applies

$$\mathbb{E}(\mathbf{u}_t\mathbf{u}_t^T) = \mathbf{A}_0^{-1}\mathbb{E}(\varepsilon_t\varepsilon_t^T)\mathbf{A}_0^{-T} = \mathbf{A}_0^{-1}\Omega_\varepsilon\mathbf{A}_0^{-T} = \mathbf{D} \tag{3.10}$$

where $\mathbf{D}$ is diagonal positive definite matrix.

Wold representation (3.6) can now be expressed with the aid of structural innovations $\mathbf{u}_t$

$$\mathbf{x}_t = \mathbf{A}_0\mathbf{u}_t + \mathbf{A}_1\mathbf{u}_{t-1} + \mathbf{A}_2\mathbf{u}_{t-2} + \mathbf{A}_3\mathbf{u}_{t-3} + \ldots = \sum_{j=0}^{\infty}\mathbf{A}_j\mathbf{u}_{t-j} \tag{3.11}$$

where $\mathbf{u}_t = \mathbf{A}_0^{-1}\varepsilon_t$ and $\mathbf{A}_j = \mathbf{C}_j\mathbf{A}_0$ for each $j \geq 0$. Entries of matrix $\mathbf{A}_j$, $j = 0, 1, \ldots,$ represent directly the values of orthogonalized impulse responses, because

$$\frac{\mathrm{d}\,\mathbf{x}_t}{\mathrm{d}\,\mathbf{u}_{t-j}^T} = \mathbf{A}_j = \begin{pmatrix} a_{11}^{(j)} = \frac{\partial x_{1t}}{\partial u_{1\,(t-j)}} & \cdots & a_{1n}^{(j)} = \frac{\partial x_{1t}}{\partial u_{n\,(t-j)}} \\ \vdots & \ddots & \vdots \\ a_{n1}^{(j)} = \frac{\partial x_{nt}}{\partial u_{1\,(t-j)}} & \cdots & a_{nn}^{(j)} = \frac{\partial x_{nt}}{\partial u_{n\,(t-j)}} \end{pmatrix} \tag{3.12}$$

apparently, $\mathbf{A}_j$ is Jacobi matrix. The form of $\mathbf{A}_j$ generally depends on the ordering of ε_t. In fact, importance of the ordering decreases when Ω_ε converges to the diagonal matrix and vice versa.

Because to choose a proper ordering of the vector ε_t is very often a demanding task, Koop et al. (1996) and Pesaran and Shin (1998) defined the

[3] In fact it is a special type of LU factorization applied to symmetric matrix; see Hamilton (1994) for instance.

generalized impulse response function, which enables to avoid this challenging choice. Generalized impulse response function (GIRF) for the vector of variables $\mathbf{x}_t$ and for h-period departs from the general expression[4]

$$GIRF_x(h, \delta_i, \Upsilon_{t-1}) = \mathbb{E}(\mathbf{x}_{t+h} \mid \varepsilon_{it} = \delta_i, \Upsilon_{t-1}) - \mathbb{E}(\mathbf{x}_{t+h} \mid \Upsilon_{t-1}) \tag{3.13}$$

where Υ_{t-1} is an information set consisting of the past values of $\mathbf{x}_t$; ε_{it} is i-entry of ε_t, which changes its value by δ_i in time t. Under the condition that the distribution of ε_t is characterized by the properties (3.4) and (3.5), it is possible to integrate out the influence of ε_{jt} for every $j \neq i$. This is due to the fact that if ε_t is multivariate normal then it applies[5]

$$\mathbb{E}(\varepsilon_t \mid \varepsilon_{it} = \delta_i) = (\sigma_{1i}, \sigma_{2i}, \ldots, \sigma_{ni})^T \sigma_{ii}^{-1} \delta_i = \Omega_\varepsilon \mathbf{e}_i \sigma_{ii}^{-1} \delta_i \tag{3.14}$$

where $\mathbf{e}_i$ is n-dimensional vector with one at i-th position and zero everywhere else; σ_{ji}, for $j \neq i$, are covariances from Ω_ε and $\sigma_{ii} = Var(\varepsilon_{it})$. Then if $\{\mathbf{x}_t\}$ is generated by (3.3) or (3.6) the GIRF takes the following particular form

$$GIRF_x(h, \delta_i, \Upsilon_{t-1}) = \left(\frac{\mathbf{C}_h \Omega_\varepsilon \mathbf{e}_i}{\sqrt{\sigma_{ii}}}\right)\left(\frac{\delta_i}{\sqrt{\sigma_{ii}}}\right) \tag{3.15}$$

where $\mathbf{C}_h$ is a parametric matrix from the Wold representation (3.6). When the matrix Ω_ε is diagonal, generalized impulse responses and orthogonalized impulse responses are equivalent.

3.4 Variance decomposition

The variance of $\mathbf{x}_t$ can be decomposed to

$$Var(\mathbf{x}_t) = \overbrace{\underbrace{Var\left(\mathbb{E}[\mathbf{x}_t|\Upsilon_{t-1}]\right)}_{\text{IR analysis}} + \underbrace{\mathbb{E}\left[Var(\mathbf{x}_t|\Upsilon_{t-1})\right]}_{\text{FEVD}}}^{\text{overall unconditional variance}} \tag{3.16}$$

where $Var\left(\mathbb{E}[\mathbf{x}_t|\Upsilon_{t-1}]\right)$ is the variance of the expected value of $\mathbf{x}_t$ conditioned on its history Υ_{t-1}. In dynamic models, this part of overall variance can be well explained by the impulse response analysis. On top of the expected value variance, there is also variance related to the stochastic nature of variables within the system. It captures the deviations from expected value due to

[4]This equation generally expresses the substance of impulse response analysis.
[5]It holds just for the linear models.

the external shocks and therefore it was called as the variance of forecast error. The forecast error variance decomposition (FEVD) was then proposed to analyze the deviations.

Accordingly, let us define forecast error of VAR (3.3) for period $t + h$[6]

$$\mathbf{x}_{t+h} - \mathbb{E}_t(\mathbf{x}_{t+h}) = \varepsilon_{t+h} + \mathbf{C}_1\varepsilon_{t+h-1} + \mathbf{C}_2\varepsilon_{t+h-2} + \mathbf{C}_3\varepsilon_{t+h-3} + \cdots + \mathbf{C}_{h-1}\varepsilon_{t+1} \tag{3.17}$$

and also corresponding mean square forecast error

$$\begin{aligned}\text{MSFE}\left(\mathbb{E}_t(\mathbf{x}_{t+h})\right) &= \mathbb{E}\left\{\left[\mathbf{x}_{t+h} - \mathbb{E}_t(\mathbf{x}_{t+h})\right]\left[\mathbf{x}_{t+h} - \mathbb{E}_t(\mathbf{x}_{t+h})\right]^T\right\} = \\ &= \Omega_\varepsilon + \mathbf{C}_1\Omega_\varepsilon\mathbf{C}_1^T + \mathbf{C}_2\Omega_\varepsilon\mathbf{C}_2^T + \mathbf{C}_3\Omega_\varepsilon\mathbf{C}_3^T + \cdots + \mathbf{C}_{h-1}\Omega_\varepsilon\mathbf{C}_{h-1}^T \end{aligned} \tag{3.18}$$

Rewrite the expression (3.9) as

$$\varepsilon_t = \mathbf{A}_0\mathbf{u}_t = \mathbf{a}_1 u_{1t} + \mathbf{a}_2 u_{2t} + \mathbf{a}_3 u_{3t} + \cdots + \mathbf{a}_n u_{nt} \tag{3.19}$$

where $\mathbf{a}_i$ is i-th column of matrix $\mathbf{A}_0$.
Using expression (3.19), covariance matrix Ω_ε can be written as

$$\begin{aligned}\Omega_\varepsilon = \mathbf{A}_0\,\mathbb{E}(\mathbf{u}_t\mathbf{u}_t^T)\mathbf{A}_0^T &= \mathbf{a}_1\mathbf{a}_1^T \times Var(u_{1t}) + \mathbf{a}_2\mathbf{a}_2^T \times Var(u_{2t}) + \\ &+ \mathbf{a}_3\mathbf{a}_3^T \times Var(u_{3t}) + \cdots + \mathbf{a}_n\mathbf{a}_n^T \times Var(u_{nt})\end{aligned} \tag{3.20}$$

where $Var(u_{it})$ is i-th diagonal entry of matrix $\mathbf{D}$.

To substitute expression (3.20) into (3.18), mean square forecast error attains the weighted sum of variances of structural innovations

$$\begin{aligned}\text{MSFE}\left(\mathbb{E}_t(\mathbf{x}_{t+h})\right) = \sum_{i=1}^{n}\{Var(u_{it}) \times [\mathbf{a}_i\mathbf{a}_i^T + \mathbf{C}_1\mathbf{a}_i\mathbf{a}_i^T\mathbf{C}_1^T + \mathbf{C}_2\mathbf{a}_i\mathbf{a}_i^T\mathbf{C}_2^T + \\ + \mathbf{C}_3\mathbf{a}_i\mathbf{a}_i^T\mathbf{C}_3^T + \cdots + \mathbf{C}_{h-1}\mathbf{a}_i\mathbf{a}_i^T\mathbf{C}_{h-1}^T]\}\end{aligned} \tag{3.21}$$

which is directly usable for the forecast error variance decomposition (FEVD). Unfortunately, FEVD also depends on the chosen ordering of ε_t.

[6]We use $\mathbb{E}_t(\mathbf{x}_{t+h})$ as a shorthand for the conditional expectation $\mathbb{E}(\mathbf{x}_{t+h}|\Upsilon_t)$, i.e. expectation of $\mathbf{x}_{t+h}$ based on the past development of $\mathbf{x}_t$ until the time t.

3.5 Cointegration and VECM

Disadvantage of VAR (3.3) is its overparametrization inducing an increase in the standard errors of estimated parameters. Overparametrization can be partially resolved by the application of cross-equation restrictions concerning the existence of cointegration. Taking into account non-stationary version of VAR (3.3), so $\mathbf{x}_t \sim I(1)$, and write it in the form of vector error correction model (VECM)[7], we receive

$$\Delta \mathbf{x}_t = \Pi\, \mathbf{x}_{t-1} + \Gamma_1\, \Delta \mathbf{x}_{t-1} + \Gamma_2\, \Delta \mathbf{x}_{t-2} + \Gamma_3\, \Delta \mathbf{x}_{t-3} + \cdots + \Gamma_{p-1}\, \Delta \mathbf{x}_{t-p+1} + \varepsilon_t \tag{3.22}$$

where[8]

$$\Pi \equiv -\left(\mathbf{I}_{n\times n} - \sum_{j=1}^{p} \Phi_j\right) \qquad \Gamma_j \equiv \left(-\sum_{i=j+1}^{p} \Phi_i\right) \tag{3.23}$$

If ε_t is multivariate normal, or $\varepsilon_t \sim i.i.d.\, \mathrm{N}(\mathbf{0}, \Omega_\varepsilon)$, then using symmetric transformation on matrix Π the eigenvalues of that matrix are obtained and based on them, one can determine the dimension of cointegration space (space generated by the rows of matrix Π); see Johansen (1988, 1991). Therefore, let r be the dimension and let $r \in (0, n)$. Matrix Π of order n and with the rank r can be consequently decomposed into the product of two matrices

$$\Pi = \Lambda\, \mathbf{B}^T \tag{3.24}$$

where matrix $\mathbf{B} \in \mathrm{M}(n \times r)$ includes coefficients of r linearly independent cointegrating vectors and matrix $\Lambda \in \mathrm{M}(n \times r)$ contains loading parameters.[9]

Once the VEC system (3.22) was estimated, VAR with cross-equation restrictions is derived as (see Lütkepohl, 2005)

$$\mathbf{x}_t = \Psi_1 \mathbf{x}_{t-1} + \Psi_2 \mathbf{x}_{t-2} + \Psi_3 \mathbf{x}_{t-3} + \ldots + \Psi_p \mathbf{x}_{t-p} + \varepsilon_t \tag{3.25}$$

where

$$\Psi_1 = \Pi + \mathbf{I}_{n\times n} + \Gamma_1 \tag{3.26}$$
$$\Psi_j = \Gamma_j - \Gamma_{j-1}, \qquad j = 2, \ldots, p-1 \tag{3.27}$$
$$\Psi_p = -\Gamma_{p-1} \tag{3.28}$$

[7]In fact it is a multivariate generalization of Dickey-Fuller test.
[8]Matrices Φ_j, $j = 1, 2, \ldots, p$, are parameters from the baseline VAR (3.3).
[9]$\mathrm{M}(n \times r)$ denotes the matrix space of order $n \times r$.

The VAR (3.25) is appropriate for Granger causality testing among variables in levels. In that respect, see Granger (1969) and Sims (1972). Impulse responses and forecast error variance decomposition can also be used for the analysis of estimated VAR (3.25), but in this case only finite amount of parameters would be achieved within the Wold representation. In order to prevent spurious regression, we assume a sufficiently long order of lag in VARs discussed above and below.[10] Accordingly, we use both information criteria and autocorrelation tests for the identification of optimum lag order.

3.6 Overview of cointegration techniques

As the cointegration is largely used in the thesis, we shall give a short overview of the time series cointegration techniques. Basically, we can distinguish three main approaches; classical OLS-based (Engle and Granger, 1987), likelihood-based (Johansen, 1988 and 1991) and structural-based (Pesaran et al., 2001). The Engle-Granger (1987) methodology, also known as the two-step approach, involves the estimation of the long-run equilibrium equation using a standard OLS procedure and subsequent application of the stationarity test on regression residuals. The Engle-Granger (1987) methodology is nevertheless appropriate and sufficient only in the case of testing cointegration for first-difference stationary bivariate random variables, because it does not provide any way to determine cointegration rank. Additional obstacles arise from the asymmetric nature of possible normalizations of the estimated long-run relationship as well as from the not fully specified dynamic structure of cointegrating regression (autocorrelated errors in the long-run equilibrium equation). Furthermore, no distinction between a trend in the data generating process and one in the cointegration relationship is possible.

The Johansen (1988, 1991) methodology, see the section 3.5, is comprehensive and less restrictive compared to the Engle-Granger one. It therefore generally allows the cointegration test for n-dimensional first-difference stationary vector variables and the possibility of more than one cointegrating vector. This approach is based on a multivariate generalization of ADF-factorization, using the maximum likelihood method for estimating a cointegration space and the likelihood ratio test for determining its dimension. The centre of interest is the relation among the number of non-zero eigenvalues of the matrix of long-run multipliers, its rank and the cointegration rank. The advantages of the Johansen (1988, 1991) methodology are a symmetric attitude to all variables (eliminating the decision about exogeneity), the

[10] Refer to Granger and Newbold (1974) for more information about spurious regression.

complex dynamic structure of the entire system and a power analytical tool in the form of impulse-response functions. On the contrary, a problematic aspect of this approach is its rather statistical nature, which leads in some instances to a problematic economic interpretation of the estimated system.

Finally, Pesaran et al. (2001) apply some restrictions on the Johansen system[11], and therefore we use the designation structural approach; for the exposition of a long-run structural approach, see also Garratt, Lee, Pesaran and Shin (2012). Restrictions consist mainly of a limitation to at most one cointegrating vector relating to the dependent variable; except for one variable, all other variables are considered long-run forcing (but this does not mean that variables cannot be mutually Granger causal) and allow the possibility of mixed I(0) and I(1) independent variables. Albeit long-run dynamics is restricted alongside an economic theory, the short-run dynamics is left unrestricted. Accordingly, the Pesaran et al. (2001) methodology requires, unlike the Johansen approach, an initial consideration of which variable will be taken as endogenous; other variables will then automatically be taken as weakly exogenous. These weakly exogenous regressors may be mutually cointegrated, but this is not of interest. Pesaran et al. (2001) approach is generally known instead as the bounds-testing approach or ARDL approach.

3.7 ARDL and bounds testing

Let us assume that we have $\{\mathbf{s}_t\}_{t=1}^{\infty}$, a $(k+1)$-dimensional vector stochastic process, which is generated by the following VAR(p)

$$\Phi(L)(\mathbf{s}_t - \mu - \eta t) = \varepsilon_t, \qquad t \in \mathbb{N} \tag{3.29}$$

Therefore, unlike previous sections, this section takes seriously the treatment of deterministic terms. To establish a link to the baseline VAR (3.3), let $\mathbf{x}_t \equiv \mathbf{s}_t - \mu - \eta t$ be a demeaned and detrended vector process, i.e. $\mathbf{x}_t$ is a zero mean purely random process (without any deterministic component).[12] The matrix polynomial in the multidimensional lag operator is defined as $\Phi(L) = \mathbf{I}_{k+1} - \sum_{j=1}^{p} \Phi_j L^j$, where $\mathbf{I}_{k+1}$ is the identity matrix of order $(k+1)$ and Φ_j is a $(k+1 \times k+1)$ unknown parametric matrix. Ultimately, the vector error term has an $i.i.d.$ $\mathrm{N}(\mathbf{0}, \Omega_\varepsilon)$ distribution, with a Ω_ε positive definite covariance matrix.

[11] See the next section for the full exact definition.

[12] In previous sections the vector $\mathbf{x}_t$ was a part of n-dimensional Euclidean space, now just assume $n = k+1$. The purpose of this decomposition of the dimension will be evident from the text below.

As previously, VAR(p) from (3.29) might be rewritten in the vector error correction form,[13]

$$\Delta \mathbf{s}_t = \left\{ -\Pi\mu + \left(\mathbf{I}_{k+1} - \sum_{j=1}^{p-1} \Gamma_j + \Pi \right) \eta \right\} - \Pi\eta t + \Pi \mathbf{s}_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta \mathbf{s}_{t-j} + \varepsilon_t \tag{3.30}$$

where

$$\Pi \equiv - \left(\mathbf{I}_{k+1} - \sum_{j=1}^{p} \Phi_j \right) \qquad \Gamma_j \equiv \left(- \sum_{i=j+1}^{p} \Phi_i \right) \tag{3.31}$$

If we partition the vector $\mathbf{s}_t$ as $\left(y_t, \mathbf{z}_t^T\right)^T$, then the purpose of Pesaran et al. (2001) approach is the conditional modeling of the scalar variable y_t given the k-vector $\mathbf{z}_t$, the past values $\{\mathbf{s}_{t-j}\}_{j=1}^{t-1}$ and $\mathbf{S}_0 = (\mathbf{s}_{1-p}, \ldots, \mathbf{s}_0)$, where $\mathbf{S}_0$ are initial conditions. Conformably with $\mathbf{s}_t = \left(y_t, \mathbf{z}_t^T\right)^T$, the error term ε_t is partitioned as $\varepsilon_t = \left(\varepsilon_{yt}, \varepsilon_{zt}^T\right)^T$ and its covariance matrix as

$$\Omega_\varepsilon = \begin{pmatrix} \omega_{yy} & \omega_{yz} \\ \omega_{zy} & \Omega_{zz} \end{pmatrix} \tag{3.32}$$

Consequently, ε_{yt} is defined throughout the sum of two mutually-separated elements,

$$\varepsilon_{yt} = \omega_{yz} \Omega_{zz}^{-1} \varepsilon_{zt} + v_t \tag{3.33}$$

where $v_t \sim i.i.d.\, \mathrm{N}(0, \omega_{vv})$, $\omega_{vv} = \omega_{yy} - \omega_{yz}\Omega_{zz}^{-1}\omega_{zy}$ and v_t is independent of ε_{zt}.

Upon two crucial assumptions, namely that the roots of the lag polynomial in (3.29) lie outside the unit circle or rest on it[14] and that there exists just one long-run equilibrium including the variable y_t ($\pi_{zy} = \mathbf{0}$, see below), the system of equations (3.30) can be simplified into the ARDL model (or conditional ECM)

$$\Delta y_t = \alpha + \pi_{yy}\tilde{y}_{t-1} + \left(\pi_{yz} - \theta^T \Pi_{zz}\right) \tilde{\mathbf{z}}_{t-1} + \sum_{j=1}^{p-1} \left(\gamma_{yj} - \theta^T \Gamma_{zj}\right) \Delta \mathbf{s}_{t-j} + \theta^T \Delta \mathbf{z}_t + v_t \tag{3.34}$$

[13] It differs from (3.22) only with the inclusion of deterministic terms.

[14] Naturally, the variable which is treated as dependent within the ARDL model has to be integrated of order one. In general, this assumption excludes the possibility of explosive roots and whereas the I(2) variables have a low probability in economics, it is often concluded that the methodology does not suffer from the so-called pre-testing problem (i.e. sometimes demanding decision, especially in the near unit root cases, concerning which variables are I(0) and I(1)).

where the tilde denotes trend-adjusted variables[15], hence $\tilde{y}_{t-1} = (y_{t-1} - \eta_y\, t)$ and $\tilde{\mathbf{z}}_{t-1} = (\mathbf{z}_{t-1} - \eta_z\, t)$; $\theta = \Omega_{zz}^{-1}\omega_{zy}$ traces out the covariance structure within the vector $\mathbf{s}_t$; and the intercept α relates to the parameters of (3.30). Finally, two partitions must be mentioned:

$$\Pi = \begin{pmatrix} \pi_{yy} & \pi_{yz} \\ \pi_{zy} & \Pi_{zz} \end{pmatrix} \qquad \Gamma_j = \left(\gamma_{yj}^T, \Gamma_{zj}^T\right)^T \tag{3.35}$$

The null hypothesis test of no level (cointegrating) relationship between y_t and $\mathbf{z}_t$ is equivalent to the test of linear restrictions in conditional ECM (3.34) in the form

$$H_0: \qquad \pi_{yy} = 0 \quad \wedge \quad \pi_{yz} - \theta^T \Pi_{zz} = \mathbf{0}^T \tag{3.36}$$

which is testable using the standard F-statistic

$$F = \frac{T - \ell}{m} \frac{RSS_0 - RSS_1}{RSS_1} \tag{3.37}$$

where m indicates the number of linear restrictions (in our case $m = k + 1$), T is the number of observations and ℓ represents the number of regressors in (3.34), so $(T - \ell)$ is the number of degrees of freedom of the unrestricted regression (3.34), RSS_1 refers to the residual sum of squares in this unrestricted regression and, finally, RSS_0 denotes the residual sum of squares in the restricted regression (model (3.34) with the above-stated linear restrictions applied).

Although the statistic (3.37) does not have and also does not converge to a standard F-distribution, Pesaran et al. (2001) proposed bounds on the critical values for the asymptotic distribution of that statistic. For a given number of variables in $\mathbf{z}_t$ (here it is k) and the significance level α, we can get the lower and upper bounds of critical values. The lower bound is based on the assumption that all variables in $\mathbf{z}_t$ are I(0) and, similarly, the upper bound on the assumption that all variables in $\mathbf{z}_t$ are I(1). These two sets of critical values provide critical value bounds covering all possible classifications of $\mathbf{z}_t$ into I(0), I(1), and mutually cointegrated processes. If the computed F-statistic falls below the lower bound, then cointegration is not possible by definition; on the contrary, F-statistic exceeding the upper bound is sufficient for drawing a conclusion about cointegration. In the third case, when the F-statistic lies between these boundary values, the test is inconclusive and in such circumstances, knowledge of the cointegration rank of forcing variables $\mathbf{z}_t$ is required to proceed further.

[15]We restricted the deterministic trend just to the long-run relation.

3.8 Bayesian VAR

To this point, presented models were solely based on the observed data and as such they are a part of the so-called frequentist econometrics. Aim of the frequentist econometrics is to estimate the parameters of the likelihood function of the underlying data generating process. Likelihood function of the Gaussian VAR(p) model (3.3), baseline model of the thesis, is

$$l(\phi|\mathbf{x}) = \left(\frac{1}{2\pi}\right)^{nT/2} \left|\mathbf{I}_{T\times T} \otimes \Omega_\varepsilon\right|^{-1/2} \times \\ \times \exp\left\{-\frac{1}{2}\left[\mathbf{x} - \left(\mathbf{Z}^T \otimes \mathbf{I}_{n\times n}\right)\phi\right]^T \left(\mathbf{I}_{T\times T} \otimes \Omega_\varepsilon^{-1}\right)\left[\mathbf{x} - \left(\mathbf{Z}^T \otimes \mathbf{I}_{n\times n}\right)\phi\right]\right\} \tag{3.38}$$

where $\phi = \text{vec}(\Phi_1, \ldots, \Phi_p)$, $\mathbf{x} = \text{vec}(\mathbf{x}_1, \ldots, \mathbf{x}_T)$, $\mathbf{Z} = [\mathbf{Z}_0, \ldots, \mathbf{Z}_{T-1}]$ and $\mathbf{Z}_t^T = [\mathbf{x}_t, \ldots, \mathbf{x}_{t-p+1}]$.

In addition to the data, Bayesians also include their initial guess of the model parameters ϕ into the analysis.[16] This initial guess is formulated by the prior probability density function (prior p.d.f.). Consequently, let the prior p.d.f. has a multivariate normal distribution

$$g(\phi) = \left(\frac{1}{2\pi}\right)^{n^2p/2} \left|\mathbf{V}_\phi\right|^{-1/2} \times \exp\left[-\frac{1}{2}(\phi - \phi^*)^T \mathbf{V}_\phi^{-1}(\phi - \phi^*)\right] \tag{3.39}$$

where ϕ^* is the prior mean of model parameters, $\mathbf{V}_\phi$ is the corresponding prior covariance matrix, n denotes the number of variables in VAR and p stands for the order of lag length.

There are many ways how to set the prior mean ϕ^* and the prior covariance matrix $\mathbf{V}_\phi$. We choose a widely known practice proposed by Doan, Litterman and Sims (1984) and Litterman (1986). Assuming stationary VAR, all AR(1) coefficients are set to have the same value of prior mean, which is smaller than one. For AR(p), when p > 1, it holds the simple rule that $\text{P}[\text{AR(p)} = 0] \to 1$[17] as $\text{p} \to \infty$.[18] The rate of convergence is just a matter of particular setting; see also the next paragraph. Generally, the prior value of autoregressive parameters reflects expected or observed rate of persistence of the studied time series. To enclose the considerations about the prior mean

[16] In a strict Bayesian sense, the initial guess should by no mean depend on the data. Nowadays, there are nevertheless used priors with some empirical meaning.

[17] Expression $\text{P}[\text{AR(p)} = 0]$ denotes the probability that the AR(p) coefficient equals the zero value.

[18] Often, prior mean of AR(p), for p > 1, is simply set to zero.

of model parameters, all cross-variable coefficients are set to have the value of zero for their prior mean.

Prior covariance matrix $\mathbf{V}_\phi$ is generated as

$$v_{ij,l} = \begin{cases} (\lambda/l)^2 & \text{for} \quad i = j \\ (\kappa\lambda\sigma_i/l\sigma_j)^2 & \text{for} \quad i \neq j \end{cases} \tag{3.40}$$

where $v_{ij,l}$ is a prior standard deviation for the coefficient between i-th and j-th variable and for the l-th lag. Based on this, autoregressive coefficients are coefficients with $i = j$ and cross-variable coefficients the coefficients with $i \neq j$. Parameter λ is the prior standard deviation for AR(1) coefficients. For other autoregressive coefficients AR$(1 + l)$, $0 < l < p$, prior standard deviation equals to λ/l with obvious property $\lambda/l \to 0$ with $l \to \infty$. Parameter κ then denotes the rate of the decay of prior variance λ^2 for the cross-variable coefficients, which is κ-times faster than for autoregressive coefficients. Prior variance of cross-variable coefficients is mainly driven by the ratio σ_i^2/σ_j^2 (ratio of residual variances[19]). In the case of the log-linear form of VAR model, the residual variances are smaller than one. Therefore, if the residual variance of the forcing variable (σ_j^2) is small enough, then much of the cross-variable dependency probably acts within the systematic part of the model. Accordingly, the prior variance of the cross-variable coefficient will be large enough to provide a huge space for the data in the estimation process. Conversely, if the residual variance of the forcing variable is large enough, then much of the cross-variable dependency is probably fostered by the working of external shock. Now, the cross-variable coefficient in the systematic part of the model should be near the zero and this fact is also reflected by the prior variance.

According to the Bayesian mixing rule[20]

$$g(\phi|\mathbf{x}) \propto g(\phi)l(\phi|\mathbf{x}) \tag{3.41}$$

kernel of the posterior probability density function is proportional to

$$\begin{aligned} g(\phi|\mathbf{x}) \propto \exp\Bigg\{-\frac{1}{2}\Bigg[\Big(\mathbf{V}_\phi^{-1/2}(\phi - \phi^*)\Big)^T\Big(\mathbf{V}_\phi^{-1/2}(\phi - \phi^*)\Big) + \\ + \left\{\left(\mathbf{I}_{T\times T}\otimes\Omega_\varepsilon^{-1/2}\right)\mathbf{x} - \left(\mathbf{Z}^T\otimes\Omega_\varepsilon^{-1/2}\right)\mathbf{x}\right\}^T \times \\ \times \left\{\left(\mathbf{I}_{T\times T}\otimes\Omega_\varepsilon^{-1/2}\right)\mathbf{x} - \left(\mathbf{Z}^T\otimes\Omega_\varepsilon^{-1/2}\right)\mathbf{x}\right\}\Bigg]\Bigg\} \end{aligned} \tag{3.42}$$

Posterior p.d.f. (3.42) represents a likelihood function of Bayesian VAR (BVAR). As the prior p.d.f. and the likelihood function are both normally

[19] Diagonal entries of the matrix Ω_ε.

[20] Prior view on ϕ is updated about the data information.

distributed (conjugate pair), the posterior p.d.f. also has normal distribution. Because posterior distribution has a closed-form solution, there is not necessary to use numerical integration. Covariance matrix Ω_ε frequently takes a fixed value within the BVAR estimation, when it is easily let to be equal to the ML estimate of residual covariance matrix of the VAR (3.3). Sometimes, zero restrictions are also posed on non-diagonal entries of the matrix Ω_ε.

Based on the posterior p.d.f. (3.42), posterior mean of ϕ takes the form[21]

$$\bar{\phi} = \left[\mathbf{V}_\phi^{-1} + \left(\mathbf{Z}\mathbf{Z}^T \otimes \Omega_\varepsilon^{-1}\right)\right]^{-1} \left[\mathbf{V}_\phi^{-1}\phi^* + \left(\mathbf{Z} \otimes \Omega_\varepsilon^{-1}\right)\mathbf{x}\right] \tag{3.43}$$

and posterior covariance matrix of ϕ looks like this

$$\bar{\Sigma}_\phi = \left[\mathbf{V}_\phi^{-1} + \left(\mathbf{Z}\mathbf{Z}^T \otimes \Omega_\varepsilon^{-1}\right)\right]^{-1} \tag{3.44}$$

VAR (3.3) can then be looked as a special case of BVAR with diffuse (uninformative) prior, for which $\mathbf{V}_\phi \to \infty$. If $\mathbf{V}_\phi \to \infty$ then also $\mathbf{V}_\phi^{-1} \to 0$ and $\bar{\phi}$ shrinks into the GLS estimator of usual frequentist VAR

$$\phi^{GLS} = \left(\mathbf{Z}\mathbf{Z}^T \otimes \Omega_\varepsilon^{-1}\right)^{-1} \left(\mathbf{Z} \otimes \Omega_\varepsilon^{-1}\right)\mathbf{x} \tag{3.45}$$

and the GLS estimator of its covariance matrix

$$\Sigma_\phi^{GLS} = \left(\mathbf{Z}\mathbf{Z}^T \otimes \Omega_\varepsilon^{-1}\right)^{-1} \tag{3.46}$$

For more informative treatise about Bayesian statistics and BVAR see Koop (2003) and Lütkepohl (2005).

[21] Bayesian inference considers the model parameters as random variables and so they have usual statistical distribution.

4 Results

4.1 Money demand behavior

4.1.1 Description of the data

The data used for the research of money demand behavior come from the databases of the Czech Statistical Office and the Czech National Bank. The data are in the form of quarterly time series and cover the period of the first quarter of 1998 through the second quarter of 2014. Consequently, there are 66 observations for each time series. It could be said, that the sample is sufficient for a purpose of the estimation of long-run fundamental linkages among the studied variables. Moreover, the period possesses the stability of structural parameters of the Czech economy. It is also consistent with respect to the monetary policy regime – the inflation targeting has been adopted in the Czech Republic in January 1998. The results presented in this section can thus be understood as a continuation of Arlt et al. (2001) and Hanousek and Tůma (1995), based on a more reliable and more up-to-date data.

Within the research we consider both the narrow and broader money. Narrow money are defined as the M1 monetary aggregate and so they include the currency (money in the circulation without the cash at the banks' cash desks) and the demand deposits of non-banking residents (excluding the government). Definition of the broader money corresponds to the M2 monetary aggregate. As a result, broader money includes the whole M1 aggregate and on top of that also the time deposits and repo operations. Credit aggregate is formed by the total volume of loans provided to the domestic agents, such as households, firms and government (including also government bonds). Real money (credit) balances are the deflated value (by the GDP deflator) of the respective monetary or credit aggregate. Real effective exchange rate is measured as the number of units of effective foreign currency per one unit of domestic currency. The weights for the computation of effective index were based on the share of a particular country on the total foreign trade turnover of the Czech Republic. Domestic and foreign GDP deflators were used as the price indices. Unemployment rate conforms the ILO rules for its computation. Interest rate is proxied by the Prague interbank offered rate (know also as PRIBOR) for the three-month deposits. Real production is measured as the real gross domestic product (GDP) of the Czech Republic. Finally, for

Table 4.1: Integration order of observed time series

	Order of integration
Monetary aggregate M1	I(2)
Monetary aggregate M2	I(2)
Credit aggregate	I(1)
Real money balances M1	I(1)
Real money balances M2	I(0)
Real credit balances	I(1)
Income velocity of money M1	I(1)
Income velocity of money M2	I(1)
Income velocity of credit	I(1)
Three-month interest rate PRIBOR	I(1)
Real production	I(1)
Unemployment rate	I(1)
Real effective exchange rate	I(1)

Note: I(·) denotes the order of integration so that the I(2) variables are stationary in second differences, I(1) variables in first differences and I(0) variables are stationary in levels.

Source: Own computations.

the two monetary aggregates and the credit aggregate we have computed the money velocities, as we divided by them the nominal volume of production. For all time series, we have tested the presence of seasonality. It was the case of only the real production and all three money velocities. The seasonality was therefore removed for these time series and the TRAMO/SEATS method was used for this purpose. Notice also that all the time series are in natural logarithms when enter into the model.

4.1.2 Stochastic properties of observed time series

Before the actual analysis of the main questions of this section, we would like to mention stochastic properties of the observed time series. These properties largely determine the way in which a research is conducted. In particular, the first-moment stationarity of time series is the most important and therefore Table 4.1 contains the results of Augmented Dickey-Fuller tests.[1] Regarding this, all the time series were expressed in natural logarithms, which frequently lead into a linearization of possibly non-linear deterministic trends and it also

[1]For a space saving the detailed numerical results are not reported, but they are available upon request.

induces stationary within the second moments.

To start with the monetary aggregates, Table 4.1 shows that these aggregates are stationary up to the second differences. It means that changes in the money supply, and in its rate of growth as well, have permanent effect on the future development of money in the circulation. This outcome corresponds to the inflation targeting regime, which has been used by the Czech National Bank since January 1998. In fact, it should be expected for any central bank conducting policy based on the rules rather than discretion. Beside the monetary aggregates, credit aggregate attains stationarity on the first differences. Therefore, growth rate of loans was stable over the observed period and until the 2005 it reflected the growth rate of real production. After that year, growth rate of loans was higher than growth rate of real production.

Comparing the development of both monetary aggregates with the development of corresponding real money balances on Figure 4.1, we observe a high degree of similarity.[2] This is mainly due to a visual dominance of deterministic trends of observed time series. Looking at the stochastic behavior, one realizes substantial differences. Real money balances in the broader sense (defined through M2 aggregate) exerts the trend stationarity and therefore they are stable along the deterministic trend and are also easily predictable. The volume of this balances changes only slowly and economic agents demand them in accordance with the evolution of their long-run needs. During the demand, economic agents are not systematically affected by economic disturbances.

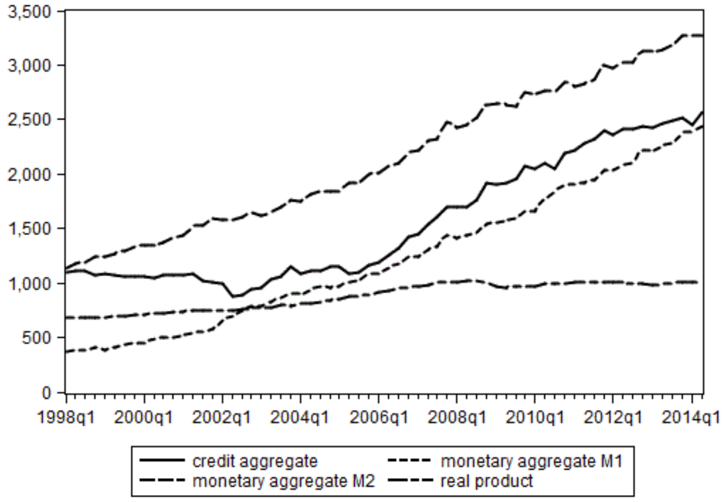
On the contrary, real money balances in the narrow sense (within M1 aggregate) are first-difference stationary.[3] Different order of integration between money balances in the broader and narrow sense can be explained by a portfolio re-optimization effect, which comes into play after an influence of economic shock. The essence of portfolio re-optimization effect consists in the existence of financial instruments with a similar level of liquidity and risk as money have, but with a higher level of interest. These instruments are mainly the time deposits and treasury bills. Actually, they are the time deposits which might explain the difference in order of integration between M1 and M2 real money balances, because in a consequence of interest-rate changes the M2 aggregate only adjusts its structure, but M1 aggregate differs in volume.[4]

Regarding money velocities, they are first-difference stationary as well;

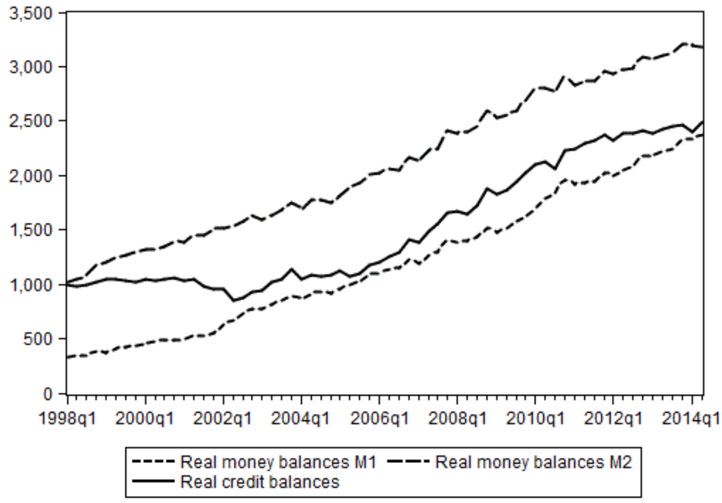
[2]The same also applies for credit aggregate and real credit balances.
[3]The same also holds for the real credit balances.
[4]To remind, M2 aggregate includes the time deposits, but M1 does not.

Figure 4.1: Observed time series - first group

(a) Monetary aggregates and real production



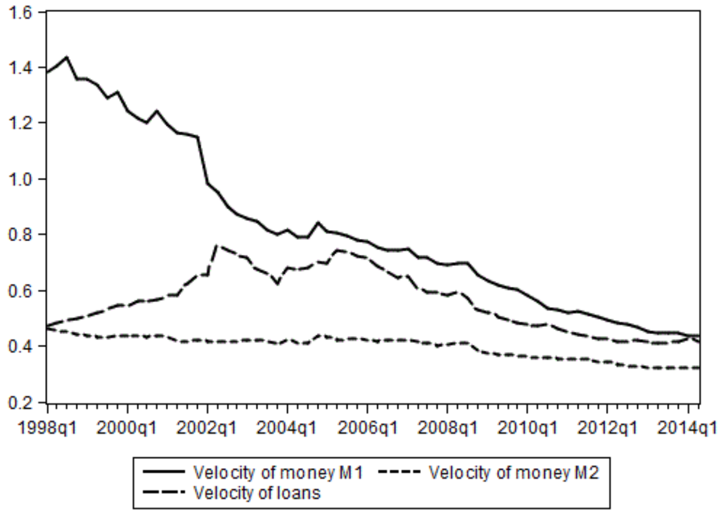
(b) Real money balances



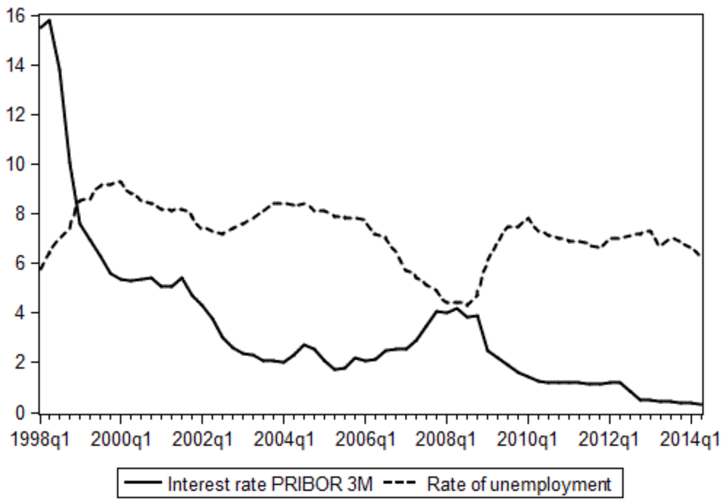
Source: Czech Statistical Office, Czech National Bank.

Figure 4.1: Observed time series - second group

(c) Income velocities



(d) Rate of interest and unemployment rate



Source: Czech Statistical Office, Czech National Bank.

see Table 4.1. It can be assumed that these velocities absorb a part of disequilibriums in the economy. Downward linear trend of the velocities is linked to improvements on the Czech financial market during the time and it relates to a growing importance of speculative demand. Relationship between speculative demand and economic development was first observed by Polak (1957). Increased importance of speculative demand was further strengthened by observed tendencies towards a higher risk of financial instruments. Riskiness of government bonds during the European debt crisis may serve as an example. A faster decline in income velocity M1 is due to a greater sensitivity of the narrow money to the interest rate; this is in accordance with the above mentioned portfolio re-optimization effect. The interest rate attains stationarity on the first differences, which reflects its role as an operating target within the inflation targeting regime – the monetary policy based on the mid-term trends rather than on a fine tuning the economy. To complete the list of variables, notice that the real production, unemployment rate and real effective exchange rate are all first-difference stationary.

Considering the existence of common stochastic trends, we construct the VAR model with the usage of following variables[5]: real money balances M1 (M/P), real production (Y), rate of unemployment (u), rate of interest PRIBOR 3M (i), and the real effective exchange rate ($REER$). All of the variables have the same order of integration; see Table 4.1. Table 4.2 presents the results of estimation of the VAR for a varying lag order and the different structure of deterministic components. More specifically, it includes the values of computed information criteria and the values of test statistics from Ljung-Box autocorrelation tests. The VAR was estimated both on levels and on first differences. As Table 4.2 shows, Akaike information criterion (AIC) indicates the value of two as an optimal lag order for the VAR in levels and without deterministic linear trend. On the other hand, Schwarz Bayesian criterion (SBC) recommends the value of one in this specification. But according to the autocorrelation tests, VAR(1) is insufficient for the description of persistence in level variables.[6] For the VAR with linear deterministic trend, AIC indicates the order of three as optimal, whereas SBC remains at the order of one. Also in this case, VAR(1) is insufficient due to the presence of autocorrelated residuals. If we compare the information criteria for the VAR model with and without the deterministic linear trend, both AIC and SBC speak for the specification with linear trend. This conclusion is supported by Figure 4.1. To describe the behavior of growth rates, so the stationary variables, VAR(1) with constant seems to be appropriate; see Table 4.2.

[5] Parentheses contain the shortcuts for a simplification of further writing.

[6] Autocorrelated residuals are detected in three equations.

Table 4.2: VAR representation of observed time series

	VAR(p) with constant for variables in levels						
	Information criteria		4th-order Ljung-Box Q-stat for the equation				
p	AIC	SBC	M/P	Y	u	i	REER
1	-20.3252	-19.2871*	2.90	4.99	19.47***	11.17**	8.75*
2	-20.4632*	-18.5599	0.68	7.41	4.32	3.73	4.64
3	-20.4547	-17.6863	3.21	3.20	0.73	3.94	4.10
4	-20.2863	-16.6529	4.89	2.87	0.37	4.26	0.99
5	-20.2575	-15.7589	4.06	6.09	2.32	2.23	0.44
	VAR(p) with constant and linear trend for variables in levels						
	Information criteria		4th-order Ljung-Box Q-stat for the equation				
p	AIC	SBC	M/P	Y	u	i	REER
1	-20.7034	-19.4922*	1.74	2.05	15.36***	8.69*	8.39*
2	-20.6738	-18.5975	1.66	6.99	4.48	4.45	2.36
3	-20.7496*	-17.8083	3.10	2.43	0.71	3.32	0.93
4	-20.5198	-16.7133	3.72	3.33	0.47	1.58	0.59
5	-20.4600	-15.7884	3.71	5.58	2.29	1.32	0.55
	VAR(p) with constant for variables in first differences						
	Information criteria		4th-order Ljung-Box Q-stat for the equation				
p	AIC	SBC	M/P	Y	u	i	REER
1	-20.1013*	-19.0541*	1.01	5.14	5.28	6.37	6.42
2	-19.8499	-17.9301	1.57	11.13	1.37	4.82	3.36
3	-19.8847	-17.0922	0.90	2.34	0.57	3.20	0.22
4	-19.7846	-16.1195	2.29	1.81	0.76	1.97	0.17
5	-19.6958	-15.1581	1.91	4.06	0.94	0.53	0.02

Note: Star at the information criteria signifies the minimal value, or the optimal lag order. Stars at the Ljung-Box autocorrelation tests indicate when the test statistic exceeds the critical value $\chi^2_{1-\alpha}(4)$ and they are used in the following manner: * for significance at 10 %, ** for significance at 5 %, and *** for significance at 1 %.

Source: Own computations.

4.1.3 Estimated money demand function and its implications

Definition of the real money balances used for the econometric investigation corresponds to the M1 aggregate. Two reasons can be raised for that decision. First reason is rather technical and consists in the order of integration of the narrowly defined real money balances. Stationarity at the first differences of the real money balances M1 enables to differentiate between short-run fluctuations and long-run trends. Above that, this demand is not immune to the action of economic disturbances and therefore it also allows to observe the adjustments to these shocks. In contrast, the real money balances M2 are stationary in levels and therefore they do not move significantly away from the long-run trend. As such, the broad demand for real money balances can be explained by the steady-state development of forcing variables (determinants of money demand).

Table 4.3 includes pairwise correlations between the steady-state variables, where real production, unemployment rate, interest rate and real effective exchange rate were considered as the determinants of M2 money demand. Steady-state development of the forcing variables was derived through the Hodrick-Prescott filter; see Hodrick and Prescott (1997). As follows from Table 4.3, the demand for real money balances M2 (RM2 in Table 4.3) coincides with the real production from 96 %, with the unemployment rate from 79 %, with the interest rate from 81 %, and with the real effective exchange rate from 91 %.[7] Demand for the real money balances M2 reacts positively to an increase in the real production and the real effective exchange rate, but negatively to an increase in the unemployment rate and the rate of interest. Except the unemployment rate, all remaining variables influence the demand for real money balances in expected way. Regarding the statistical significancy, all estimated coefficients are significant at the five-percent level.

Second reason for the choice of real money balances M1 is the content of monetary aggregates measured by the Czech National Bank. Apart from the currency and demand deposits, M2 aggregate includes also the time deposits and repo operations. If we take into account the usual definition of money, where they are defined as the funds with a high degree of liquidity, minimal risk (consisting only in a high rate of inflation) and zero yield held by the non-banking residents, the M2 aggregate obviously does not fit well into this definition. The most contentious are the repo operations, which need not be transform through the credit creation into the hands of non-banking agents. For their lower level of liquidity and non-zero yield, the time deposits

[7]Notice that the relationships are not necessary direct in nature.

Table 4.3: Determinants of real money balances M2

	RM2	Y	u	i	REER
RM2	1	0.9579 (26.6916) [< 0.0001]	-0.7846 (-10.1238) [< 0.0001]	-0.8119 (-11.1258) [< 0.0001]	0.9078 (17.3160) [< 0.0001]
Y		1	-0.8885 (-15.4900) [< 0.0001]	-0.8468 (-12.7360) [< 0.0001]	0.9859 (47.1340) [< 0.0001]
u			1	0.5493 (5.2588) [< 0.0001]	-0.8921 (-15.7950) [< 0.0001]
i				1	-0.8515 (-12.9912) [< 0.0001]
REER					1

Note: Correlation coefficients are based on the steady-state developments of observed variables, which were derived through the Hodrick-Prescott filter. Parentheses include the test statistics (for the test of the null $\rho = 0$) computed as $T = \left(r\sqrt{n-2}\,\right)/\left(\sqrt{1-r^2}\,\right)$, where n is the number of observations used for the computation of pairwise correlation r. Values in square brackets are the corresponding two-sided probabilities of the Student t-distribution with 64 degrees of freedom.

Source: Own computations.

Table 4.4: Results of the Johansen test for cointegration

Trace test			
Eigenvalue	Test statistic	Critical value	Probability
0.5227	116.0417	88.8038	0.0002
0.4073	69.4468	63.8761	0.0158
0.2752	36.4956	42.9153	0.1888
0.1256	16.2164	25.8721	0.4753
0.1159	7.7587	12.5180	0.2720
Eigenvalue test			
Eigenvalue	Test statistic	Critical value	Probability
0.5227	46.5950	38.3310	0.0045
0.4073	32.9512	32.1183	0.0345
0.2752	20.2792	25.8232	0.2275
0.1256	8.4577	19.3870	0.7788
0.1159	7.7587	12.5180	0.2720

Note: Critical values are computed based on MacKinnon, Haug and Michelis (1999) and they correspond to the 0.05 probability.

Source: Own computations.

should be considered rather as a quasi money as well. To summarize, the M2 aggregate is undesirable for its internal heterogeneity.

Let us now explore the existence of cointegrating relationships inside the VAR of variables M/P, Y, u, i, $REER$. Based on Table 4.2 we used the VAR(3) with constant and trend, and the Johansen approach for testing of cointegration (see Johansen (1988,1991)). Results of the cointegration test are summarized in Table 4.4. Both trace test and eigenvalue test of the matrix Π jointly declare the existence of two linearly-independent cointegrating vectors. According to the Granger theorem (see Engle and Granger, 1987), the VEC representation can be estimated consequently. See Appendix A in that respect. Moreover, upon the existence of cointegration we might apply the cross-equation restrictions on the parameters of unrestricted VAR. Estimated VAR with cross-equation restrictions then looks as follows

$$\mathbf{x}_t = \mu + \beta t + \Psi_1 \mathbf{x}_{t-1} + \Psi_2 \mathbf{x}_{t-2} + \Psi_3 \mathbf{x}_{t-3} + \varepsilon_t, \qquad \varepsilon_t \sim (\mathbf{0}, \Omega_\varepsilon) \tag{4.1}$$

where

$$\mathbf{x}_t = (M_t/P_t, Y_t, u_t, i_t, REER_t)^T \tag{4.2}$$
$$\mu = (2.718, -1.199, 1.775, -14.725, -4.417)^T \tag{4.3}$$
$$\beta = (0.004, -0.002, 0.003, -0.019, -0.006)^T \tag{4.4}$$

$$\Psi_1 = \begin{pmatrix} 0.423 & 0.185 & -0.162 & -0.057 & 0.792 \\ 0.013 & 1.218 & 0.005 & 0.012 & 0.052 \\ -0.087 & -2.964 & 1.033 & -0.046 & -0.136 \\ -0.536 & 2.469 & -0.695 & 1.114 & -0.691 \\ 0.214 & 0.197 & 0.017 & 0.023 & 0.995 \end{pmatrix} \tag{4.5}$$

$$\Psi_2 = \begin{pmatrix} 0.128 & -1.263 & 0.036 & 0.006 & -0.367 \\ 0.047 & -0.289 & -0.002 & -0.029 & -0.156 \\ -0.445 & 2.761 & 0.219 & 0.102 & 0.908 \\ 0.654 & -2.246 & 0.503 & -0.375 & -0.899 \\ 0.087 & -1.278 & 0.009 & -0.023 & -0.362 \end{pmatrix} \tag{4.6}$$

$$\Psi_3 = \begin{pmatrix} 0.018 & 1.029 & 0.096 & -0.027 & 0.455 \\ -0.034 & 0.149 & 0.009 & 0.011 & 0.069 \\ 0.165 & 0.198 & -0.278 & -0.128 & -0.013 \\ 0.307 & 0.687 & 0.224 & 0.210 & 0.920 \\ -0.057 & 1.317 & 0.026 & 0.013 & -0.083 \end{pmatrix} \tag{4.7}$$

$$\Omega_\varepsilon = \begin{pmatrix} 1 & -0.085 & -0.246 & -0.056 & 0.318 \\ -0.085 & 1 & -0.435 & -0.139 & -0.015 \\ -0.246 & -0.435 & 1 & -0.046 & -0.235 \\ -0.056 & -0.139 & -0.046 & 1 & 0.026 \\ 0.318 & -0.015 & -0.235 & 0.026 & 1 \end{pmatrix} \tag{4.8}$$

The VAR (4.1) was derived with the aid of expressions stated in the section 3.5 and with the usage of estimated VECM in Appendix A.[8] At this moment, we shall also mention the two equilibrium relationships. First equilibrium is the long-run demand for the real money balances M1 in open economy and has the form

$$\frac{M}{P} = 4.5995 + 0.0084t - 0.0708u - 0.1987i + 2.0728REER \tag{4.9}$$

Accordingly, the relationship between M/P and i, and between M/P and $REER$ as well, confirms the initial assumptions. Increase in the interest rate therefore leads in equilibrium into a decrease in the demand for real money balances M1; irrespective of whether from the speculative or transaction motive. On the other hand, appreciation of the real effective exchange rate[9] affects the demand for real money balances M1 positively and leads into its increase. In a conflict with the initial assumption seems to be the relationship between real money balances M1 and the rate of unemployment. Against the two previous ones, this relationship is statistically insignificant; see Appendix A. Notice that the negative link was also revealed between unemployment rate and real money balances M2. According to our analysis the precautionary motive is rather procyclical than countercyclical. This outcome probably binds to the expectations of economic agents. As rational-expectation agents realize the different phases of business cycle, they hoard the precautionary savings during a boom and spend them during a recession. Based on estimated elasticities in the equation (4.9), real effective exchange rate exhibits the most profound influence on the demand for real money balances M1. It reflects the high degree of capital mobility and the working of uncovered interest rate parity. Beside the elastic demand with respect to the real effective exchange rate (elasticity equals 2.1), the demand for real money balances M1 is inelastic with respect to the interest rate (elasticity equals 0.2).

Equation (4.9) also implies that there is no direct link in equilibrium between the demand for real money balances M1 and real production (volume of transactions). That link is only mediated by other variables in the system (interest rate, real effective exchange rate and unemployment rate) and by the existence of second equilibrium. The second equilibrium reminds the open-economy IS curve

$$Y = 14.0159 + 0.0171t - 0.0024u + 0.1486i - 0.2317REER \tag{4.10}$$

[8] The derivation is more difficult with a presence of deterministic components; see Pesaran et al. (2001) for more information.

[9] Increased purchasing power of the domestic currency with respect to foreign goods and services.

but this interpretation is cumbersome due to a positive slope of the IS curve (with respect to the interest rate).[10] Hence, we have tried to change the position of real production and the interest rate in equation (4.10) to reach the following

$$i = -94.3197 - 0.1151t + 6.7295Y + 0.0162u + 1.5592REER \qquad (4.11)$$

Equation (4.11) then acts as a monetary-policy reaction function with respect to the real economy.[11] For endogeneity of interest rate in the second equilibrium speaks also the value of loading parameter; Appendix A provides a comparison with other variables. Relationship between interest rate and real production is the only statistically significant in the equation (4.11).

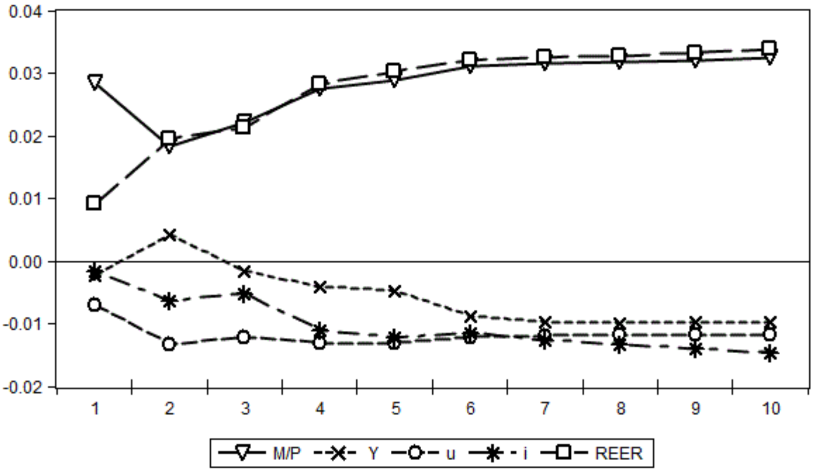
To consider both equilibriums together, one can see that the growth of real production leads into an increase in the interest rate with a follow-up decrease in the demand for real money balances M1. Negative indirect link between the real production and the demand for real money balances M1 is confirmed by the estimated impulse responses; see Figure 4.2. Absence of the direct connection between the real production and real money balances M1, together with the observed negative relationship between money balances and unemployment rate, encourage us to believe that money demand depends on the business cycle rather than on the level of real production itself. Consequently, real money balances are demanded with respect to a ratio of the actual volume of transactions to the volume of transactions at the natural level of production, rather than along to the current level of transactions. This hypothesis implies a variation in the money velocity, which poses a higher rate of persistence. As stated above, the persistence in money velocity was actually revealed in the Czech Republic. Unemployment rate therefore substitutes the output gap in equation (4.9). Figure 4.3 measures the goodness of fit of that proxy. To conclude, economic agents demand more money balances in the upswing of economic activity and demand less during the downturns.

However, taking into account the elasticities from equation (4.9), sensitivity of the demand for real money balances to the business cycle is very low (elasticity takes the value of 0.07). We thus come to the conclusion that a large part of the transactions demand is probably constant over time and its influence on the equilibrium demand for real money balances concentrates

[10] Signs at the real effective exchange rate and unemployment rate are in line with economic theory.

[11] It is usual in the flexible inflation targeting regime that a central bank reacts not only to the development of inflation but also to the development of real economy. That does not impose a mismatch between the number of monetary policy targets and the tools for their achievement, because the inflation is targeted in a medium term.

Figure 4.2: Impulse responses of the demand for real money balances M1



Note: Figure includes the generalized impulse responses of the demand for real money balances M1 to one standard deviation shock in a specified variable. Vertical axis is measured as the percentage ratio and the horizontal axis is in quarters.

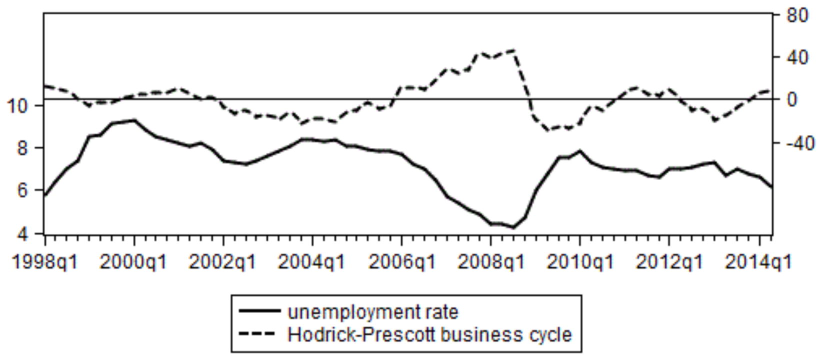
Source: Own computations.

mainly within the intercept.[12] It entitles us to think about a certain level of saturation of the transactions demand and about its achievement in the Czech Republic. If we additionally assume that the opportunity costs of holding money play a role in the determination of transactions demand only in the situation of higher interest rates (see Tobin, 1956), the evolution of money demand as a whole depends crucially on the speculative demand. Development of the interbank interest rate in the Czech Republic during the period under the review is captured on Figure 4.1. Higher interest rate might be observed just at the beginning of the period.

Granger causality tests (see Appendix B) show strong interdependence among the observed variables. The exceptions are the unemployment rate and real production, and the interest rate and real effective exchange rate. Unemployment rate does not Granger cause the real production and similarly the rate of interest does not Granger cause the real effective exchange rate. Due to this strong interdependency and because of the some large non-diagonal entries of matrix Ω_ε in the VAR (4.1), the usage of usual orthogonalized impulse responses is somewhat tricky. We can expect a great dependence of these orthogonalized impulse responses on the ordering of vector ε_t. In

[12]This applies for the transaction motive rather than for the precautionary one.

Figure 4.3: Unemployment rate as a business cycle indicator



Source: Czech Statistical Office; own computations.

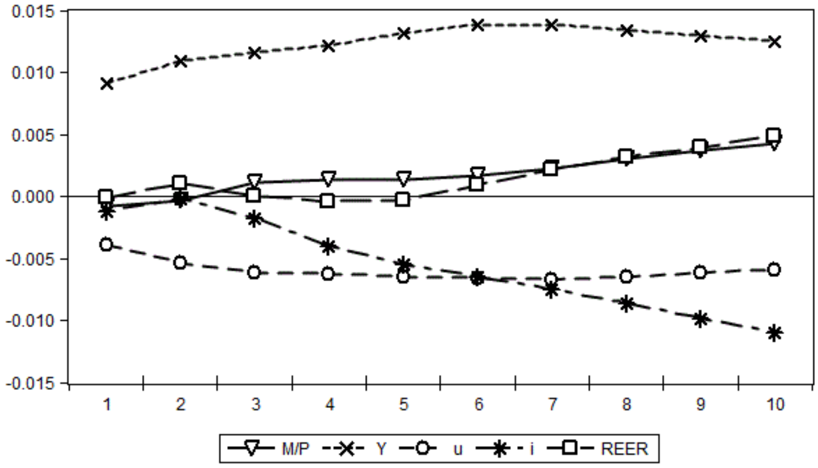
fact, there are 120 options how to order the vector ε in VAR (4.1). For that reason we chose to capture the pass-through of the shocks by the generalized impulse responses. Figure 4.2 includes the generalized impulse responses for the real money balances M1 and Figure 4.4 for the real production, rate of unemployment, interest rate and real effective exchange rate. Interpretation of Figure 4.2 is similar to the foregoing. Figure 4.4 indicates the existence of feedback between the demand for real money balances and the real effective exchange rate. So, the appreciation of real effective exchange rate enforces an increase in the money demand and this increase is followed by a further appreciation. The feedback (together with the descending interest rates) can be a factor behind the long-run upward trend of the demand for real money balances and also partly behind the long-run tendency of the real effective exchange rate to appreciate.

Obstacles raised against the application of orthogonalized impulse responses remain also valid for the variance decomposition of forecast error. We therefore avoid this analysis for its imprecise results. Finally notice that Appendix C contains the generalized impulse responses for the growth rates of observed variables.[13] As Appendix C presents, the growth rates are mutually independent. For example, shock to the growth of interest rate does not influence a growth path of the demand for real money balances. In fact the same holds for a shock to the growth of unemployment rate and the real effective exchange rate.

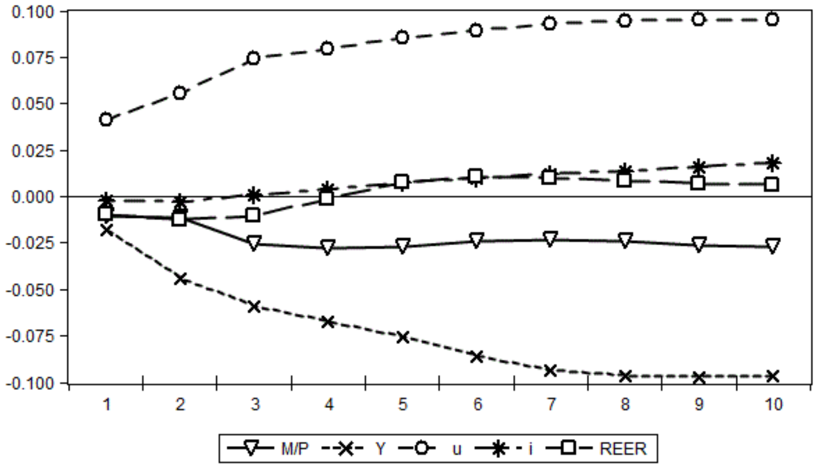
[13]Because of the stationary of these variables, VAR(1) with constant seemed to be the most appropriate.

Figure 4.4: Impulse responses of other variables - real-economy variables

(a) Impulse responses of real production



(b) Impulse responses of unemployment rate

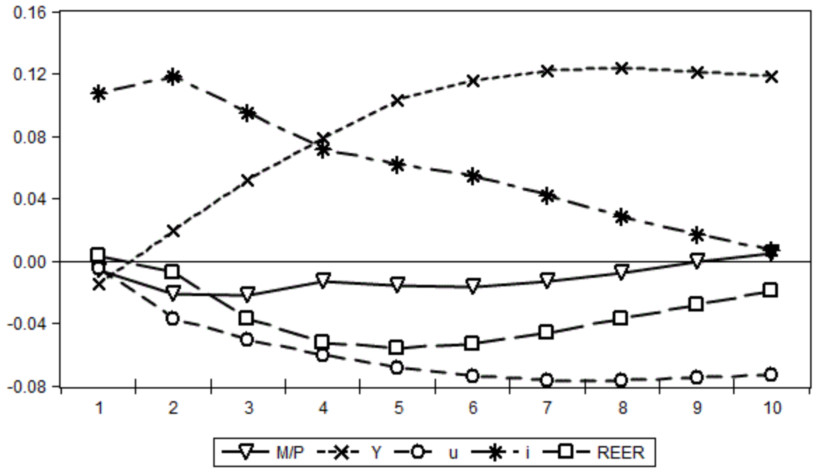


Note: Generalized impulse responses to one standard deviation shock in a specified variable. Vertical axis is measured as the percentage ratio and horizontal axis is in quarters.

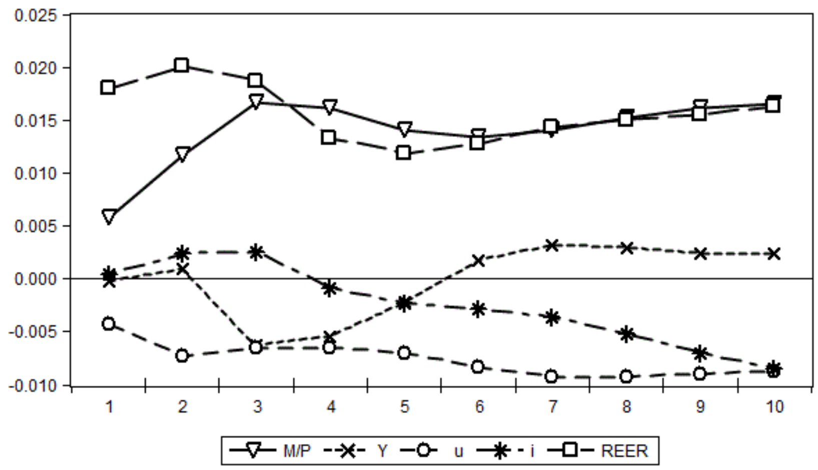
Source: Own computations.

Figure 4.4: Impulse responses of other variables - monetary variables

(c) Impulse responses of interest rate



(d) Impulse responses of real effective exchange rate



Note: Generalized impulse responses to one standard deviation shock in a specified variable. Vertical axis is measured as the percentage ratio and horizontal axis is in quarters.

Source: Own computations.

4.2 Macroeconomic consequences of exchange-rate devaluation

4.2.1 Trade balance model and the data

A trade balance model in the long run or a long-run equilibrium model can be defined as

$$tb_t = \delta_0 + \delta_1 t + \delta_2\, yd_t + \delta_3\, yf_t + \delta_4\, reer_t + \delta_5\, PRB_t + \delta_6\, LRB_t + v_t, \quad v_t \sim i.i.d.\,(0, \sigma_v^2) \quad (4.12)$$

where tb_t is the logarithm of the Czech trade balance expressed as exports of goods and services to the rest of the world over imports of goods and services from the rest of the world.[14]

The logarithm of domestic income in the small open economy, labeled as yd_t, is computed in the following manner

$$yd_t \equiv \log(RGDP_t + BI_t + BT_t + TT_t) \quad (4.13)$$

$RGDP_t$ represents the Czech Republic's gross domestic product at constant prices, BI_t is the balance of incomes deflated by the GDP deflator[15], BT_t is the balance of transfers, also deflated by the GDP deflator[16], and TT_t is the income effect of a change in the terms of trade. We compute the income effect of a change in the terms of trade as

$$TT_t \equiv \frac{NX_t}{P_t^A} - \left(\frac{EX_t}{P_t^{EX}} - \frac{IM_t}{P_t^{IM}}\right) \quad (4.14)$$

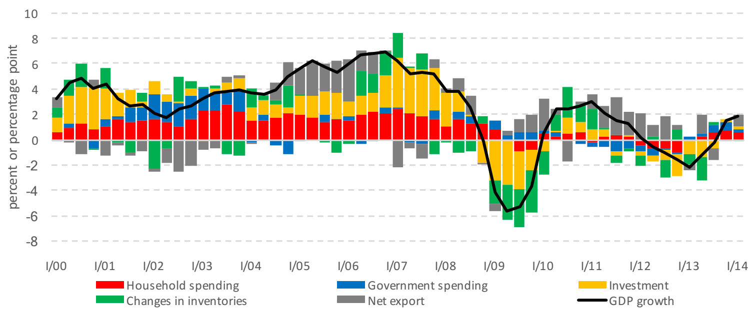
where NX_t denotes the difference between exports of goods and services EX_t and imports of goods and services IM_t, P_t^{EX} is the index of export prices and, similarly, P_t^{IM} the index of import prices, and finally P_t^A is the arithmetic average of the two previous price indices.

[14] The index expression is chosen because of its logarithmic tractability.

[15] Under the balance of incomes we consider the difference between interests, profits and dividends (generally, income derived from the ownership of assets) received from abroad and those paid abroad. Balance of incomes forms a sub-balance of the current account of the balance of payments.

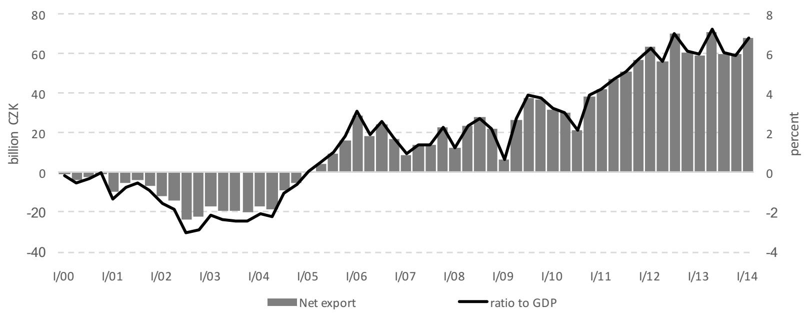
[16] Balance of transfers is defined as the difference between unilateral receipts from abroad and unilateral payments sent abroad. Balance of transfers is also a sub-balance of the current account of the balance of payments.

Figure 4.5: Contributions to the Czech economic growth



Note: Contributions to the year-on-year growth of GDP. The reported data are at constant prices and are seasonally adjusted.
Source: Czech Statistical Office; own computations.

Figure 4.6: Development of net export



Note: At constant prices and seasonally adjusted.
Source: Czech Statistical Office; own computations.

As a proxy for foreign income we chose the EU-27's gross domestic product at constant prices, or its logarithm. This choice is clear if we say that about 70 % of total turnover of the Czech foreign trade in the year 2013 was realized with EU-27 countries. The variable $reer_t$ is the logarithm of the real effective exchange rate of the Czech koruna, weighted by a share in the Czech foreign trade and deflated by the GDP deflator. An increase in $reer_t$ indicates appreciation of the Czech koruna relative to a basket of foreign currencies, while a decrease indicates its depreciation. PRB_t denotes the Prague Interbank Offered Rate on three-month Czech koruna deposits and LRB_t stands for the London Interbank Offered Rate on dollar deposits with

Table 4.5: Data sources for the trade balance model

	Source of the data
Export, import, trade balance	Czech Statistical Office
Czech gross domestic product	Czech Statistical Office
EU-27 gross domestic product	Eurostat
Exchange rates	Czech National Bank
3M PRIBOR	Czech National Bank
3M LIBOR	Federal Reserve Economic Data
Price indices	Czech Statistical Office
Balance-of-payments items	Czech National Bank

three-month maturity. Therefore PRB_t represents the domestic interest rate and LRB_t its foreign counterpart.[17] All variables were observed with quarterly frequency over the first quarter of 2000 through the first quarter of 2014. Where it was necessary, seasonality was removed using the TRAMO/SEATS method. Sources of the data are described in Table 4.5.

The real effective exchange rate, as well as the domestic and foreign income, are usually chosen as regressors in the trade balance model. This statement is supported by the papers cited in the section 2.2. In addition, we also choose the foreign and domestic interest rates as factors which could influence the volume of export and import through the export and consumer loans; in other words through the intertemporal substitution. A decrease in interest rates also stimulates investment, with a subsequent positive effect on the export potential of a domestic country or on its competitiveness towards the foreign imports. Especially in small open economies, export credit can play an important role. Insomuch as the export is a significant factor in the growth of these economies, export credit is often supported by the government. As an illustration, Figure 4.5 provides a picture of the contributions of expenditure components to the Czech economic growth and Figure 4.6 includes the development of the real net export during the examined period.

It follows that the influence of domestic interest rate on the behavior of trade balance could be ambiguous. If we concentrate on a decrease in the interest rate, it could imply both an increase in the export by an increase in the export credit and as well an increase in the import due to increased consumer loans.[18] The situation is similar for the foreign interest rate; a

[17] We do not express the interest rates in logarithms, because we prefer to interpret their changes in percentage points, i.e. as simple differences rather than as growth rates.

[18] The reverse applies to an increase in the domestic interest rate.

decrease causes an increase in the supply of foreign exports, a decrease in their price, and the subsequent growth of demand for foreign exports in domestic country. In the same time, decrease in the foreign interest rate stimulates the demand for domestic exports due to the increased foreign consumer loans. In theory, the above stated assertions are derivable with the aid of intertemporal trade model, which is enclosed by the multi-period optimizing agents. See Obstfeld and Rogoff (1996) in that respect.

For the income, the general wisdom is that if income goes up then the demand for imports increases as well. But income growth could also be due to a development in the import competing sectors, leading to a consumption being switched from the imported goods to domestic goods. So the ambiguous also prevails in the case of incomes. The nature of the relationship between the real effective exchange rate and the trade balance is the subject of this research, where the tested statement says that the effect of real effective exchange rate depreciation is negative in the short run, and the positive effect occurs only after a time delay, i.e. in the long run. Long-run equilibrium (4.12) also contains the time vector, as we assume that the equilibrium is a dynamic or moving one. Our assumption is supported by the empirical evidence, because if we look at the behavior of studied variables (see Figure 4.7), we can see the trending behavior in all of them. Thus, it is possible to expect that this behavior will also be shared by the long-run equilibrium.

The income in a small open economy defined by the expression (4.13) and (4.14) instead of the usual real gross domestic product is used, with an intention to include aspects related to the foreign direct investments (FDIs) and the terms of trade. The impact of FDI inflow on an economy is undoubtedly positive, but it can at the same time overestimate the level of domestic income; mainly after the FDIs are put into service. Again the foregoing applies to small open economies, especially the transition ones. Even if FDI firms produce in the domestic economy, many of their profits go abroad, with an inevitable deficit in the balance of incomes.

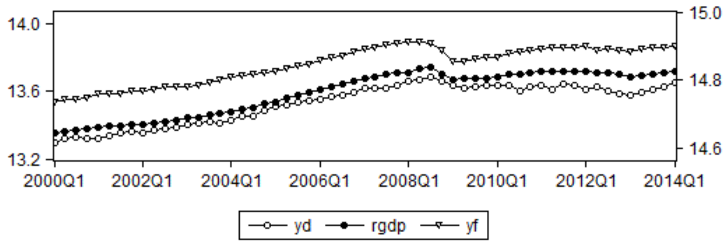
The development of balance of incomes, balance of transfers and terms of trade in the Czech Republic is shown in Figure 4.7. You can see that the development of balance of incomes and the terms of trade is not negligible. During the period 2000-2014, the deficit in balance of incomes to nominal GDP was about 5 % on average.[19] The influence of the balance of transfers on the current account was marginal, but we included it for the completeness.

At the end of this section, the real effective exchange rate of the Czech koruna is related to the nominal CZK/EUR exchange rate, which is the key exchange rate for the Czech economy and, moreover, the Czech National

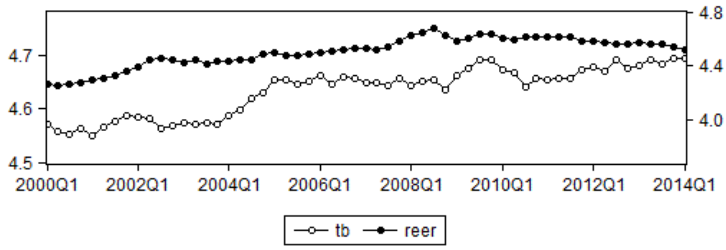
[19] Computed from seasonally adjusted quarterly data.

Figure 4.7: Selected macroeconomic indicators

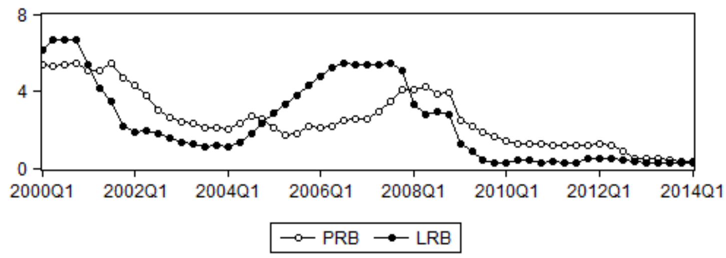
(a) Domestic and foreign economic activity



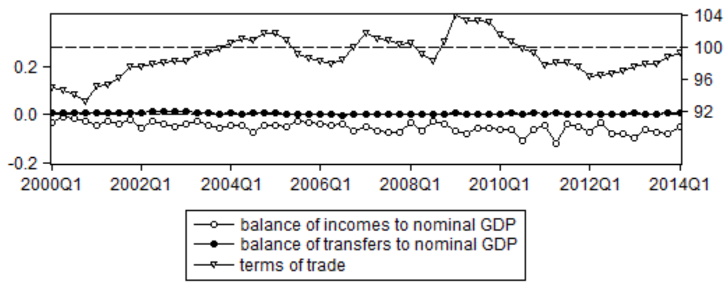
(b) Trade balance and real effective exchange rate



(c) Domestic and foreign interest rate



(d) Balance of incomes, balance of transfers and TOT



Note: yd, rgdp, yf, tb and reer are expressed in logarithms; PRB, LRB, the balance of incomes to nominal GDP and the balance of transfers to nominal GDP in %; and terms of trade as an index, with the base year 2005.

Source: Czech Statistical Office, Czech National Bank, Eurostat, Federal Reserve System.

Bank uses this market for its interventions. The procedure will be very simple. First, we state the formula for the bilateral real exchange rate between the Czech Republic and the euro area

$$Q_t \equiv \frac{ER_t \times HICP_t}{HICP_t^*} \tag{4.15}$$

where ER_t is the nominal exchange rate CZK/EUR expressed as the number of units of foreign currency per unit of domestic currency and $HICP_t$ or $HICP_t^*$ is the harmonized index of consumer prices for the Czech economy, or euro area economy, respectively. Expressing the real exchange rate (4.15) in logarithmic form we get (lowercase letters indicate natural logarithms)

$$q_t \equiv er_t + hicp_t - hicp_t^* \tag{4.16}$$

Now specify the first-order approximation of q_t

$$\begin{aligned}\Delta q_t &\simeq \frac{\partial q_t}{\partial er_t} \times \Delta er_t + \frac{\partial q_t}{\partial hicp_t} \times \Delta hicp_t - \frac{\partial q_t}{\partial hicp_t^*} \times \Delta hicp_t^* \simeq \\ &\simeq \frac{\partial q_t}{\partial er_t} \times \Delta er_t + \frac{\partial q_t}{\partial hicp_t} \times \pi_t - \frac{\partial q_t}{\partial hicp_t^*} \times \pi_t^* \end{aligned} \tag{4.17}$$

where π_t refers to the Czech inflation and π_t^* to the euro area inflation, as soon as the increments in $hicp_t$ and $hicp_t^*$ are infinitesimal.

If we assume a high correlation between $reer_t$ and q_t (actually, the correlation coefficient equals 0.95[20]), we can estimate the following regression using the standard OLS technique[21]

$$\begin{aligned}\Delta reer_t = \underset{(0.002)}{0.001} + \underset{(0.068)}{0.766}\,\Delta er_t + \underset{(0.193)}{0.155}\,\Delta hicp_t - \underset{(0.302)}{0.238}\,\Delta hicp_t^* + e_t\end{aligned} \tag{4.18}$$

$$e_t \sim i.i.d.\,\mathrm{N}(0, \sigma_e^2), \qquad \hat{\sigma}_e = 0.012$$
$$\chi^2_{BG}(4) = 3.426, \quad \chi^2_{White}(9) = 8.084, \quad \chi^2_{JB}(2) = 1.331, \quad R^2 = 0.73$$

Therefore, under the condition of the zero inflation differential between the Czech and euro area economy[22], one-percent depreciation of the nominal exchange rate CZK/EUR causes, on average, a depreciation of the real effective

[20] Weight of the euro in the basket of currencies for calculating the real effective exchange rate is 68.4 %.

[21] Standard errors in parentheses.

[22] Average inflation differential between the Czech and the euro area economy, i.e. $\pi_t - \pi_t^*$, computed as the quadratic mean of yearly inflation differentials based on quarterly data has been in reality during the observed period equal to 1.41 pp.

exchange rate of the Czech koruna of about 0.7 percent. The extent of the response corresponds to the weight of Eurozone used in the computation of the real effective exchange rate; the outcome expectable in the sticky-price environment.

4.2.2 Estimation of the trade balance model

The first task of empirical analysis is to find a common data generating process (henceforth DGP) for the level values of the observed variables. We have estimated a total of three groups of specifications of the VAR(p) process (3.3), which mainly differ in the included deterministic terms; see Table 4.6. The maximal tested lag order was set to 5. The selection of the most appropriate DGP was based on the value of Schwarz Bayesian information criterion (SBC) and Akaike information criterion (AIC), together with the results of the Ljung-Box Q-tests. Both information criteria speak in favor of including both constant and trend in DGP. This is in accordance with the observed trending behavior; see again Figure 4.7. On the other hand, the information criteria differ in the recommended optimum lag length of DGP (3.3).

The SBC criterion in all three groups chooses order 1 as the most suitable order of lag length, in contrast to AIC, which chooses order 4. But a problem with VAR(1) are the autocorrelated residuals in some equations, which indicate that this lag length is too short, with a potential threat in the form of a spurious regression. As Table 4.6 shows, the threat is most serious in the specification with constant and trend where, at the 0.05 significance level, two equations suffer with autocorrelated residuals. So instead we take into account the results of Akaike criterion and choose VAR(4) with constant and trend as the most appropriate specification.

As a consequence, we achieve the concrete form of conditional error correction model useable for the bounds test of cointegration (see also the section 3.7)

$$\begin{aligned}\Delta tb_t = c_0 + \pi_1 \widetilde{tb}_{t-1} + \pi_2 \widetilde{yd}_{t-1} + \pi_3 \widetilde{yf}_{t-1} + \pi_4 \widetilde{reer}_{t-1} + \\ + \pi_5 \widetilde{PRB}_{t-1} + \pi_6 \widetilde{LRB}_{t-1} + \sum_{i=1}^{3} \psi_{1i} \Delta tb_{t-i} + \\ + \sum_{i=0}^{3} \psi_{2i} \Delta yd_{t-i} + \sum_{i=0}^{3} \psi_{3i} \Delta yf_{t-i} + \sum_{i=0}^{3} \psi_{4i} \Delta reer_{t-i} + \\ + \sum_{i=0}^{3} \psi_{5i} \Delta PRB_{t-i} + \sum_{i=0}^{3} \psi_{6i} \Delta LRB_{t-i} + u_t \quad (4.19)\end{aligned}$$

Before to step further, two things should be mentioned. Firstly, we did not forget the need to exclude the possibility of an explosive root in the data generating process of any variable. After separation of the influence of deterministic terms, all variables were tested by the Augmented Dickey-Fuller test both on their levels and first differences, with the conclusion of difference stationarity in all cases, or symbolically I(1) for all variables. Numerical results are not reported in the text, but they are available on request.

The second important thing to consider is the choice of the form of equation (4.19), i.e. the choice among restrictions posed on the deterministic terms of that equation; see Pesaran et al. (2001) and within it the pages 295-296. The regressions without a trend was soon implicitly excluded, because of the presence of linear trends in the level values of observed variables. Thus the decision between restricted or unrestricted trend remains. Although regression with unrestricted trend implies a linear trend in the cointegrating relation, at the same time it also implies a quadratic trend in the levels of the observed variables, and is therefore inappropriate. As you can observe above, we choose the regression with unrestricted intercept and restricted trend, where the variables with a tilde denote detrended levels. The majority of previous studies on the J-curve phenomenon simply ignores trending behavior, and most often estimate regression with no trend. But because the cointegration is based exclusively on common stochastic trends, if the deterministic ones are not explicitly excluded, this may result in a conclusion confirming cointegration, even if it is not true. The results of the estimation of unrestricted ECM (4.19) are summarized in Table 4.7.

Now it is possible to test for the level relationship using the bounds testing procedure. For testing of the null hypothesis generally declared by (3.36), the computed F-statistic for six restrictions and 23 degrees of freedom in unrestricted regression equals 5.92. In this case the critical value bounds, according to Pesaran et al. (2001, pp. 301, Case IV), for five forcing weakly-exogenous variables are 2.49 and 3.38 at the 0.1 significance level, 2.81 and 3.76 at the 0.05 significance level, and 3.50 and 4.63 at the 0.01 significance level. At all three levels of significance, the existence of a cointegrating relationship was thus confirmed. In relation to this, Pesaran et al. (2001, pp. 312) noted, " *... it is important that the coefficients of lagged changes remain unrestricted, otherwise these tests could be subject to a pre-testing problem*". Unfortunately, this was not fully respected in some preceding articles. The fact that restrictions on conditional ECM (4.19) cannot be applied before cointegration testing does not mean they cannot be applied after that. On the contrary, this provides a suitable approach to achieve the most parsimonious model for estimation of short-run dynamics and level effects.

Table 4.6: Data generating process for the set of observed variables

VAR(p) without any deterministic term								
	Information criteria		4th-order Ljung-Box Q-stat for the equation					
p	AIC	SBC	tb	yd	yf	reer	PRB	LRB
1	-22.79	-21.44*	5.94	7.24	5.08	7.87*	2.82	8.60*
2	-23.44	-20.74	2.73	12.39**	1.72	5.19	6.15	12.92**
3	-23.49	-19.44	3.86	8.65*	1.25	3.64	2.97	7.14
4	-24.48*	-19.07	2.39	3.97	2.39	2.31	4.14	7.73
5	-24.33	-17.57	3.72	5.75	0.91	1.70	4.19	10.01**
VAR(p) with constant								
	Information criteria		4th-order Ljung-Box Q-stat for the equation					
p	AIC	SBC	tb	yd	yf	reer	PRB	LRB
1	-23.07	-21.49*	5.98	6.91	5.47	6.99	2.89	9.71**
2	-23.73	-20.81	2.49	13.20**	0.85	5.11	7.64	13.10**
3	-23.93	-19.65	3.75	7.89*	1.50	3.72	6.57	6.64
4	-24.86*	-19.23	2.41	4.53	3.57	2.22	3.12	7.82*
5	-24.80	-17.82	3.41	6.75	2.42	2.13	4.89	11.70**
VAR(p) with constant and trend								
	Information criteria		4th-order Ljung-Box Q-stat for the equation					
p	AIC	SBC	tb	yd	yf	reer	PRB	LRB
1	-23.73	-21.93*	5.87	8.19*	3.48	14.92***	2.48	9.66**
2	-24.15	-21.00	2.55	13.34***	0.85	7.98*	7.16	16.28***
3	-24.64	-20.14	3.51	9.17*	1.40	5.22	6.57	4.87
4	-25.36*	-19.51	2.12	4.48	3.53	3.11	3.65	8.03*
5	-25.25	-18.05	4.39	7.21	2.85	5.28	7.10	9.89**

Note: * at information criteria indicates the minimum value; in other columns, stars indicate the significance level at which the Q statistic exceeds the critical value of the $\chi^2(4)$ distribution: * for the 0.1 significance level, ** for the 0.05 significance level, and *** for the 0.01 significance level.

Source: Own computations.

Table 4.7: Baseline unrestricted error-correction model

Conditional error-correction model						
			Lagged levels			
Lag	tb	yd	yf	reer	PRB	LRB
1	-0.6648***	0.4778**	-0.1163	-0.3713**	0.0024	-0.0025
			Lagged differences			
Lag	tb	yd	yf	reer	PRB	LRB
0		0.3545***	-0.1536	0.0336	-0.0096	0.0220***
1	-0.0950	-0.0611	-0.8055**	0.1608	0.0195**	-0.0056
2	0.1305	-0.2178*	-0.3158	0.0829	-0.0092	0.0141*
3	0.1069	-0.3665***	-0.6773*	0.1629	0.0059	0.0005
Constant term					0.0089**	
Akaike information criterion					-350.58	
Schwarz Bayesian criterion					-291.47	
Autocorrelation test					7.0769	
Test of conditional heteroskedasticity					6.6954	
Normality test					2.0271	
Standard error-correction model						
Error-correction term					-0.6373***	
			Lagged differences			
Lag	tb	yd	yf	reer	PRB	LRB
0		0.2010	-0.2201	0.1910**	-0.0093	0.0114**
1	0.1481	0.1325	-0.7804**	0.0402	0.0165*	-0.0118*
2	0.4120**	-0.0446	-0.2771	-0.0794	-0.0107	0.0080
3	0.2644	-0.1496	-0.1181	0.0075	0.0051	0.0006
Constant term					0.0028	
Akaike information criterion					-330.47	
Schwarz Bayesian criterion					-281.22	
Autocorrelation test					1.5612	
Test of conditional heteroskedasticity					11.0683**	
Normality test					0.9821	

Note: * indicates significance at the 0.1 level, ** at the 0.05 level, and *** at the 0.01 level. For diagnostic tests, the test statistics are reported; all test statistics have a χ^2 distribution. Serial correlation is tested up to the fourth order and the LM test is used for it. Also conditional heteroskedasticity is tested up to the fourth order, with the usage of McLeod-Li test. Finally, Jarque-Bera test is used for the test of normality.

Source: Own computations.

The best restrictions of short-run dynamics[23] of conditional ECM (4.19) are reported in Table 4.8. What is most important is that if we compare the estimated parameters reported in Table 4.7 and Table 4.8, we realize that in most cases the type of short-run dynamics restriction applied does not affect the signs of the estimated parameters – both short-run and long-run. Even the magnitudes of the corresponding parameters are very similar. So we can consider our results to be sufficiently robust. For all models, diagnostic tests are performed (see Table 4.7 and Table 4.8), specifically the test of serial correlation, test for possible conditional heteroskedastic effects, and test of normality. Of course, the test of autocorrelated residuals is the most important, and its result relates to the correct choice of lag-length order in VAR system (3.3). From this perspective, only Model 2 may be problematic.

Regarding the J-curve phenomenon, the large part of past research considers the signs and significance of the short-run coefficients of the exchange rate. One serious objection might be raised to this practice. As has been said, the J-curve phenomenon covers the relationship between the short-run and long-run reaction of the trade balance to depreciation (devaluation) of the exchange rate. But if the information criteria are employed for the selection of the maximal lag length of DGP represented by (3.3), or for selection of the most parsimonious restriction of (4.19), then a conclusion based only on consideration of the short-run parameters must be wrong in most cases. The reason is simple; in most cases, a chosen optimal lag length which removes the problem of autocorrelated residuals, with very low probability, will be greater than one for yearly data, four for quarterly data and twelve for monthly data. Therefore, the short-run period may not be long enough to provide space for a long-term positive effect.

Making an economic interpretation of the estimated parameters, we can say that in the short run the effect of a depreciation of the real effective exchange rate on the trade balance is clearly negative (remember that a decrease in *reer* indicates its depreciation and increase its appreciation). The immediate impact of an increase in domestic income on the trade balance is positive, but it is replaced by the negative effects, if lags are considered. On the contrary, an increase in foreign income has a strictly negative effect on trade balance behavior. And finally, the nature of the linkages between the trade balance and both interest rates is mixed. The significances then differ according to model.

It is not possible to read the estimated long-run relations directly from Table 4.7 or Table 4.8; first we must compute the long-run multipliers. When we realize that the long-run or equilibrium relations are related to the model

[23] Measured by information criteria.

Table 4.8: Some restricted conditional error-correction models

		Model 1	Model 2	Model 3	Model 4	Model 5
Constant		0.0059*	0.0029	0.0108***	0.0067***	0.0069**
			Lagged levels			
	lag					
tb	1	-0.8226***	-0.7552***	-0.5621***	-0.2250	-0.3519**
yd	1	0.5280***	0.3921***	0.4716***	0.2541*	0.3333**
yf	1	-0.1060	-0.0395	-0.1318*	-0.0958	-0.1111
reer	1	-0.3973***	-0.2802***	-0.4020***	-0.2072**	-0.2644**
PRB	1	0.0028	0.0056	-0.0037	-0.0106***	-0.0107**
LRB	1	-0.0014	-0.0003	-0.0037**	-0.0007	-0.0015
			Lagged differences			
	lag					
tb	1	0.0205	0.0467	-0.2692**	-0.2334*	-0.1006
	2	0.2817*	0.3948***			0.2376
	3	0.1751	0.2362*			
yd	0	0.3509***	0.3550***	0.2346**	0.1524	
	1	-0.0913			0.0453	-0.0744
	2	-0.2096*	-0.1893*			-0.0439
	3	-0.3594***	-0.4043***			
yf	0				-0.5079	
	1	-0.8055***	-0.7490***	-1.3337***	-1.2511***	-1.4281***
	2	-0.2353		-0.8030**		-0.2578
	3	-0.4786		-0.9264***		
reer	0	0.0428	0.0367	0.0513	0.0654	
	1	0.1953	0.0908	0.3118***	0.2616**	0.3425**
	2	0.0976	-0.0372	0.2687***		0.2203*
	3	0.1548	0.0309	0.1466		
PRB	0	-0.0117*	-0.0121**		-0.0084	
	1	0.0157*	0.0095	0.0224***	0.0187***	0.0198***
	2	-0.0124	-0.0159**			-0.0060
	3					
LRB	0	0.0227***	0.0227***	0.0114**	0.0062	
	1	-0.0055	-0.0069		-0.0098*	-0.0070
	2	0.0141**	0.0137**	0.0081*		0.0041
	3					

Note: See Table 4.7.
Source: Own computations.

Table 4.8: Some restricted conditional error-correction models - continuation

Information criteria and diagnostic tests					
	Model 1	Model 2	Model 3	Model 4	Model 5
AIC	-352.82	-353.52	-343.88	-342.59	-334.27
SBC	-299.62	-306.23	-306.44	-306.45	-296.48
Autocorrelation	7.7914	12.3862**	0.6196	3.3446	3.4567
Heteroskedasticity	5.6609	8.7902*	3.3035	5.6536	1.1897
Normality	1.2260	2.3141	3.5462	1.1099	1.4007

Note: See Table 4.7.
Source: Own computations.

in the steady state, then we can reduce regression (4.19) to its steady-state form[24]

$$0 = c_0 + \pi_1 \widetilde{tb} + \pi_2 \widetilde{yd} + \pi_3 \widetilde{yf} + \pi_4 \widetilde{reer} + \pi_5 \widetilde{PRB} + \pi_6 \widetilde{LRB} \tag{4.20}$$

The reader can identify this procedure with the well-known normalization of the cointegrating vector. The long-run relationship has thus the following general form[25], and the numerical values of the long-run multipliers might be acquired from Table 4.9

$$\widetilde{tb} = \theta_0 + \theta_1 \widetilde{yd} + \theta_2 \widetilde{yf} + \theta_3 \widetilde{reer} + \theta_4 \widetilde{PRB} + \theta_5 \widetilde{LRB} \tag{4.21}$$

where θ_j, $j = 1, \ldots, 5$, are long-run multipliers computed as[26]

$$\theta_j = -\frac{\pi_{j+1}}{\pi_1} \tag{4.22}$$

Accordingly, the effect on the trade balance in the long run of an increase in domestic income and a depreciation of the real effective exchange rate is positive, and conversely, the effect of an increase in foreign income and foreign interest rate is negative. Long-run multipliers for the domestic rate of interest differ in sign throughout the models, but on average are negative. The average long-run exchange rate elasticity equals 0.6333, and therefore it is relatively high.

Comparing the domestic income elasticity with the foreign income elasticity, one can easily realize that the former is at least three times to the latter.

[24] In derivation we only use the definition of steady state.

[25] Upon the assumption about weak exogeneity or long-run forcing nature of effective exchange rate, both incomes and both interest rates.

[26] θ_0 equals $-c_0/\pi_1$.

Table 4.9: Long-run multipliers

	yd	yf	reer	PRB	LRB
Model 0	0.7187**	-0.1749	-0.5585**	0.0036	-0.0038
Model 1	0.6419***	-0.1289	-0.4830***	0.0034	-0.0017
Model 2	0.5192***	-0.0523	-0.3710***	0.0074	-0.0004
Model 3	0.8390***	-0.2345*	-0.7152***	-0.0066	-0.0066**
Model 4	1.1293*	-0.4258	-0.9209**	-0.0471***	-0.0031
Model 5	0.9471**	-0.3157	-0.7514**	-0.0304**	-0.0043
Average	0.7992	-0.2220	-0.6333	-0.0116	-0.0033

Note: Model 0 denotes the baseline unrestricted model.

Source: Own computations.

This, in certain respects, is a reminiscent of the finding of Houthakker and Magee (1969), and it also highlights the importance of income growth for the trade pattern proposed by Johnson (1958). Both works have been already cited in the section 2.2. Alongside the sign of estimated income elasticities, the income growth improves the ability of import competing industries and export industries, respectively, rather than to lead into greater imports (in the long run). It applies for both domestic and foreign economy. This fact may be associated to the transitional phase of the Czech economy which covers a large part of the studied period (or maybe all of it, if taken more broadly).[27] During that period the economy tends to export goods with a greater added value[28] and consequently the trade balance in monetary terms improves. It does not necessarily mean that the import does not go up as well, but the influence of value added prevails. This conclusion is not specific just for the Czech Republic, on the contrary it was observed for many countries experiencing some type of transition (see for instance Wang et al. (2012) for the case of China). Regarding significances, the foreign income growth is statistically insignificant, opposite to the domestic income and the exchange rate.

Computed average elasticities for the interest rates are almost identical to the estimated long-run multipliers. Particular values are -0.0126 for the domestic rate and -0.0036 for the foreign rate.[29] From the long-run perspec-

[27] Pace of the Czech transition in the 90s and early 2000s was substantially different. While the 90s witnessed an extensively discontinuous development leading into parameter instability, the development in the early 2000s was rather continuous and gradual, characterized by qualitative improvements.

[28] Simultaneously, it frequently leads into a decrease in the value of imports.

[29] Because we have not expressed the interest rates in logs initially, we can't interpret the estimated long-run multipliers as elasticities, as in other cases. Instead, we use usual

tive, the interest rates are statistically significant only in the models with simpler internal dynamics (see further).

In relation to the J-curve phenomenon, we consider a practice consisting in the combined inference based on both short-run coefficients and a long-run multiplier, rather than only on short-run coefficients (due to the objections mentioned above), as the better way to identify J-curve within post-devaluation behavior of the trade balance. In conformity with this, we can infer from our present results the existence of the J-curve phenomenon in the Czech economy.

4.2.3 Hysteresis and impulse-response analysis

As the existence of a level relationship has been already confirmed, we can also construct standard error correction models in the Engle-Granger sense. For this purpose, we use the long-run equilibrium relation defined above by (4.12), or more precisely its residuals representing deviations from the long-run equilibrium.[30] The general form of the standard Engle-Granger ECM is the following

$$\begin{aligned}\Delta\, tb_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i}\,\Delta\, tb_{t-i} + \sum_{i=0}^{q} \beta_{2i}\,\Delta\, yd_{t-i} + \\ + \sum_{i=0}^{r} \beta_{3i}\,\Delta\, yf_{t-i} + \sum_{i=0}^{s} \beta_{4i}\,\Delta\, reer_{t-i} + \sum_{i=0}^{u} \beta_{5i}\,\Delta\, PRB_{t-i} + \\ + \sum_{i=0}^{v} \beta_{6i}\,\Delta\, LRB_{t-i} + \rho\,\hat{v}_{t-1} + \tau_t, \qquad \tau_t \sim i.i.d.\, \mathrm{N}(0, \sigma_\tau^2)\end{aligned} \quad (4.23)$$

where p, q, r, s, u, and v correspond to the choice of lag length in the conditional error correction models. The estimation of standard Engle-Granger ECMs is presented in Table 4.7 and Table 4.10, for unrestricted model and its various restrictions, respectively. It may be observed that in all cases, the parameter ρ has the correct sign and is significant on at least the level 0.1, which supports error-correcting behavior. The magnitudes of six reported ρ imply that a deviation from steady-state development of the trade balance

formula for the elasticity computation $\theta_j\, \bar{x}_j/\bar{y}$, where the bar over variable indicates a sample average.

[30] In relation to this, it is necessary to emphasize that it is not possible to use (4.21) instead of (4.12) for computation of equilibrium errors. Relationship (4.21) is a deterministic one and therefore has no stochastic (error) element. The fact that residuals from regression (4.12) are in most cases serially correlated here only represents a natural property of equilibrium errors.

is corrected during one quarter within the range of 30 to 70 percent (with a full recovery after 2-4 quarters).[31]

Using this procedure, by which we mean the bounds testing for cointegration and the subsequent construction of a standard Engle-Granger ECM, we bypass the deficiencies of the cointegration test defined by Engle and Granger (1987), and instead get involved with a more powerful tool defined by Pesaran et al. (2001). The greatest advantage of the latter is, from our point of view, the possibility of testing cointegration in a fully dynamically specified model (without autocorrelated residuals) as well as more efficient estimation of both the short-run and long-run parameters, which are estimated together in one step. A conditional ECM is therefore appropriate for the investigation of direct short- and long-run linkages between regressand and its regressors. By contrast, a standard Engle-Granger ECM is a very good description of short-run dynamics, which allows for the precise measurement of how short-run dynamics responds to past deviation from the overall long-run equilibrium.

We will exploit the estimated standard error correction models in Table 4.7 and Table 4.10 for yet another purpose specifically, for the inclusion of hysteresis effects in our understanding of trade balance behavior. Demirden and Pastine (1995) may have been the first and perhaps also the only ones, who emphasized that drawing a conclusion about the J-curve phenomenon based on direct interpretation of the estimated parameters is not so straightforward.[32] Hysteresis signifies that the current state of a dynamic system depends on its previous state or states, i.e. a system with the property of hysteresis has an obviously nonzero autoregressive part. But if we want to investigate relations in this system in a comprehensive form, we need to take hysteresis into account.

Perhaps the best way to do it is through the impulse-response analysis, a common tool in multivariate approaches but unusual in univariate approaches. Due to the use of IR analysis, we may assign a date to the response or, in other words, say how long the long run is, a question which cannot be answered in the conditional ECM environment. From the significance of (at least some) autoregressive parameters in Tables 4.7, 4.8 and 4.10, as well as from the sample autocorrelation function described in Table 4.11, it is possible to deduce that hysteresis effects are not negligible for the description of trade balance behavior, at least for the studied Czech Republic. Generally, the hysteresis of trade balance easily follows from staggered contracts in the

[31] Under the condition that the original equilibrium remains unchanged, see the next.

[32] The objection of Demirden and Pastine (1995) relates to feedback effects which may occur between regressand and regressors and thus invalidate the univariate approach. The authors do not deal with hysteresis.

Table 4.10: Standard error-correction models

		Model 1	Model 2	Model 3	Model 4	Model 5
Constant		0.0022	0.0029	0.0070***	0.0042**	0.0024
EC term		-0.6611***	-0.7035***	-0.3753**	-0.3251**	-0.2717*
Lagged differences						
	lag					
tb	1	0.1225	0.1457	-0.0953	-0.1250	0.1430
	2	0.4822***	0.5061***			0.3620**
	3	0.3060*	0.3399**			
yd	0	0.1769	0.1715	0.1738	0.1806	
	1	0.0892			0.1069	0.0959
	2	-0.0359	-0.0566			-0.0265
	3	-0.1246	-0.1303			
yf	0				0.0023	
	1	-0.8985***	-0.8090***	-0.9907***	-0.8873***	-0.9127***
	2	0.1392		0.0590		0.4034
	3	0.0072		-0.4841		
reer	0	0.1637**	0.1576**	0.1313	0.0711	
	1	0.0543	0.0649	0.0550	0.0216	0.0692
	2	-0.0328	0.0088	0.0486		-0.0502
	3	0.0025	0.0278	-0.0126		
PRB	0	-0.0071	-0.0060		-0.0070	
	1	0.0174**	0.0187***	0.0115*	0.0141**	0.0150**
	2	-0.0084	-0.0073			-0.0130*
	3					
LRB	0	0.0107**	0.0114**	0.0068*	0.0111**	
	1	-0.0112*	-0.0114*		-0.0080*	-0.0083*
	2	0.0070	0.0075	0.0016		0.0068
	3					
Information criteria and diagnostic tests						
AIC		-332.73	-337.19	-319.94	-335.88	-327.11
SBC		-289.38	-299.75	-292.35	-309.78	-299.26
Autocorrel.		1.5246	1.3061	5.5962	4.2657	3.9971
Heteroskedast.		3.5705	2.0995	3.4069	2.4672	1.2150
Normality		0.7069	0.6460	1.2475	1.1930	2.1286

Note: See Table 4.7.

Source: Own computations.

Table 4.11: Sample autocorrelation function of the trade balance

Lag	1	2	3	4	5	6
Levels	0.93	0.86	0.79	0.70	0.64	0.58
Differences	-0.14	0.11	0.07	-0.29	-0.01	-0.15
Lag	7	8	9	10	11	
Levels	0.53	0.49	0.45	0.41	0.36	
Differences	0.15	-0.20	-0.03	0.05	-0.06	

Note: Numbers in the first row indicate the lag, and in the second and third rows follow autocorrelation coefficients.
Source: Own computations.

international trade.

We formulate an impulse-response and cumulative impulse-response function (hereafter also IRF and CIRF) in the following way, where we assume that $\{\tau_t\}_{t=1}^{\infty}$ is the sequence of mutually independent and identically distributed random variables, with $\text{Cov}(\Delta\, yd_{t-i}, \tau_t) = 0$, $\text{Cov}(\Delta\, yf_{t-i}, \tau_t) = 0$, $\text{Cov}(\Delta\, reer_{t-i}, \tau_t) = 0$, $\text{Cov}(\Delta\, PRB_{t-i}, \tau_t) = 0$, and $\text{Cov}(\Delta\, LRB_{t-i}, \tau_t) = 0$ fulfilled simultaneously for all t and i. In fact, in this case the τ_t is just a measurement error.

At first we define a mean-value data generating process for $\Delta\, tb_t$

$$\begin{aligned} \mathbb{E}_0(\Delta\, tb_t \,|\, \hat{\beta}, \Theta_t) = \hat{\beta}_0 + \sum_{i=1}^{p} \hat{\beta}_{1i}\, \Delta\, tb_{t-i} + \sum_{i=0}^{q} \hat{\beta}_{2i}\, \Delta\, yd_{t-i} + \\ + \sum_{i=0}^{r} \hat{\beta}_{3i}\, \Delta\, yf_{t-i} + \sum_{i=0}^{s} \hat{\beta}_{4i}\, \Delta\, reer_{t-i} + \sum_{i=0}^{u} \hat{\beta}_{5i}\, \Delta\, PRB_{t-i} + \\ + \sum_{i=0}^{v} \hat{\beta}_{6i}\, \Delta\, LRB_{t-i} + \hat{\rho} \left[\left(\widehat{tb}_0 + \sum_{i=0}^{t-1} \Delta\, tb_i \right) - \widehat{tb}_{t-1} \right], \quad t = 1, 2, 3, \ldots \end{aligned} \tag{4.24}$$

with the Θ_t information set of observed values of the exogenous variables at time t, $\Theta_t = \{\Delta\, yd_t, \Delta\, yf_t, \Delta\, reer_t, \Delta\, PRB_t, \Delta\, LRB_t : t \geq 1\}$, with the initial conditions

$$\Delta\, tb_t = \Delta\, yd_t = \Delta\, yf_t = \Delta\, reer_t = \Delta\, PRB_t = \Delta\, LRB_t = 0 \qquad \text{for} \quad t < 1$$
$$\hat{v}_{t-1} = tb_{t-1} - \widehat{tb}_{t-1} = 0 \qquad \text{for} \quad t \leq 1$$

where $\{\widehat{tb}_t : t \geq 0\}$ is the set of fitted values derived from long-run equilibrium regression (4.12), and with

$$\hat{\beta} = \Big\{\hat{\beta}_0, \hat{\beta}_{11}, \ldots, \hat{\beta}_{1p}, \hat{\beta}_{20}, \ldots, \hat{\beta}_{2q}, \hat{\beta}_{30}, \ldots, \hat{\beta}_{3r}, \\ \hat{\beta}_{40}, \ldots, \hat{\beta}_{4s}, \hat{\beta}_{50}, \ldots, \hat{\beta}_{5u}, \hat{\beta}_{60}, \ldots, \hat{\beta}_{6v}, \hat{\rho}\Big\}$$

the set of OLS estimates of parameters from regression (4.23) (not all must be nonzero).

An additional data generating process, which is base on (4.24), has the form

$$\begin{aligned}\mathbb{E}_1(\Delta\, tb_t \,|\, \hat{\beta}, \Theta_t, \Sigma) = \hat{\beta}_0 &+ \sum_{i=1}^{p} \hat{\beta}_{1i}\, \Delta\, tb_{t-i} + \\ &+ \sum_{i=0}^{q} \hat{\beta}_{2i}\, \{\Delta\, yd_{t-i} + [\xi_{yd}(t-i) \times \hat{\sigma}_{yd}]\} + \\ &+ \sum_{i=0}^{r} \hat{\beta}_{3i}\, \{\Delta\, yf_{t-i} + [\xi_{yf}(t-i) \times \hat{\sigma}_{yf}]\} + \\ &+ \sum_{i=0}^{s} \hat{\beta}_{4i}\, \{\Delta\, reer_{t-i} + [\xi_{reer}(t-i) \times \hat{\sigma}_{reer}]\} + \\ &+ \sum_{i=0}^{u} \hat{\beta}_{5i}\, \{\Delta\, PRB_{t-i} + [\xi_{PRB}(t-i) \times \hat{\sigma}_{PRB}]\} + \\ &+ \sum_{i=0}^{v} \hat{\beta}_{6i}\, \{\Delta\, LRB_{t-i} + [\xi_{LRB}(t-i) \times \hat{\sigma}_{LRB}]\} + \\ &+ \hat{\rho}\left[\left(\widehat{tb}_0 + \sum_{i=0}^{t-1} \Delta\, tb_i\right) - \widehat{tb}_{t-1}\right], \qquad t = 1, 2, 3 \ldots\end{aligned} \tag{4.25}$$

where $\Sigma = \{\hat{\sigma}_{yd}, \hat{\sigma}_{yf}, \hat{\sigma}_{reer}, \hat{\sigma}_{PRB}, \hat{\sigma}_{LRB}\}$ is the set of sample standard deviations of observed exogenous variables, or more precisely of their first differences, and ξ_x is an indicator function for a particular independent variable with properties defined below.

Now, the impulse-response function itself can be defined as

$$IRF(w) = \mathbb{E}_1(\Delta\, tb_{j+w} \,|\, \hat{\beta}, \Theta_{j+w}, \Sigma) - \mathbb{E}_0(\Delta\, tb_{j+w} \,|\, \hat{\beta}, \Theta_{j+w}) \tag{4.26}$$

where j is a fixed non-negative integer and $w = 0, 1, \ldots$ or $w \in \mathbb{N}_0$[33], and we

[33]With $\mathbb{N}_0$ we denote the set of natural numbers extended by the number zero.

can choose just one x[34], $x \in \{yd, yf, reer, PRB, LRB\}$, such that

$$\xi_x(t-i) = \begin{cases} 1 & \text{if} \quad t-i = j \\ 0 & \text{if} \quad t-i \neq j \end{cases} \tag{4.27}$$

where for non-chosen x applies $\xi_x(t-i) = 0$ for all $t-i$.

Similarly, the cumulative impulse-response function is defined as

$$CIRF(w) = \mathbb{E}_1(\Delta\, tb_{j+w} \,|\, \hat{\beta}, \Theta_{j+w}, \Sigma) - \mathbb{E}_0(\Delta\, tb_{j+w} \,|\, \hat{\beta}, \Theta_{j+w}) \tag{4.28}$$

where j is a fixed non-negative integer and $w = 0, 1, \dots$ or $w \in \mathbb{N}_0$, and we can choose just one x, $x \in \{yd, yf, reer, PRB, LRB\}$, such that

$$\xi_x(t-i) = \begin{cases} 1 & \text{if} \quad t-i \geq j \\ 0 & \text{if} \quad t-i < j \end{cases} \tag{4.29}$$

where for non-chosen x applies $\xi_x(t-i) = 0$ for all $t-i$. The influence of initial conditions fades out with increasing j.

To be more precise in our reasoning, we will be more abstract for a moment. Therefore, let $(\Omega_t, \mathcal{F}_t, \lambda_t)$ be a measure space, where Ω_t is some fixed set of possible states of nature or the economy, "observed" in time t; $\mathcal{F}_t$ is a σ-field of all subsets of Ω_t; and λ_t is a Lebesgue measure on $\mathcal{F}_t$, for which additionally $\lambda_t(\Omega_t) = 1$ for all t. Under the assumption, all sets in $\mathcal{F}_t$ are Lebesgue-measurable. Let the both mean-value data generating processes (4.24) and (4.25) be a function $f_t : \Omega_t \to \mathbb{R}$ and let f_t be Lebesgue-measurable. In a similar way, we can define another measure space $(\Omega'_t, \mathcal{F}'_t, \lambda'_t)$ which differs from $(\Omega_t, \mathcal{F}_t, \lambda_t)$ only in that the set Ω'_t denotes the set of possible states of the economy for which it can be observed a temporary exogenous shock, i.e. there exists j such that $\Omega_t \neq \Omega'_t$ for $t \geq j$ and simultaneously $\Omega'_t \to \Omega_t$ as $|t-j| \to \infty$.[35] For $t < j$ we have $\Omega_t = \Omega'_t$, both measure spaces are therefore identical in this case. After that, the impulse-response function then corresponds to the difference of two mean-value data-generating processes, i.e.

$$IRF(w) = \int_{\Omega'_{j+w}} f'_{j+w}(\omega'_{j+w})\, \mathrm{d}\,\lambda'_{j+w} - \int_{\Omega_{j+w}} f_{j+w}(\omega_{j+w})\, \mathrm{d}\,\lambda_{j+w}, \quad w \in \mathbb{Z} \tag{4.30}$$

[34] If we choose more than one x, then it is not possible to separate effects (impulses) of different regressors to regressand. The same reasoning also applies in the next case of the cumulative impulse-response function.

[35] It is hard to define mathematically the convergence of two sample spaces. The reader can think about that as a greater and greater similarity of two sets.

The expression (4.30) is naturally non-zero only for $w \in \mathbb{N}_0$.[36]

Equivalently, the cumulative impulse-response function coincides with

$$CIRF(w) = \int_{\Omega''_{j+w}} f''_{j+w}(\omega''_{j+w}) \,\mathrm{d}\,\lambda''_{j+w} \; - \int_{\Omega_{j+w}} f_{j+w}(\omega_{j+w}) \,\mathrm{d}\,\lambda_{j+w}, \quad w \in \mathbb{Z} \tag{4.31}$$

where $(\Omega''_t, \mathcal{F}''_t, \lambda''_t)$ is the measure space which differs from $(\Omega_t, \mathcal{F}_t, \lambda_t)$ as the set Ω''_t represents the set of possible states of the economy for which a permanent exogeneous shock may be observed; thus there exists j such that $\Omega_t \neq \Omega''_t$ for $t \geq j$, but in contrast to the previous $\Omega''_t \nrightarrow \Omega_t$ as $|t-j| \to \infty$. The measure spaces $(\Omega_t, \mathcal{F}_t, \lambda_t)$ and $(\Omega''_t, \mathcal{F}''_t, \lambda''_t)$ remain identical for $t < j$.

In everything we have said, we have assumed $f_t = f'_t = f''_t$ on S, where $S = \Omega_t \cap \Omega'_t \cap \Omega''_t$, and for all t. Furthermore, if $f_t, f'_t, f''_t \in L^2$, where L^2 denotes the Hilbert space of square-measurable functions[37], then we assume that there exists ε such that $\|f_t - f'_t\|_2 < \varepsilon$ and $\|f_t - f''_t\|_2 < \varepsilon$ for all $t \geq j$.[38] Alternatively, $\|f_t - f'_t\|_2 < \varepsilon$ and $\|f_t - f''_t\|_2 < \varepsilon$ on S^c for all t.[39] From the above, we know $\|f_t - f'_t\|_2 = 0$ and $\|f_t - f''_t\|_2 = 0$ for all $t < j$. This premise related to the dynamic stability of expectations will be further discussed (see the section 4.3.2), and its validity will be check empirically. In our concrete case, all the functions f_t, f'_t and f''_t take the form of a standard error-correction model in the Engle and Granger (1987) sense.

After explaining the methodology, we can proceed to empirical analysis and trace the response of trade balance to one-standard-deviation shock in a particular regressor. The responses of the trade balance to one-standard-deviation shock (either temporary or permanent in nature) in the real effective exchange rate are included in Figure 4.8. In fact, it is minus-one-standard-deviation shock in the real effective exchange rate which is thought to simulate the effects of depreciation. Responses vary according to the imposed lag restrictions, but we may generally conclude that they support the J-curve phenomenon. Considering a one-time shock (development of IRFs), positive effects occur as early as the second quarter and disappear after eight quarters or two years. Model 0 to 2 and Model 5 have more complex dynamics; see Table 4.12. So the first three IRFs in Figure 4.8 also show a rather marginal deterioration of the trade balance after eight quarters.

The shape of the cumulative impulse-response functions in Figure 4.8

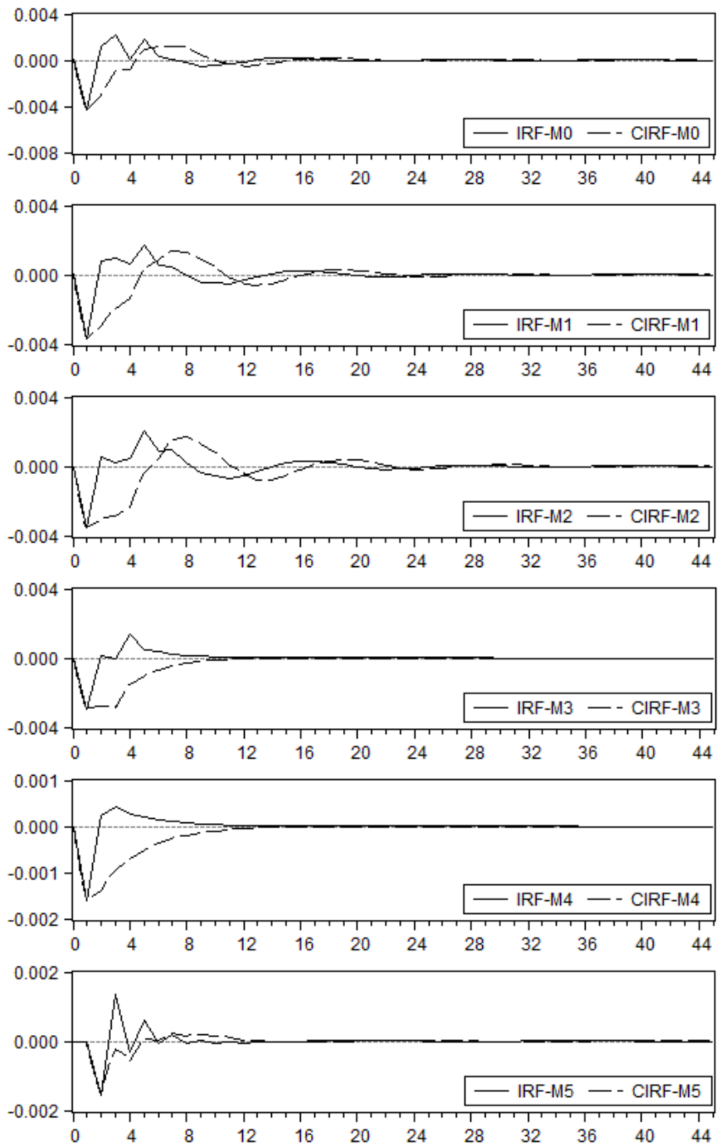
[36] The same applies for the expression (4.31), see the following paragraph.

[37] Functions for which the expression $\left(\int_E |f|^2 \,\mathrm{d}\,\lambda\right)^{\frac{1}{2}}$ is finite, for some measurable set E.

[38] The domain of the functions must be extended to $\Omega_t \cup \Omega'_t$ in the first case and to $\Omega_t \cup \Omega''_t$ in the second.

[39] Using De Morgan's law, the set S^c is defined as $S^c = (\Omega_t)^c \cup (\Omega'_t)^c \cup (\Omega''_t)^c$. For formal accuracy, assume the sets Ω_t, Ω'_t and Ω''_t are elements of some universal set.

Figure 4.8: Impulse responses for the real effective exchange rate



Note: The solid line traces IRF and the dashed line CIRF in all cases. M0 denotes Model 0 (or unrestricted standard EC model), and, similarly, M1 Model 1, M2 Model 2, and so on (or restricted models). Responses correspond to minus-one-standard-deviation shock (i.e. representing depreciation) in the real effective exchange rate, where $\hat{\sigma}_{reer} = 0.0227$ (standard deviation computed on the first differences). Dating on the horizontal axis is related to periods in which a reaction is observed rather than to the argument of IRF, or CIRF. So the first period refers to the period in which a shock occurs for the first time, namely IRF(0) or CIRF(0), and the second period is then equivalent to IRF(1) or CIRF(1), and so on.

Source: Own computations.

Table 4.12: Dynamic properties of estimated standard EC models

	Root no. 1	Root no. 2	Root no. 3
Model 0	0.9146	-0.3833 + 0.3771 i	-0.3833 - 0.3771 i
		(in modulus 0.5377)	(in modulus 0.5377)
Model 1	0.9586	-0.4180 + 0.3801 i	-0.4180 - 0.3801 i
		(in modulus 0.5650)	(in modulus 0.5650)
Model 2	0.9962	-0.4253 + 0.4004 i	-0.4253 - 0.4004 i
		(in modulus 0.5841)	(in modulus 0.5841)
Model 3	-0.0953		
Model 4	-0.1250		
Model 5	0.6774	-0.5344	

Source: Own computations.

relates to a permanent shock in the real effective exchange rate, or to a never-ending sequence of its depreciation. Although both IRF and CIRF converge to the zero, the main difference between them is that the IRF simulates the convergence to the original equilibrium and the CIRF to the new one. So, we already know that the exchange-rate depreciation has a positive effect in the long run (based on estimated long-run multipliers; see Table 4.9) and CIRFs tell us something about the pass-through to this new equilibrium. In this sense the Model 3 to 5 clearly speak for the J-curve phenomenon because the trade balance goes from a short-run deterioration to a long-run improvement. As previously, the models with complex dynamics (the first three cases in Figure 4.8) do not generate just one-sided transition but also some short-run improvement can be observed.

Comparison of IRFs and CIRFs in Figure 4.8 reveals that there exists an extensive delay of trade balance improvement if the depreciation, or maybe rather devaluation, is considered as permanent. The delay amounts up to two or three years according to the model considered. Moreover, CIRFs are smoother than IRFs. The perception of the devaluation by the public as permanent will probably be the case in the exchange-rate-peg monetary policy regime or a type of exchange-rate commitment. However, it takes a time than the commitment gains a credibility, and than agents fully incorporate the new conditions into their expectations. Unlike temporal depreciation, the permanent loss of external purchasing power provides a greater space for optimization. Actually, a temporal change in exchange rate does not necessitate any change in production, probably opposite to the permanent change. The previous therefore promotes a slower and smoother (cautious) response of the trade balance.

Mathematical derivation of IRF and CIRF for the real effective exchange rate can be found in Appendix D (IRF) and Appendix E (CIRF). The derivation procedure of both functions is the same for other variables and is left as a possible exercise. Impulse-response functions and cumulative impulse-response functions for other four exogenous variables are reported in Appendix F – for models with the best Schwarz Bayesian criterion, and in Appendix G – for models with the best Akaike information criterion.

4.3 Microeconomic consequences of exchange-rate devaluation

4.3.1 Data and model

As in the section 4.2, we use conditional error correction (CEC) models and bounds testing for cointegration to investigate the J-curve phenomenon on the level of individual industries and trading partners. At the same time, there is used the same practice as proposed in the section 4.2, including the concurrent consideration of both short and long run parameters when identifying the J-curve. We also employ the impulse response analysis defined in the section 4.2.3. So, the model for particular industry or particular trading partner takes the form[40]

$$\begin{aligned}\Delta tb_t = c_0 + \pi_1 \widetilde{tb}_{t-1} + \pi_2 \widetilde{yd}_{t-1} + \pi_3 \widetilde{yf}_{t-1} + \pi_4 \widetilde{q}_{t-1} + \pi_5 \widetilde{irdf}_{t-1} + \\ + \sum_{i=1}^{1} \psi_{1i} \Delta tb_{t-i} + \sum_{i=0}^{1} \psi_{2i} \Delta yd_{t-i} + \sum_{i=0}^{1} \psi_{3i} \Delta yf_{t-i} + \\ + \sum_{i=0}^{1} \psi_{4i} \Delta q_{t-i} + \sum_{i=0}^{1} \psi_{5i} \Delta irdf_{t-i} + u_t \quad (4.32)\end{aligned}$$

where tb_t is the index of export over import when considering the trade with particular foreign partner and the index of import over export when considering the trade of particular industry. This, at the first sight confusing choice for the expression of trade balance, is due to a different type of quotations for the real effective exchange rate of the Czech koruna and the bilateral real exchange rates with respect to the Czech koruna. Whereas the real effective exchange rate is computed as the number of units of effective foreign currency per one unit of domestic currency, bilateral real exchange rates are the

[40] As in the section 4.2, variables with tilde denote the detrended levels.

amount of domestic currency paid for the unit of foreign currency.[41] Weakening of the domestic currency therefore causes a decrease of the real effective exchange rate and an increase of the bilateral real exchange rate. As a consequence, the J-curve hypothesis assumes the negative short-run parameters of trade balance with respect to exchange rate and the respective long-run multiplier with positive sign – it holds for both industry and bilateral trade. Although the notation of trade balance could be confusing, the results will not be, and this was the main intention. Exchange rate is denoted as q_t in the model (4.32). It takes the form of the real effective exchange rate for the study of industry trade and the bilateral real exchange rate for the study of trade with particular partner.

Regarding the scope of research, we have researched 13 most important partners in foreign trade of the Czech Republic and the trade of 58 Czech industries (equivalent to 58 SITC trade classes).[42] The list of investigated industries is evident from Appendix I and it covers most of the two-digit SITC trade classes. From trading partners are researched Austria, Belgium, France, Germany, Hungary, Italy, the Netherlands, Poland, Slovakia, the United Kingdom, the United States, the Russian Federation and China. They were chosen according to the value trade structure of the Czech Republic in the year 2013; in this respect see Figure 4.12. Because of the substantial scope of the investigation, we rest on the unrestricted models rather than to search for particular restriction. In all cases, symmetric maximum lag order of model (4.32), consisting in the value of one, provides a very good approximation. Resting on unrestricted models, contemporaneous coefficients were naturally included as well.

Period under the review ranges from 2000 to 2013, by observation per each quarter. In the case of countries in the Eurozone, conversion ratios at the time of entrance were used to receive consistent time series of bilateral exchange rates. As in the section 4.2, yd_t denotes the domestic income and yf_t the foreign income. The same also remains their empirical content, so yd_t is based on equation (4.13) and (4.14), and yf_t is the European Union real GDP. Opposite to the model (4.19), model (4.32) does not include the domestic and foreign interest rate separately but in the form of the interest rate differential (denoted as $irdf_t$). In the analysis, interest rate differential is taken as the difference between 3-month Prague Interbank Offered Rate (PRIBOR) and 3-month dollar-deposit London Interbank Offered Rate (LIBOR). The reasoning for the interest rate differential is similar to the inclusion of domestic and foreign interest rates in model (4.19). In line with

[41] GDP deflators were used as the price indices in all cases.

[42] SITC means the Standard International Trade Classification.

the mentioned intertemporal trade model, positive interest rate differential fosters the domestic country to run a current account deficit at present, with a promise of current account surplus in the future. For modeling purposes, all mentioned time series were transformed into the natural logarithms and where necessary, they were seasonally adjusted by TRAMO/SEATS method. Sources of the data are the same as in the section 4.2 and can thus be found in Table 4.5.

4.3.2 The threat of Lucas critique

As stated previously, the models for both bilateral and industry trade were estimated over the horizon of the years 2000 to 2013. Estimated models were properly diagnosed, and no potential danger for the reliable statistical inference was found. It can thus be expected that from a statistical point of view, our analysis is correct within the sample. What may impair the applicability of our results outside of the sample, or to the ZLB economy, is the perception of the liquidity trap as a structural break.[43] Another possible source of parameter instability could be the switch to the exchange-rate commitment.[44]

In this case, out-of-sample parameter instability is closely related to the Lucas (1976) critique. If the ZLB economy or the installation of exchange rate commitment leads to a change in policy behavior then, according to Lucas (1976), a change in the value of parameters is highly probable because of a shift in the expectations of private agents. The delay between the start of the investigation and the time of collecting results provides us with a chance to authenticate this suspicion empirically. In fact, we use aggregate quarterly data from the period 2000-2015 to test the parameter instability with the aid of standard econometric tests, namely Chow tests (Chow, 1960) and CUSUM tests (Brown, Durbin and Evans, 1975; or also Ploberger and Krämer, 1990).[45]

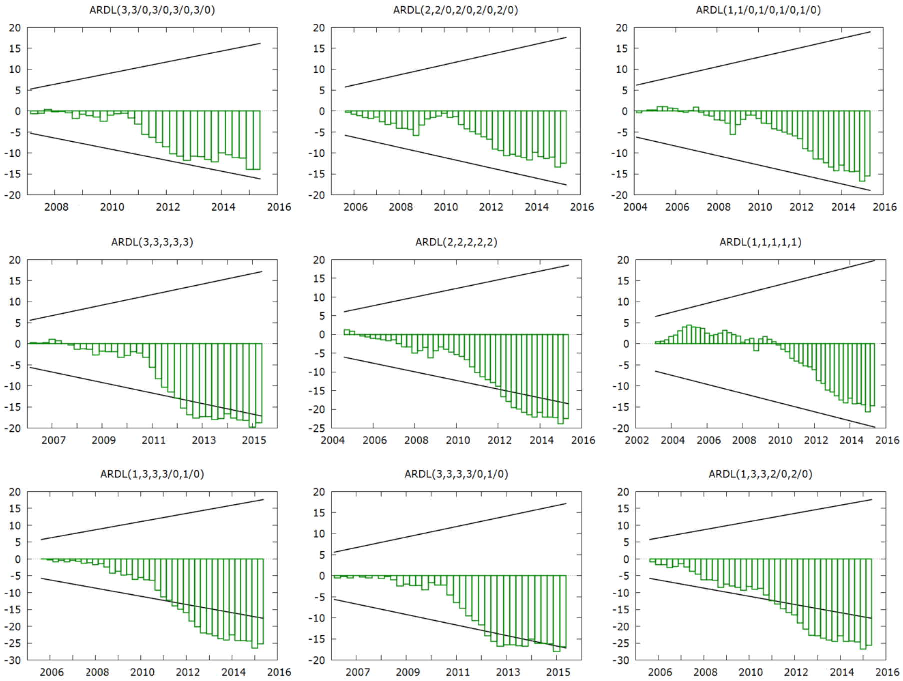
As results of the CUSUM tests show, see Figure 4.9, under some specifications of the model (4.32), or also model (4.19), the prediction errors are pronounced and explode outside the 95 percent bounds. A substantial increase in the prediction errors can be observed roughly from the year 2012 – the year of the beginning of the zero lower bound in the Czech Republic. The performed Chow tests tell the same story, when they find the evidence

[43] Zero lower bound (ZLB) on nominal interest rates started to be binding for the Czech economy since Autumn 2012; see the section 2.4 for an in-depth description.

[44] One side exchange rate commitment was introduced by the Czech National Bank in November 2013; see the section 2.4.

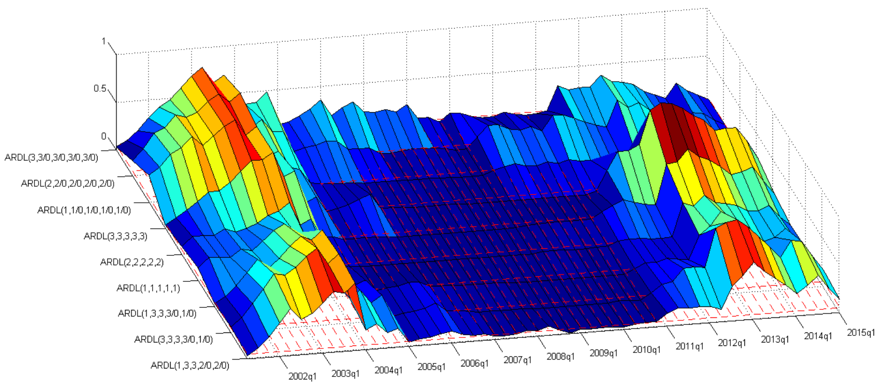
[45] Concretely, we had only the first two quarters of the year 2015.

Figure 4.9: CUSUM tests for parameter stability



Source: Own computations.

Figure 4.10: Probabilities arising from the Chow tests



Note: The dashed red plane displays the 0.05 significance level. If the colored surface, capturing p-values based on the Chow tests, lies beneath the dashed red plane, the evidence for a structural break is sufficient.

Source: Own computations.

of a structural break in all the tested specifications; see Figure 4.10.[46] This finding therefore supports the contention about a certain type of discontinuity between the pre-ZLB era and the ZLB period itself. It is then clear that the conclusions drawn from this work must be applied very carefully to the ZLB economy.

In a specific case of the trade balance model, it is possible to believe that the parameter drift relates to exchange rate commitment rather than to the virtually zero interest rates. The fact that the exchange rate regime matters with respect to the J-curve has a relatively strong basis in the previous research. See for instance Warner and Kreinin (1983), who compare results of the J-curve investigation for the Bretton Woods period and a follow-up floating era, and find substantial discrepancies. At least, the establishment of an asymmetric exchange rate commitment actually removes the exchange-rate risk from exporters; it may therefore induce a behavioral change. A change in behavior likely occurs in the negotiating of new contracts for international trade.

4.3.3 Country- and industry-specific elasticities

Going to the results of investigation on micro level, trade of the Czech Republic with a particular foreign partner might be considered first. Table 4.13 summarizes the estimated long-run relations. Based on a steady state, a real-exchange-rate depreciation of the Czech koruna would probably affect positively the trade with Austria, Belgium, Germany, Poland, Slovakia, the United States, the Russian Federation and China. Conversely, a negative impact could be expected for the trade with France, Hungary, Italy, the Netherlands and the United Kingdom. The existence of a steady state has been statistically confirmed for almost all countries, see Appendix H. Appendix H also provides an estimation of conditional error-correction (CEC) models.

[46]The Chow test might suffer from a beginning-/end-point bias. If the division is performed at some point near the beginning or the end of the sample, then the conclusion about a structural break could be biased due to an insufficient observation number in one of the subsamples. Sometimes the subsample is so small that the estimation of subregression is impossible (because of a degrees-of-freedom insufficiency). Here the Chow predictive variant may serve, and it works on a similar basis as the CUSUM test. In fact, we have used the Chow test in sequential searching for a structural break. Quandt (1960) and Andrews (1993) propose a systematic procedure for testing for a structural break observed at an unknown date. But employing the QLR test we have reached the same conclusion.

Table 4.13: Long-run multipliers for trade with a particular foreign partner

Country	yf	yd	rer	irdf
Austria	1.7778	-1.2825	0.5095	0.4206
Belgium	-1.3954	1.2002	0.9916	-0.0565
France	-0.2454	0.6039	-0.4710	0.0436
Germany	-0.0997	0.3728	0.2796	0.0294
Hungary	2.8346	-1.7352	-0.1692	0.0625
Italy	-1.3697	1.7150	-0.4108	0.0004
The Netherlands	2.2892	-1.5115	-0.9826	0.2309
Poland	0.2018	0.1453	0.2560	0.0332
Slovakia	-1.3785	1.2037	0.2775	0.0046
United Kingdom	1.5091	-0.9456	-0.5012	0.0170
United States	-1.3577	1.1468	0.6163	-0.0896
Russian Federation	1.7366	-1.7692	0.7387	0.0363
China	0.0574	0.0458	0.5853	-0.0094

Note: Based on the estimated steady-state relationships.

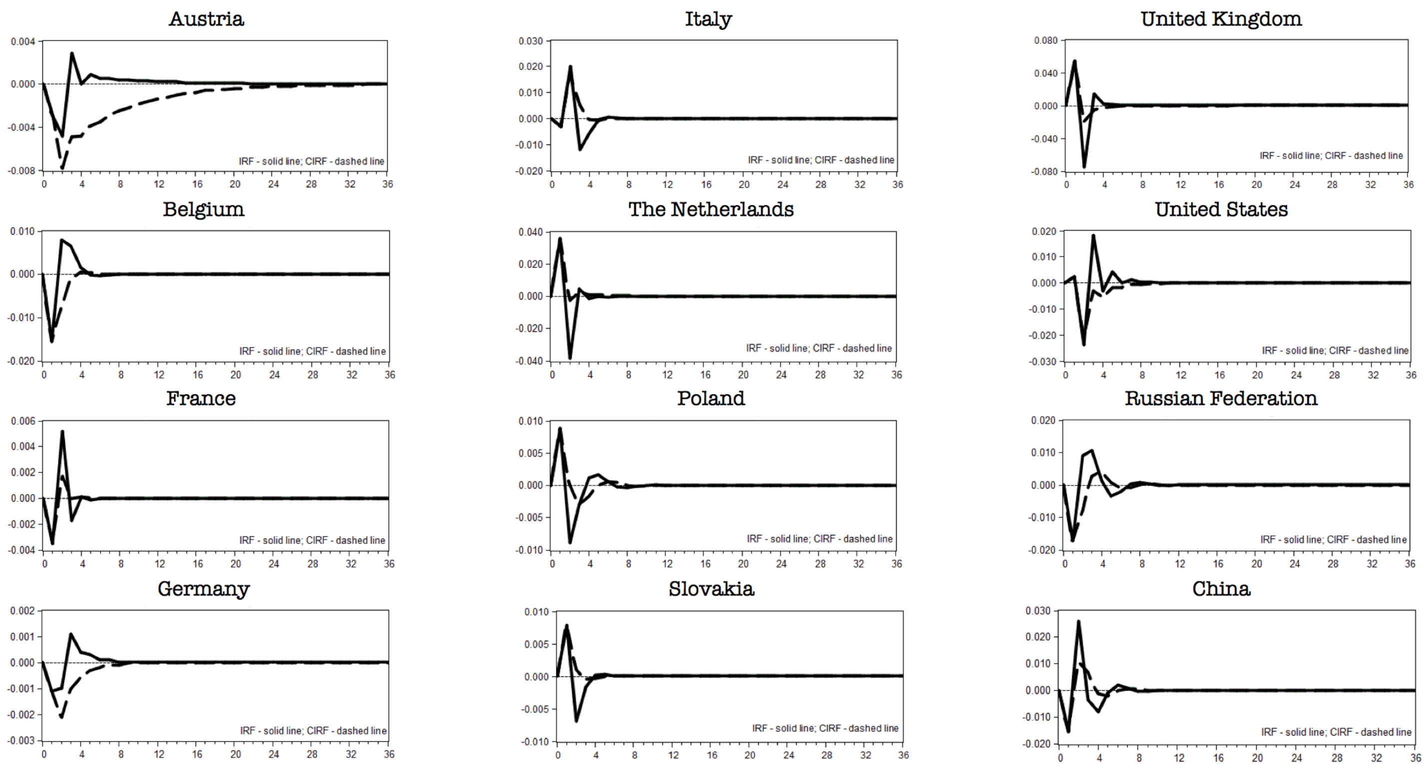
Source: Own computations.

The pattern of adjustment processes is observable from Figure 4.11.[47] Basically, a J-curve or inverse J-curve provide a good approximation for all countries. The trade with Austria, Belgium, France, Germany, the United States, the Russian Federation and China behaves along the J-curve. The trade with Italy, the Netherlands, Poland, Slovakia and the United Kingdom follows the inverse J-curve. If the J-curve applies, there is an improvement in the bilateral trade balance from the second or third quarter, lasting around two to four quarters. The initial positive effect within the inverse J-curve is relatively short-lived, with an approximate duration of two quarters.

The previous adjustments correspond to transitory perturbation. When the foreign-exchange disturbance is judged, in the eyes of private agents, as permanent, the transition is predominantly one-sided. Generally, an initial movement from the J-curve or inverse J-curve is prolonged to the entire period. Sometimes minor ripples also occur at later stages.

[47] Impulse responses trace a reaction to a temporal shock which does not induce a shift in steady state. On the contrary, a permanent shock changes a steady state, and cumulative impulse responses depict the transmission. As a consequence, the IR function converges to zero due to the convergence to the original equilibrium and cumulative IR function because of the convergence to a new equilibrium.

Figure 4.11: Country response to the foreign-exchange shock

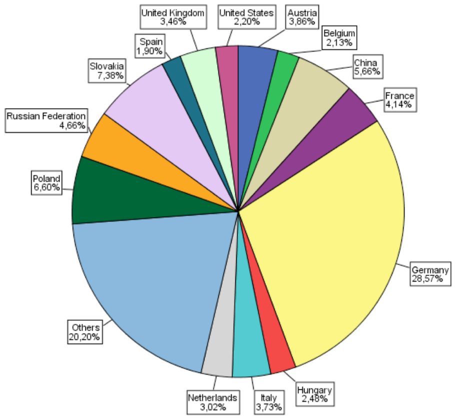


Note: The impulse-response and cumulative impulse-response function for Hungary have not been stated above; the shape and magnitude of both these functions are in fact identical with the functions for Slovakia. Responses correspond to the one-standard-deviation shock. Trade balance is computed as exports over imports.

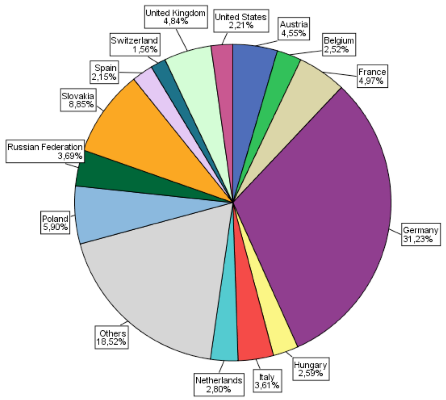
Source: Own computations.

Figure 4.12: Czech foreign trade structure

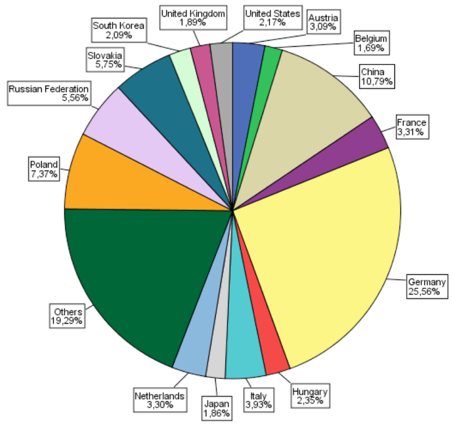
(a) Country share of total turnover



(b) Country share of export



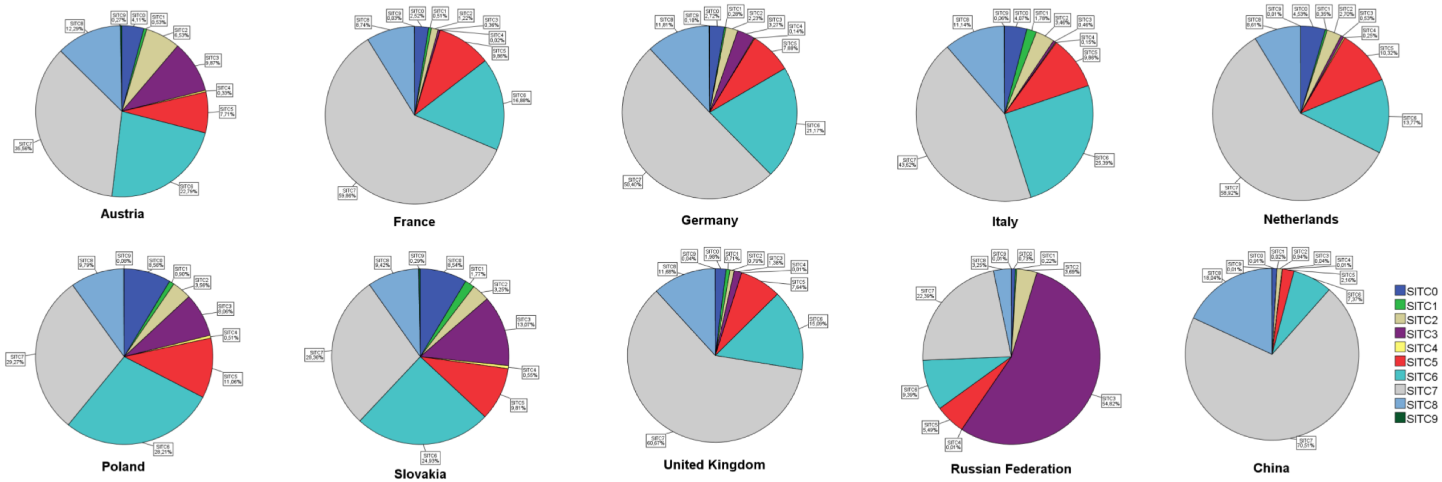
(c) Country share of import



Note: Based on the trade flows of the year 2013.

Source: Czech Statistical Office; own computations.

Figure 4.13: Country value trade structure



Note: The value trade structure is not displayed for the United States, Belgium and Hungary. The U.S. trade structure is close to that of the United Kingdom. Similarly, Belgian and Hungarian trade structures are close to the Italian. Shares displayed in the figure are averages over the years 2000 to 2013.

Source: Czech Statistical Office; own computations.

Table 4.14: Moments of long-run multipliers for a particular industry - change in REER

	Units in group	Mean	Median	RMS	Std. deviation
Food and life animals (SITC 0)	9	0.77	1.10	2.50	2.52
Beverages and tobacco (SITC 1)	2	0.50	0.50	1.58	2.12
Raw materials, except fuels (SITC 2)	7	-1.11	0.16	5.69	6.03
Mineral fuels and electrical energy (SITC 3)	4	0.66	0.58	0.89	0.70
Oils, fats and waxes (SITC 4)	3	7.58	1.80	11.43	10.48
Chemicals (SITC 5)	8	0.12	0.46	1.46	1.55
Manufactured goods - sorted by material (SITC 6)	9	0.71	0.77	2.28	2.30
Machinery and transport equipment (SITC 7)	9	-0.64	-0.71	2.90	3.00
Miscellaneous manufactured articles (SITC 8)	7	0.55	0.69	2.50	2.64

Note: The table comprises only long-run multipliers for the real effective exchange rate; in contrast to Table 4.13. Within commodity trade, we use the effective exchange rate, which is standardly computed as the number of units of the effective foreign currency to one unit of domestic currency. With respect to this, the trade balance was defined as imports over exports, and therefore a positive long-run multiplier implies the positive effect of exchange rate devaluation (as well as for the bilateral trade). RMS is a shorthand for the root mean square.

Source: Own computations.

In order to solve the J-curve precisely, we have to go to the level of individual industries. In so doing, we can provide microeconomic fundamentals for the trade balance behavior. Table 4.14 contains the moments of estimated long-run multipliers for industries, which relate to a change in the equilibrium level of the real effective exchange rate (REER). For individual multipliers see Appendix I. From these results, it can be seen that the reaction of trade balance to exchange rate devaluation is mostly positive. This applies for seven of nine (or eight of nine, if median is taken into consideration) studied trade classes. But within trade classes a large dispersion is observed. Hence, Appendix J highlights the three most important trade classes for each trading partner (in each case, they form more than three-quarters of the total trade volume). In that respect see also Figure 4.13. And what is more important, the weights of two-digit trade subclasses are also shown in Appendix J.

In fact, machinery and transport equipment (SITC 7) occupy a large part of the Czech foreign trade. The automotive industry (SITC 78) and electrical engineering industry (SITC 75 and 76) seem most important, if the size of the multiplier and the weight of the industry are taken into account. But there exists a substantial difference between these industries. The automotive industry responds positively to exchange rate devaluation, in contrast to the electrical engineering industry, which responds negatively. As the Marshall-Lerner condition implies, foreign-trade demands[48] are probably inelastic for the electrical engineering industry and elastic for the automotive industry.

Of manufactured goods (SITC 6), those made from iron and steel are most important. For the majority of trading partners, the weight has a tendency to peak at the SITC 67 subclass; see Appendix J. In this case, the trade balance responds negatively and elastically to exchange rate devaluation. Trade of the Czech Republic with two countries, namely Russia and China, has a specific structure (compared to other trading partners). Trade with Russia is extensively biased towards the import of fuels. Mainly crude oil and gas are imported. Trade in crude oil reacts negatively to devaluation of the exchange rate, but the magnitude of the long-run multiplier is very close to zero. Trade in gas reacts positively, with a greater multiplier (however, still smaller than one). Compared to other countries, trade with China has a larger share of SITC 8, chiefly due to the import of clothing and footwear. In both cases, the reaction to exchange rate devaluation is positive.

Trade with two neighboring countries, namely Slovakia and Poland, may be highlighted likewise. Trading with Slovakia and Poland is characterized by a higher share of food and life animals (SITC 0) and a higher proportion

[48]Domestic demand for foreign exports and foreign demand for domestic exports.

of SITC 3.[49] Trade within SITC 0 is largely determined by the geographical proximity of these countries.[50] Generally, if we consider the trade volume and the magnitude of estimated long-run multipliers, trade in vegetables and fruits (SITC 05), cereals (SITC 04), meat (SITC 01) and dairy products (SITC 02) are revealed as decisive. With respect to exchange rate devaluation, only cereals react negatively; the others react positively. A higher share of SITC 3 arises from trading coal (import from Poland), electricity (export to Slovakia) and what is known as residual petroleum products (classified as SITC 335). Electrical current (SITC 35) is one of the two commodities for which no cointegrating relationship was ascertained. It may be assumed that the absence of a long-run relationship follows predominantly from an inability to store the electrical current. Estimated pass-through of the foreign-exchange shock for individual industries is depicted in Figure 4.14. The J-curve and inverse J-curve fit well to most of the impulse responses.

Because the information about long-run multipliers relating to a change in YD is at our disposal, we may also think about consequences of domestic economic growth for the foreign trade structure. As Table 4.15 shows, domestic economic growth left the trade within SITC 0 and 1 almost unchanged. Other trade classes react with a higher sensitivity. Accordingly, as the Czech natural level of production (or its steady state trajectory) rises upward, the Czech economy tends to export more manufactured goods (in terms of SITC 6), chemicals and goods within SITC 4. Partly as a result of that, the Czech economy depends more on imports of raw materials and fuels. Deterioration of the SITC 7 balance can be observed as well. It is generally hard to say what stands behind that, but based on the above, the reason may likely be found in the automotive industry or electrical engineering industry. A story about a greater dependency on products from foreign electrical engineering industries is more believable than a story about a competitiveness loss of the Czech automotive industry. This statement is also supported by the value of estimated long-run multipliers reported in Appendix I. A final piece of information supplied by Table 4.15 is the tendency to import more products such as clothing, footwear and related accessories (SITC 8 in general) from Southeast Asia, especially China. Adjustment processes are contained in Appendix K and Appendix N.

Economic growth in the Czech Republic probably changes the structure of its trading partners as well. According to Table 4.13, trade with Belgium, France, Germany, Italy, Poland, Slovakia and the United States is affected

[49] On this count, Austria can be mentioned as well.

[50] The most important partner of the Czech Republic in the trade of agricultural products is Germany, but the proportion of agricultural products in the total trade volume with this country is relatively small.

positively.[51] The trade balance with Austria, Hungary, the Netherlands, the United Kingdom and the Russian Federation deteriorates. And trade with China is almost unaffected. It can therefore be expected that the import of clothing, footwear and related accessories would also be undertaken with other countries. This tendency could be supported by higher growth in China, which goes hand-in-hand with greater wage costs. The trade balance with Russia is worsening mainly thanks to a greater amount of fuel imports.

Similarly, developments in a foreign economy act upon foreign-trade flows. We approximate foreign economy by the economy of EU 27, which provides a very good proxy for the Czech Republic. Therefore, an increase in the natural level of production in the European Union left trade with food and life animals (SITC 0), beverages and tobacco (SITC 1), and fuels (SITC 3) almost intact; see Table 4.16. An improvement is observed only within SITC 2 and SITC 8, probably because of a decrease in imports as a consequence of increasing foreign demand. Other trade classes are influenced negatively. Therefore, if the rate of growth between the Czech Republic and the European Union differs significantly, welfare effects for the Czech Republic might not be negligible. See Appendix L and Appendix O for more information about the response to the foreign-income shock.

The last question which remains to be answered is the rate of responsiveness of foreign trade flows to the interest rate differential. In other words, we want to clarify the role of intertemporal substitution in the international exchange between the Czech Republic and its trading partners. Actually, its role is nothing more than marginal. First moments (measured by both the mean and the median) of the estimated multipliers are virtually zero.[52] Moreover, the standard deviations are very low.[53] Therefore, the results securely speak for the dominance of uncovered interest rate parity. We thus achieve conformity with our previous investigation conducted at the aggregate level. Pass-through of a temporary disturbance in the interest rate differential can be found in Appendix M and Appendix P.

[51] Meaning that the trade balance improves.

[52] A nonzero first moment is achieved only for the trade class SITC 4. The mean is equal to -0.21 and the median to -0.40. The same picture can be seen if bilateral trade is taken into account. Just two countries have nonzero multipliers, namely Austria and the Netherlands; see Table 4.13.

[53] We do not report the moments of estimated multipliers for the interest rate differential, but they are available upon request.

Table 4.15: Moments of long-run multipliers for a particular industry - change in YD

	Units in group	Mean	Median	RMS	Std. deviation
Food and life animals (SITC 0)	9	-0.09	0.34	2.99	3.17
Beverages and tobacco (SITC 1)	2	0.16	0.16	0.97	1.35
Raw materials, except fuels (SITC 2)	7	1.56	1.03	7.57	8.00
Mineral fuels and electrical energy (SITC 3)	4	0.24	1.21	5.72	6.60
Oils, fats and waxes (SITC 4)	3	-10.07	-9.00	14.81	13.30
Chemicals (SITC 5)	8	-1.27	-1.44	1.83	1.40
Manufactured goods - sorted by material (SITC 6)	9	-0.80	-0.55	4.17	4.34
Machinery and transport equipment (SITC 7)	9	0.26	0.51	3.73	3.95
Miscellaneous manufactured articles (SITC 8)	7	1.73	0.43	4.41	4.38

Note: The trade balance is considered to be imports over exports. Therefore, a positive reaction to a positive domestic-income shock is related to a negative long-run multiplier. RMS is a shorthand for the root mean square.

Source: Own computations.

Table 4.16: Moments of long-run multipliers for a particular industry - change in YF

	Units in group	Mean	Median	RMS	Std. deviation
Food and life animals (SITC 0)	9	0.19	0.13	2.22	2.35
Beverages and tobacco (SITC 1)	2	0.05	0.05	0.35	0.48
Raw materials, except fuels (SITC 2)	7	-0.78	-0.62	5.28	5.64
Mineral fuels and electrical energy (SITC 3)	4	-0.03	-0.80	5.38	6.21
Oils, fats and waxes (SITC 4)	3	7.38	8.22	10.67	9.45
Chemicals (SITC 5)	8	1.46	1.34	1.75	1.02
Manufactured goods - sorted by material (SITC 6)	9	0.83	0.53	3.23	3.31
Machinery and transport equipment (SITC 7)	9	0.27	-0.04	2.61	2.76
Miscellaneous manufactured articles (SITC 8)	7	-1.43	-0.31	3.46	3.40

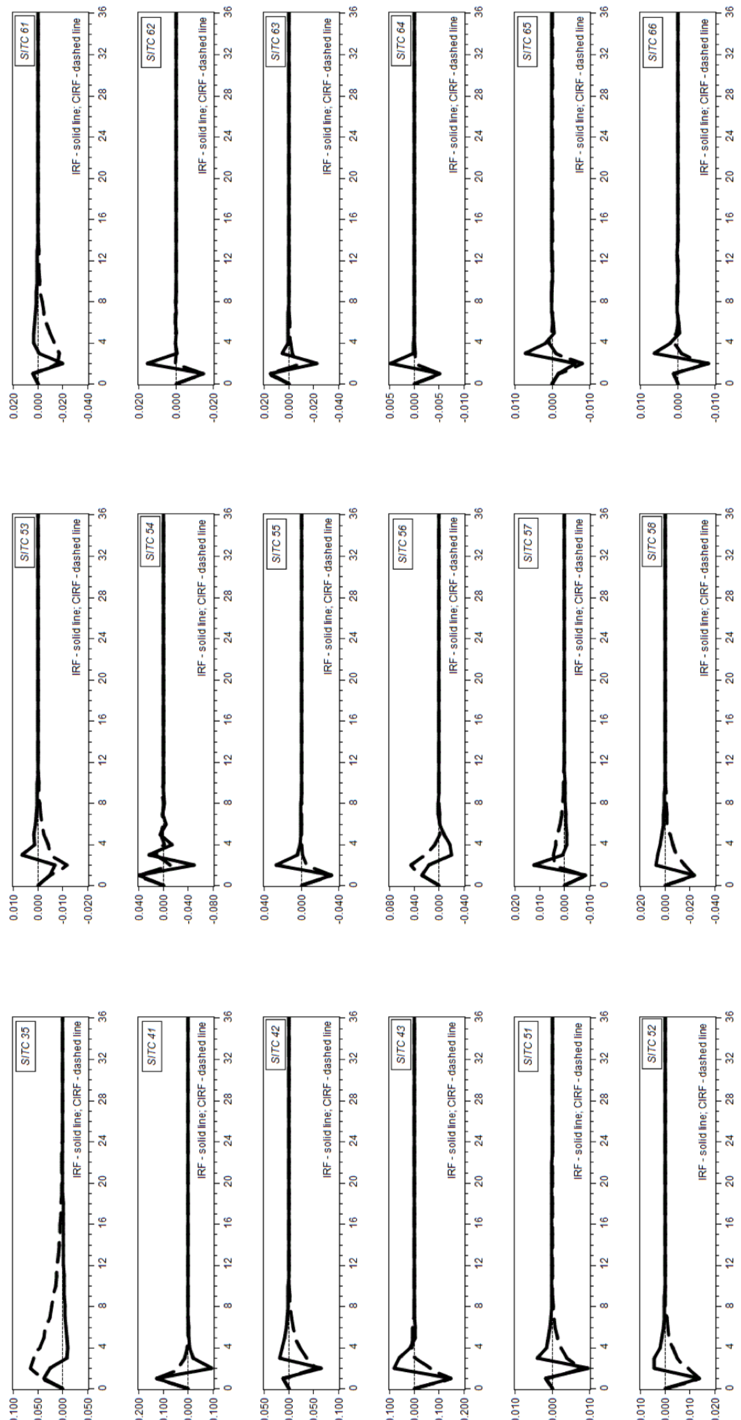
Note: The trade balance is considered to be imports over exports. Therefore, a positive reaction to a positive foreign-income shock is related to a negative long-run multiplier. RMS is a shorthand for the root mean square.

Source: Own computations.

Figure 4.14: Industry response to the foreign-exchange shock - part 1

Note: Trade balance expressed as imports over exports. Responses correspond to the one-standard-deviation shock.
Source: Own computations.

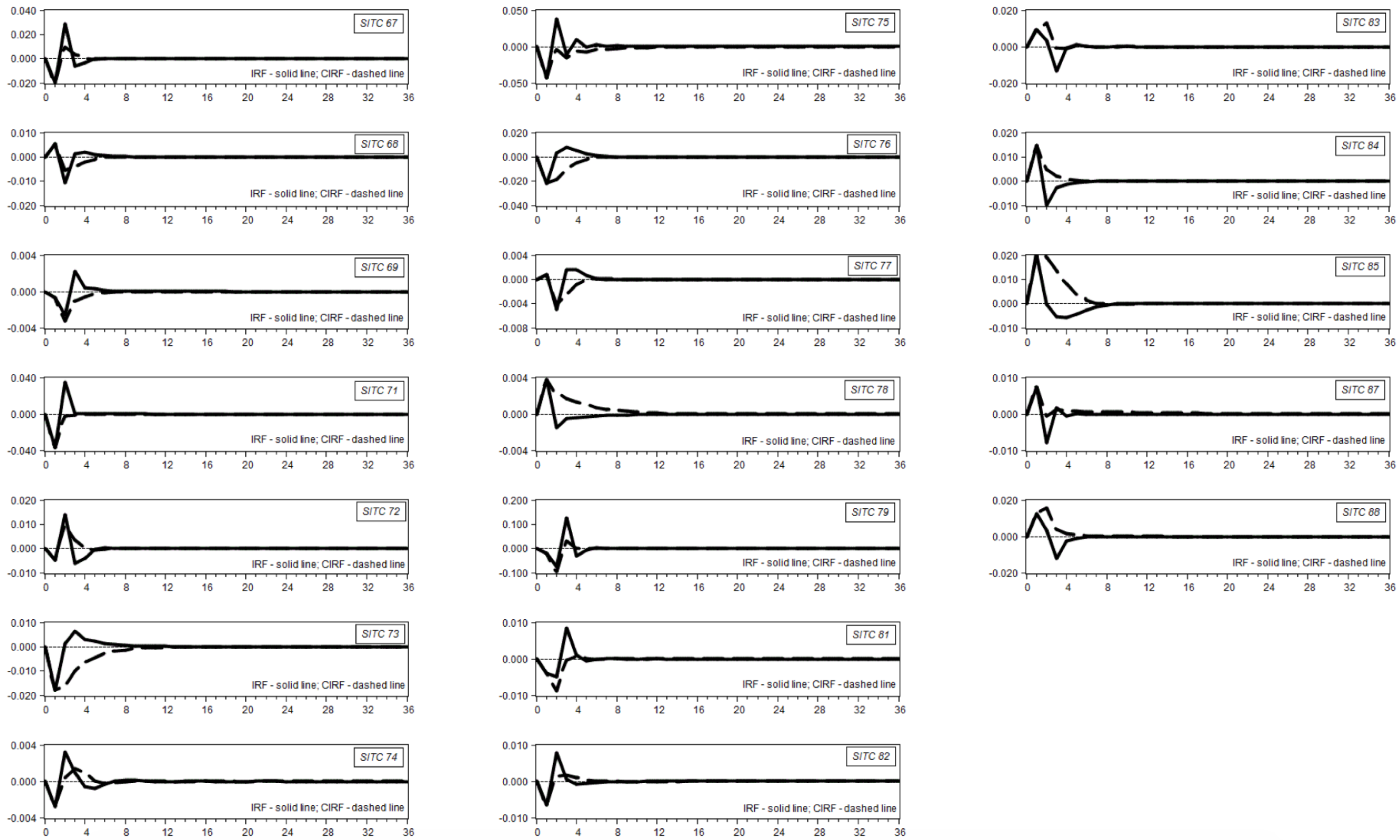
Figure 4.14: Industry response to the foreign-exchange shock - part 2



Note: Trade balance expressed as imports over exports. Responses correspond to the one-standard-deviation shock.

Source: Own computations.

Figure 4.14: Industry response to the foreign-exchange shock - part 3



Note: Trade balance expressed as imports over exports. Responses correspond to the one-standard-deviation shock.

Source: Own computations.

4.4 Determinants of business investment

4.4.1 Sample of the firms

For the research there are used individual or micro-level data on non-financial corporations (NFCs) situated in the Czech Republic; both under the domestic and foreign control. The data come from the quarterly survey of the Czech Statistical Office (CSO) and so they have the quarterly frequency. Because the data are confidential, they are not publicly available. Survey is slightly biased towards the larger companies, as the average number of employees per a firm is around 50 or more; see Table 4.17 showing the average number of employees by selected industries. More information about the distribution of firms in the sample with respect to the number of employees is supplied by Appendix X. As the experience instructs, larger companies provide more reliable data in the questionnaire (opposite to the smaller ones), as they have more time and more educated people to deal with it. The sample ranges from the year 2008 to 2015. Total number of questioned firms in each quarter is around 30 thousand on average. In fact, only a half of the firms is in the sample for the entire period. The rest is chosen in order to attain the representativeness of the sample. The data thus form an unbalanced panel. Regarding their origin, scope and granularity, the data represent a unique sample for the research of investment behavior.

Regarding the behavior of investment, main interest consists in the observations on the purchases of tangible and intangible fixed assets written by the firms in the questionnaire. Purchases are recorded in the thousands of CZK, but for the modeling purposes they are used in logarithms and were also seasonally adjusted. Because the purchases reflect increases in the stock of fixed assets during the quarter (flow variable), they can be considered as the gross investment. If we aggregate these fixed assets purchases over all firms in the sample, we obtain an alternative indicator of investment activity of the NFCs, which can be compared with the usual measure from national accounts – the gross fixed capital formation for the whole NFC sector (this measure is publicly available from the CSO website and comprises all non-financial corporations, including the smaller ones). As Figure 4.15 illustrates, dynamics of these two measures highly correlate. Although the dynamics correlate, there still exist discrepancies in the levels of annual growth rates. These discrepancies are obviously driven by the companies not included in the sample. Against the aggregated data from national accounts, the granular data provide a space for the investigation on the level of individual industries. It is a very welcome feature of the data set allowing us to dive deeper into the researched area.

With the purchases of fixed assets of one specific firm, there are also identifiers, such as the number of employees and sector of the economy. Sector of the economy is determined with the aid of NACE classification[54]; see Appendix W for the definition of industries used for the investigation. Distribution of firms within the sample over the different sectors of the Czech economy is described by the last column of Table 4.17.

Table 4.17: Investment and number of employees by average firm

Industry	Investment mil. CZK	Number of employees	Number of firms in the sample
Automotive	26.0	373	386
Chemicals	5.2	118	1510
Transportation	6.3	136	1462
Other means of transport	7.8	209	91
Electrical engineering	5.2	164	711
Energy	22.1	103	679
Metallurgy and heavy engineering	3.0	102	2665
Retail	2.2	117	1539
Motor vehicle trade	2.9	49	692
Other services (n.s.e.)	2.1	72	5611
Other manufacturing (n.s.e.)	1.5	74	1597
Tourism	0.5	47	1136
Food and beverages	2.9	91	1060
Construction	1.0	53	2927
Telecommunication	45.9	226	77
Clothing	1.3	74	577
Mining	25.1	355	95
Wholesale	1.2	44	2949
Agriculture	3.0	55	1491

Note: Investment was computed as the ratio of average quarterly investment in the sector to the number of firms in the sector and employment as the ratio of average number of employees in the sector to the number of firms in the sector. The shorthand n.s.e. means not specified elsewhere.

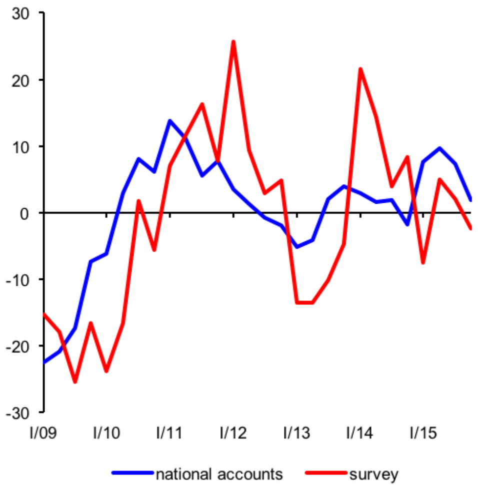
Source: Own computations.

Table 4.17 also presents average quarterly investment of average firm in a selected sector. Averaging is therefore done both across time-series dimension and cross-sectional dimension. Accordingly, although other services (n.s.e.)[55] include a large number of firms, their investment on average firm is relatively low. Other services (n.s.e.) comprise mainly services in informatics and data processing, real estate activities, professional, scientific, technical and

[54] NACE is the French shorthand for the classification of economic activities in the European Union.

[55] The shorthand n.s.e. means “not specified elsewhere”.

Figure 4.15: Alternative measures of business investment



Note: Annual growths of the gross fixed capital formation of non-financial corporations (national accounts) and the purchases of fixed assets (survey), both in constant prices. Source: Czech Statistical Office; own computations.

Table 4.18: Macroeconomic covariates

Variable	Source	Transformations
Real GDP in EA14	CNB	In logs and seasonally adjusted.
Real effective exchange rate	CNB	In logs and seasonally adjusted.
Real interest rate	CNB	Without data transformation.
Real government investment	CSO	In logs and seasonally adjusted.
Real volume of EU funds	Ministry of RD	In logs and seasonally adjusted.
Confidence indicator for EU	Eurostat	In logs and seasonally adjusted.

Variable	Mean	Median	Std. Dev.	Skewness	Kurtosis
Real GDP in EA14	4.80	4.80	0.03	-0.59	-0.07
Real effective exchange rate	4.59	4.60	0.04	-0.07	-0.56
Real interest rate	-0.10	-0.04	1.23	0.15	0.10
Real government investment	10.73	10.70	0.15	0.58	-0.36
Real volume of EU funds	14.58	15.07	1.64	-1.96	3.60
Confidence indicator for EU	4.56	4.60	0.12	-1.41	1.79

Note: Logs mean natural logarithms. Seasonal adjustment was done by TRAMO/SEATS method in all cases.

Source: Own computations.

administrative activities, and services in education and health. The lowest level of investment on average firm was recorded in tourism. Low investment on average firm also exhibit trade and construction. On the other hand, high level of investment on average firm was observed in telecommunication, mining, energy and in manufacturing (especially in automotive); i.e. mainly in industrial firms.

Regarding number of employees, investigated firms are rather larger ones. As Table 4.17 shows, average number of employees ranges between fifty and more than three hundred. Firms with a high number of employees are concentrated mainly in manufacturing, mining and telecommunication. Firms with lower number of employees are in services, trade, construction and agriculture.

Because the aim of this section is to describe the behavior of the business investment, we give it into the link with a diverse set of macroeconomic variables. See Table 4.18 for the list of these variables, the sources of data, transformations and the descriptive statistics. Justification for the choice of concrete covariates was discussed in the section 2.5. All variables which enter into the model are real quantities. As a proxy for external or foreign demand was chosen the real GDP of effective Eurozone, as a dominant partner of the Czech Republic in foreign trade. This effective index weights real gross domestic products in the fourteen Eurozone countries (in Table 4.18 as EA14), based on their shares on the Czech exports. Weights for the computation of the real effective exchange rate also correspond to the foreign-trade flows of the Czech Republic and as the price indices were used the indices of producer prices (PPIs). Real interest rate is computed as ex-post rate (with observed inflation instead of expected inflation in use), when the one-year maturity PRIBOR served as a base. Because of its negative values, real interest rate was not transformed into the logarithmic form – unlike all other variables. Gross fixed capital formation in government sector deflated by a fixed capital deflator is considered as a real government investment. Amount of EU funds drawn by private firms to finance their investment plans was obtained from the database of the Ministry of Regional Development. Specifically, funds from European Regional Development Fund (ERDF) form a large part of this amount.[56] Also in this case, the fixed capital deflator was used to achieve a real volume. Finally, economic confidence indicator in EU was employed to incorporate the factor of expectations.

[56]On the other hand, the amount does not include funds from Common Agricultural Policy at all.

4.4.2 Prior distribution of the model parameters

Bayesian VAR (BVAR) models adapted for the level variables are used from the methodological point of view; see the section 3.8. Actually, the final choice of BVAR models is a result of iterative process, when a large number of methodologies was entertain. We first wanted to use a full information set, or full data structure, and to employ panel data models – we tried both the static and dynamic panel data models. But to be honest, it was very hard to give economic interpretation to received results. Reason for that could be the data noise, as the survey data often faces this feature. We therefore decided to conduct the estimation on aggregated data and to use vector autoregressions. As a result, there are 19 models for industries (for the list of industries see Table 4.17 and Appendix W) and one more model for the whole non-financial economy. The list of macroeconomic covariates (see Table 4.18) remains the same in all regressions. We also tried to estimate VAR models on growth rates, but impulse responses lacked the economic sense as well. Moreover, it was hard to interpret some covariates in growth rates (e.g. interest rate, or economic sentiment). So, we decided to use levels and to establish the convergence of the models with Bayesian priors. To do that, we take as an assumption that it is possible to approximate the dynamics of unit root process with the dynamics of the process with a high rate of persistence. Prior distribution of autoregressive parameters was set according to this assumption; see the text below. To be sure that there exists a long relation among the observed variables, existence of cointegration was tested[57] and also confirmed for all 20 models. See Appendix Q for the results of cointegration testing on the aggregate level.[58]

As an underlying data generating process for all 20 models we chose Gaussian VAR(1). This decision is based on the values of information criteria. Moreover, Appendix R provides residuals from all seven equations of the aggregate investment model and they are mostly insignificant.[59] To be even more confident with VAR(1), we also tried to estimate models with higher lag length, but implied economic results were roughly the same. It should be noticed that additional lags led into exponential growth in the model parameters and to an extensive decrease in the degrees of freedom with a real threat of the overparametrization. Consequently, VAR(1) is an ideal combination between data fit and reasonable number of estimated parameters.

[57] By the usage of Johansen cointegration test; see the section 3.5 and 3.6.

[58] Results of the tests for individual industries are available on request.

[59] With aggregate investment model we mean the model estimated on data for the whole non-financial economy (data aggregated over all industries). Residuals are also insignificant in all sectoral models.

The prior probability density function of model parameters ϕ (3.39) takes in case of VAR(1) the form

$$g(\phi) = \left(\frac{1}{2\pi}\right)^{n^2/2} |\mathbf{V}_\phi|^{-1/2} \times \exp\left[-\frac{1}{2}(\phi - \phi^*)^T \mathbf{V}_\phi^{-1}(\phi - \phi^*)\right] \qquad (4.33)$$

where ϕ^* is the prior mean of model parameters, $\mathbf{V}_\phi$ is the corresponding prior covariance matrix, and n denotes the number of variables in VAR (six macroeconomic covariates and one variable for business investment amount to $n = 7$). Because we suppose that the variables exhibit a high rate of persistency, we chose the value of 0.8 as a prior mean for all AR(1) coefficients. Therefore, disturbances influence the development of economic variables for a long time but not for ever. With a proper setting of the distribution around this mean (it will be discussed inside the next paragraph), this choice ensures the convergence of estimated IR functions and the system as a whole. As the data encourage us to choose VAR(1) as an optimum lag length, the AR(1) coefficients completely describe the autoregressive structure.

Following Litterman (1986) and Doan, Litterman and Sims (1984), prior mean of cross-variable coefficients was set to zero and prior covariance matrix $\mathbf{V}_\phi$ equals to[60]

$$v_{ij} = \begin{cases} \lambda^2 & \text{for} \quad i = j \\ (\kappa\lambda\sigma_i/\sigma_j)^2 & \text{for} \quad i \neq j \end{cases} \qquad (4.34)$$

where λ is the prior standard deviation for AR(1) coefficients. We chose the value of 0.05 for λ, and so the prior value of AR(1) coefficients ranges between 0.7 and 0.9 with 0.95 probability. The parameter of the decay κ was set to 1. Prior variance of cross-variable coefficients (the case where $i \neq j$) is therefore broadly given by the ratio σ_i^2/σ_j^2; see the section 3.8 for more details.

To have defined the prior means of model parameters and also their corresponding prior variances, posterior distribution can be estimated according to the Bayesian mixing rule (3.41). In estimation process, Ω_ε is let to be equal to the covariance matrix of frequentist VAR with zero restrictions on non-diagonal entries. Therefore, the matrix Ω_ε contains actually observed covariances of model disturbances, or more precisely their maximum-likelihood estimates. When applied the zero restrictions on non-diagonal entries of Ω_ε, we have simultaneously identified the structural version of the BVAR model. For a robustness check, we also worked with various non-diagonal versions

[60]The expression (4.34) differs from (3.40) in that we let $l = 1$ for the former.

of the covariance matrix Ω_ε and so various structural versions of the BVAR, but the results did not differ significantly.

Based on the openness of the Czech economy, there could be raised the question about the application of the block restrictions on some parameters of the models. Specifically, it is the question if the cross-variable coefficients in the equations of foreign demand and economic sentiment in EU (exogenous variables for the Czech economy) should not be set the zero value in advance. In fact, we do not follow this approach and consider all cross-variable coefficients symmetrically. Moreover, the application of block restrictions would increase the computational difficulty. So, we rather checked the posterior distribution of cross-variable coefficients in the equations for foreign demand and economic sentiment in EU. In line with the expectation, all of these coefficients had the zero mean with tight confidence interval.

4.4.3 Stylized facts about the Czech investment

This section aims to give some intuitive eye-visible facts about the investment behavior in the Czech Republic during the last decade.[61] It is based on the evolution of annual growth rates of selected variables; the analysis is thus superficial and the results must be taken as preliminary. Comparison of annual dynamics of the Czech GDP and the gross fixed capital formation of non-financial corporations[62] provides an insight into the usefulness of accelerator theory for the Czech Republic. As presented in the top-left part of Figure 4.16, both dynamics have the same long-run trend, which is in line with the accelerator principle.

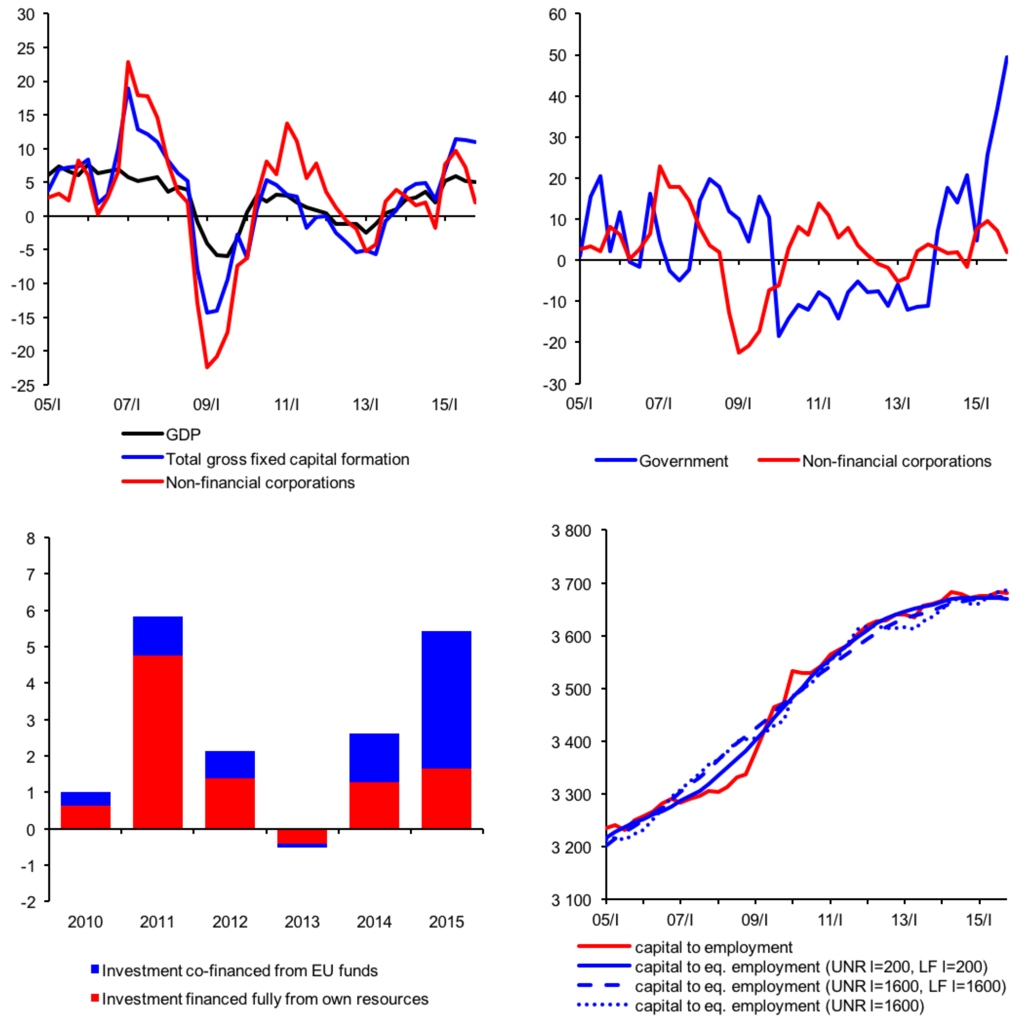
Yet, there are large deviations from this trend in the gross fixed capital formation of non-financial corporations. These deviations are more pronounced than in the case of the total gross fixed capital formation. It is because the acceleration in private investment is often scaled down by the deceleration in public investment; see the top-right part of Figure 4.16. The unusually strong growth of government investment in the year 2015 was fostered by an effort of the Czech government to draw the rest of allocated funds from the European financial perspective for the years 2007-2013.[63] Actually, similar effort was also observable for private firms. The bottom-left part of

[61] The data range used in this section, 2005 through 2015, is somewhat longer than in the following in-depth analysis based on the survey data. The disposable survey data at the beginning of the research covered the period from 2008 to 2015.

[62] With the gross fixed capital formation of non-financial corporations we mean an indicator from the Czech national accounts; see the section 4.4.1.

[63] It was possible to draw the funds up to the two years after the end of financial perspective.

Figure 4.16: Stylized facts of Czech investment



Note: The top-left and top-right figure contains annual growth rates of stable-price quantities – all come from the Czech national accounts. Line with the label of non-financial corporations (NFCs) depicts the gross fixed capital formation of non-financial corporations and equivalent holds for the government. The bottom-left figure sums up the contributions of different sources of finance (in percentage points) to the annual growth of NFCs' investment. In the last bottom-right figure we relate capital stock to the employment and various measures of equilibrium employment.

Source: Czech Statistical Office and Czech National Bank; own computations.

Figure 4.16 shows that the share of EU funds on financing private investment suddenly increase in 2015.[64]

Looking at the last bottom-right part of Figure 4.16, there was a slowdown in the growth of the capital to labor ratio. While until the year 2012 the capital stock grew faster than the employment, its growth slowed down relatively thereafter.[65] It was despite the easy monetary policy, when the policy rate stuck at the zero lower bound and the CZK/EUR exchange rate was weakened above its equilibrium level. One possible explanation of the shrinkage in growth of the capital stock to labor could be an increase in uncertainty, favoring the use of easily removable labor, in contrast to the irreversible capital, for an expansion of production capacity.

4.4.4 Macroeconomic covariates of business investment

Based on Figure 4.17, foreign demand is a main force driving the decision about new investment. Elasticity of business investment with respect to the foreign demand tends to peak within the year after the shock at the value of 0.6. It holds for the aggregate economy. Furthermore, positive effect of increased foreign demand on business investment is observed in most sectors of the Czech economy; see Figure 4.18a and Appendix S. Impulse responses are pronounced especially in manufacturing and tourism, where elasticity sometimes greatly exceeds the value of one. Within manufacturing, it is mainly automotive and electrical engineering industries which exhibit highly elastic reaction; elasticity reaches the value of 2 in both cases. It is not a fortune that these two industries also constitute a crucial part of the Czech foreign trade. Beside above mentioned, there is also significant increase in investment following an increase in foreign demand in sectors of trade and services, and in construction. In accordance with the aggregate economy, most sectors provide hump-shaped response with a peak at the fourth quarter. As in many other countries, results therefore support the predictions of the accelerator theory and the evolution of total output explains a large part of fluctuations in the Czech private investment.

Of course there are exceptions, such as investment in agriculture and food industry which are roughly immune to the foreign demand or the investment in energy, mining and telecommunication even with a negative response to foreign demand. As stated in the section 2.5, agricultural investment is greatly subsidized by the government and so it is not driven by its expected

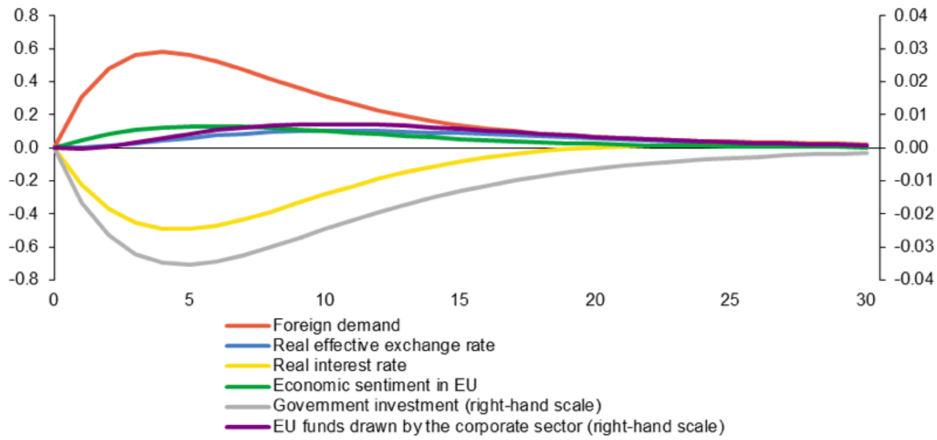
[64] I owe to Mário Vozár for his computations of this shares. This figure also appeared in CNB's Inflation Report IV/2016.

[65] The slowdown in the growth of capital to labor ratio was mainly given by a rapid increase in employment, rather than by a slower growth in capital stock.

profitability; in fact the similar applies for the food industry. Specific nature has also the investment in energy, mining and telecommunication, as the firms in these sectors frequently possess a monopoly power and they invest in a certain form of cycles without any link to the wide-economy fundamentals. According to this analysis, the investment in energy, mining and telecommunication can in final instance go against the business cycle.

Not only currently observed demand, but also demand expected in the future plays an important role; although with a smaller extent (see Figure 4.17). Optimistic expectations positively affect investment in almost every sector of the Czech economy; see Appendix S. Compared with the currently observed demand, the largest response (elasticity of 0.1) comes with a delay when it is observed in seventh or eighth quarter after an occurrence of the shock. This cautious reaction probably relates to an uncertainty surrounding the expectations; in agreement with the wait-and-see theory of irreversible investment.

Figure 4.17: Impulse responses of business investment to different shocks



Note: Responses in % to a shock of 1 %, or 1 pp in the case of the real interest rate. Horizontal axis - number of quarters.
Source: Own computations.

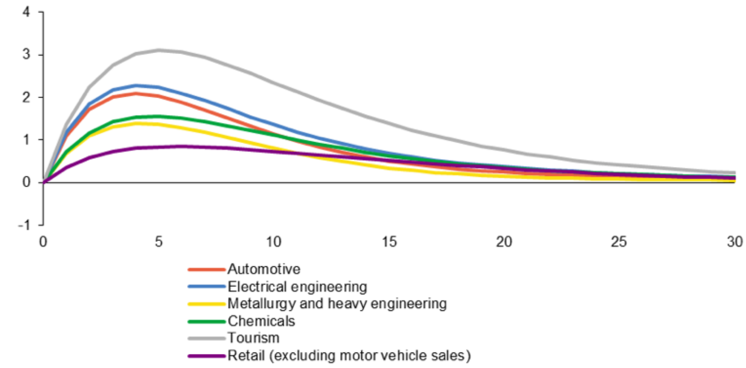
Even with a greater delay comes into effect the consequence of a change in the real effective exchange rate. Impulse response has tendency to peak (at the elasticity value of 0.1) after two years elapsing from an occurrence of the shock; see Figure 4.17. The delayed response is likely connected with staggered contracts in international trade. As impulse response also shows, depreciation of the real effective exchange rate leads into an increase in business investment. Moreover, no negative effect in the form of decreased investment activity was observed at all. Obviously, increased price competitiveness of Czech goods and services on foreign markets surpasses at the aggregate level an increase in the price of imported investment goods. As expected, similar response was recorded in export-oriented industries; particularly in manufacturing and also in tourism (see Figure 4.18b). In these industries the elasticity exceeds the aggregate value of 0.1 and ranges between 0.3 and 0.6. There is actually a low number of industries with a clear one-sided negative response to exchange-rate depreciation – namely agriculture, energy and mining (see Appendix S). All these industries are less export intensive and more investment-import intensive.

In expected manner behaves the business investment with respect to the real interest rate. Increase in the real interest rate is accompanied by a slowdown in investment; see Figure 4.17. Impulse responses have tendency to bottom around the year after the shock and they are very similar across different sectors of the Czech economy; see Figure 4.18c and Appendix S. Tourism and agriculture experienced the highest response, which nicely corresponds to their high proportion of debt in financing the investment. Above-average response has also automotive, electrical engineering, clothing, and food and beverages. Generally, it could be said that the investment in industries with rather smaller firms is more vulnerable to the interest rate movement. Notice that in a case of the real interest rate is not possible to compare its impulse responses with the impulse responses for other variables, because the shock is in 1 pp rather than in 1 %.

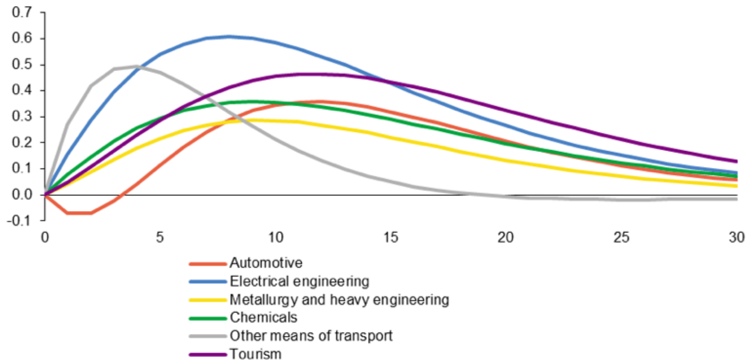
Comparatively lower impact on the behavior of business investment have the government investment and EU funds. The elasticity for the first attains the value of 0.04 and for the second the value of 0.01 (see Figure 4.17). Taking into account the direction of working on the aggregate level, government investment negatively affects private investment; in accordance with the crowding-out hypothesis. The most striking crowding out was witnessed by agriculture and manufacturing; see Figure 4.18d. On the contrary, as a consequence of increased government investment the firms within construction invest more. Mention that the majority of government investment is realized in the construction and so the building companies strive to expand their production capacity. Crowding in was also observed in services (including tourism) and trade; see Appendix S. These industries probably appreciate the improved infrastructure, education, or health (or any other product of public investment) for their future business opportunities and according to that, they are willing to invest. Eventually, we did not reveal any indication of the waiting for synergy; in other words the impulse responses do not vary in the sign.

Figure 4.18: Responses in selected industries - real economy disturbances

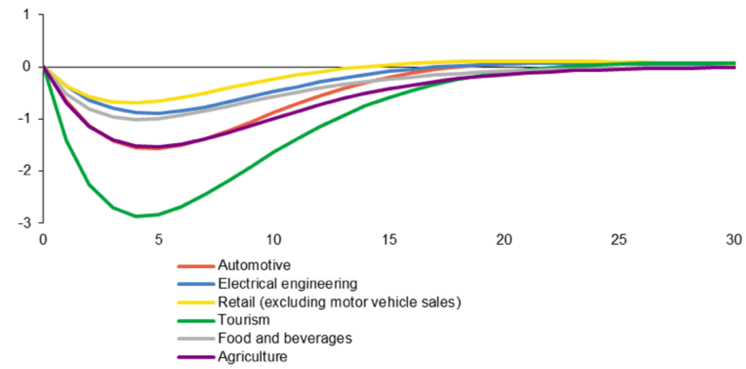
(a) Impulse responses to an increase in foreign demand



(b) Impulse responses to a weakening of the real exchange rate



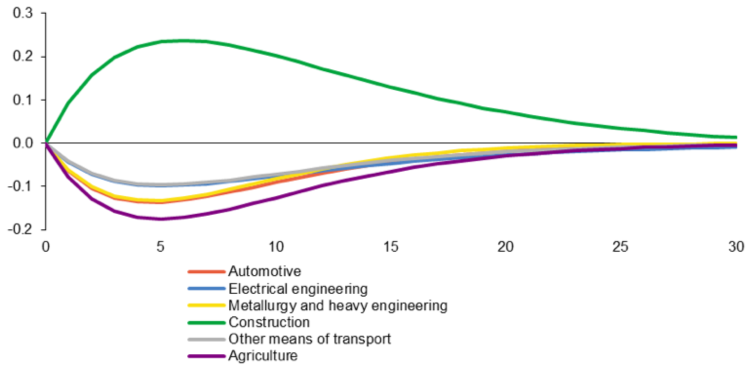
(c) Impulse responses to an increase in real interest rate



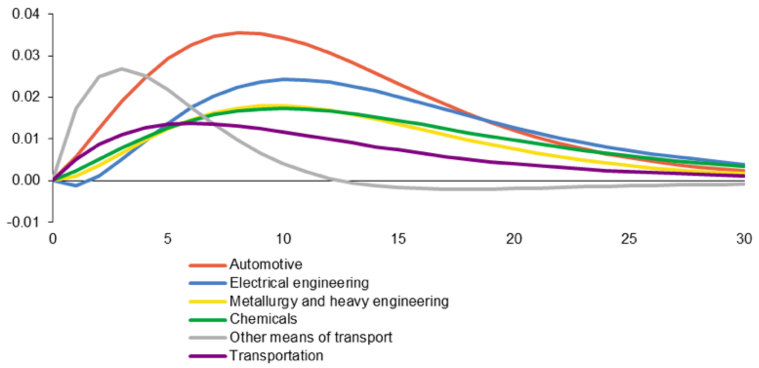
Note: Responses in % to a shock of 1 %, or 1 pp in the case of the real interest rate.
Horizontal axis - number of quarters.
Source: Own computations.

Figure 4.18: Responses in selected industries - fiscal disturbances

(d) Impulse responses to an increase in government investment



(e) Impulse responses to an increase in drawing EU funds

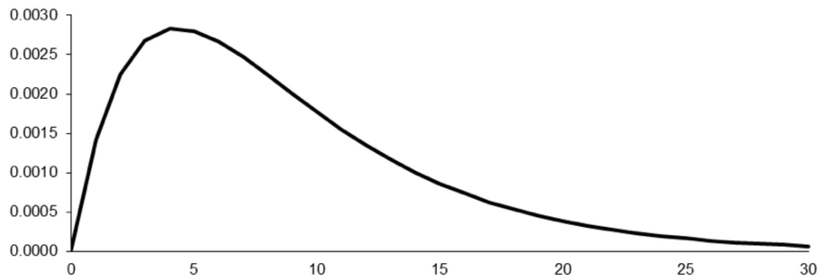


Note: Responses in % to a shock of 1 %; horizontal axis - number of quarters.
Source: Own computations.

As the most probable explanation of the crowding-out effect we consider the interaction of monetary and fiscal policy. Figure 4.19 traces out the interest rate response to an increase in government investment. In fact, the response speaks for that explanation, but also goes in line with the financial crowding out. However, the financial crowding out a little bit contradicts the observed excess of liquidity on the Czech capital market in recent years. Based on the aforementioned, the crowding out could likely be a business cycle phenomenon. This reasoning is further supported by the procyclicality of the Czech fiscal policy over the sample. Then it is not a surprise that manufacturing exhibits the most profound response, as it is a main driving force of the Czech business cycle. Crowding out in the agriculture binds to the loss-of-motivation aspect of government subsidies; see the section 2.5.

Drawing EU funds by private firms, not only by national governments, is a new way how to finance the business investment. Recently, the drawdown of those funds increased by a large amount; see the section 4.4.3. This is also reason, why we have included the drawdown of EU funds by private firms to our analysis. As Figure 4.17 shows, EU funds really encourage the private firms to invest more. It holds especially in manufacturing and transportation; see Figure 4.18e.

Figure 4.19: Response of interest rate to increase in government investment



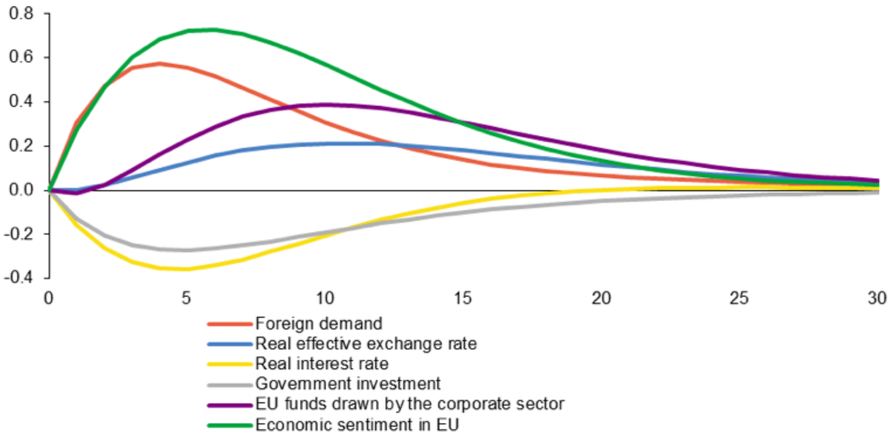
Note: Response in percentage points to a shock of 1 %; horizontal axis - number of quarters.
Source: Own computations.

So far, we have commented the long-run systematic linkages among the observed variables, without to pay special attention to the distribution of the shocks.[66] Because the period under the review (from the year 2008 to 2015) was in many aspects unusual, it should also be worthwhile to consider the responses to one standard deviation shocks.[67] See Figure 4.20 or Appendix S. Actually, the pattern of these impulse responses is similar to the case of one-unit shock, as the transmission mechanism remains the same. What differs is the magnitude of the shocks (see Appendix T).

Figure 4.20 highlights increased importance of expectations in the period 2008-2015. Remember the mentioned increase of uncertainty from the section 2.5, which influenced modern economies after the Great Recession. Figure 4.20 also points out the unprecedented drawing of EU funds by private firms; especially at the end of the sample. It is necessary to say, that a massive drawdown of EU funds by private firms was just a consequence

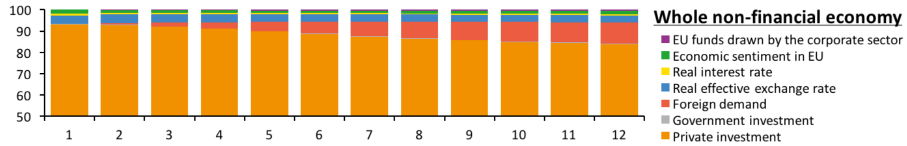
[66]In order to analyze the systematic part of the model, we have considered all shocks to have the same relative importance (except the real interest rate, all variables were shocked by 1 percent).
[67]One standard deviation shock is the disturbance of the amount typical for the observed period.

Figure 4.20: Impulse responses to one standard deviation shock



Note: Responses in % to one standard deviation shock; horizontal axis - number of quarters.
Source: Own computations.

Figure 4.21: Variance decomposition on the aggregate level



Note: Vertical axis is in % and horizontal axis in time periods.
Source: Own computations.

of the transition from one financial perspective of EU to the other. Therefore, it does not pose a structural change in the way how the Czech private investment is financed, or how it behaves; at least for the moment. Yet it can be a significant factor in some periods. Similar as well applies to the government investment. From the long-run perspective its crowding out on the private investment seems to be weak, but it is amplified when the government investment is getting large. Intense external shocks worked upon the real interest rate. It was the outcome of accommodative monetary policy during the period of depressed demand. On the other side, the installation of one-side exchange rate peg by the Czech National Bank in November 2013 protected the real effective exchange rate from the influence of external shocks. As a consequence, the conditions of low interest rates and weakerand-stable exchange rate supported the creation of new investment in the studied period.

In Figure 4.21 for the whole non-financial economy and in Appendix U for the individual industries, we also present the results of the forecast error variance decomposition (FEVD). The aggregate picture gives a clear message, that there is a little space for the fundamental factors when explaining the deviations from the expected value of business investment. These deviations are thus probably driven by the expectational factors or uncertainty. That is just a working of the animal spirit, which was mentioned in the section 2.5. Nevertheless, there are industries with a greater role of fundamental factors. Unexpected fluctuations in foreign demand explain up to 30 % of deviations from the expected value of investment in manufacturing, especially in automotive. Fluctuations in the real exchange rate then influence the investment in retail, tourism and energy. Disturbances in the real interest rate affect investment in agriculture, food and beverages, electrical engineering, and construction.

5 Conclusions

On preceding pages, we gave detailed and sometimes technical description of the results received for a particular research question. This concluding chapter aims to sum up all these results in a little bit less technical and concise manner and also to add some remarks regarding the Czech economic policy. Consequently, this chapter can have more normative character than the previous chapters had.

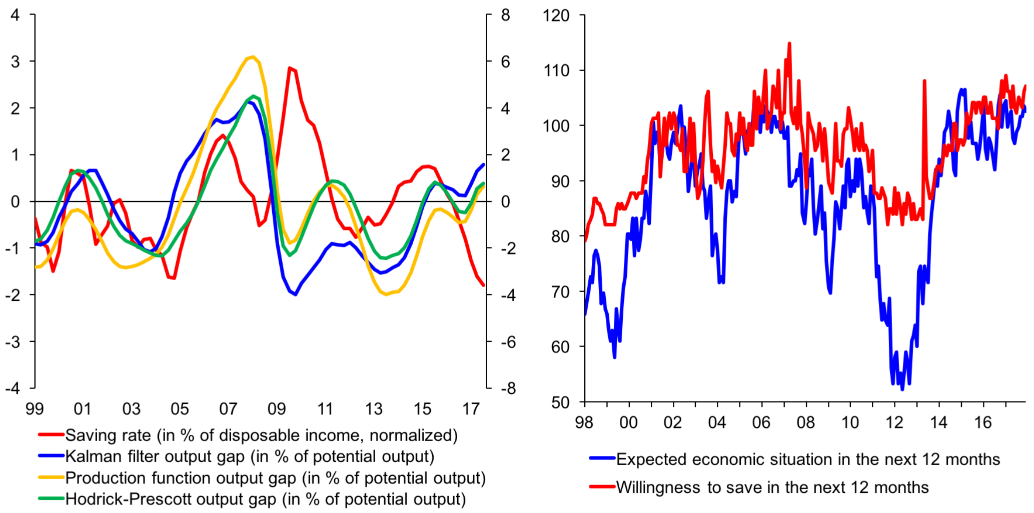
Based on the results, demand for money in the Czech Republic is largely fostered by the speculative motive for liquidity preference.[1] Broadly defined cash, meaning the M1 monetary aggregate, probably plays still important role as a store of value in the Czech Republic. Frequently negative real interest rates on this asset are likely outweighed by its low risk. It is in line with the risk-averse nature of majority of Czech agents, who do not have much historical experience with advanced financial instruments (such as equities or bonds). Moreover, the Czech capital market pays for less developed; it holds not only worldwide, but also in the Central European region. Demand for money from transaction motive appears to be saturated in the Czech Republic, as it does not evolve with the level of transactions or economic activity. It is not a surprise in the situation, when the cashless payments are increasingly popular, widely available, still faster, and they do not require additional costs (such as the fees for withdrawals from ATMs). Income velocity of transaction balances thus probably increased. It is in a conflict with the observed declining trend in total money velocity, which is nevertheless driven by a growing importance of speculative demand (known as Polak's effect and regarding the influence of economic development). Unfortunately, there is no way how to measure the income velocity of transaction and speculative balances separately. To mention the last motive for liquidity preference, the demand for precautionary savings, this depends on the phase of business cycle.[2] Apparently, economic agents hoard precautionary savings during a boom and draw them during a recession. Therefore, they

[1] With demand for money we mean the demand for real money balances, or demand for purchasing power.

[2] Both transaction motive and precautionary motive are parts of transactions demand. While the transaction motive is constant over time and the precautionary motive relates to the business cycle, the transactions demand for money as a whole also has a slight link to the business cycle.

behave rationally. To get a cross-check, the left part of Figure 5.1 compares the Czech saving rate[3] with three estimations of the Czech output gap[4]. It can be seen, that some form of the dependence really exists. Moreover, the right part of Figure 5.1 shows the results of economic sentiment survey of the Czech Statistical Office among the Czech households, where it is clear positive correlation between the willingness to save and the expectations of future economic activity.

Figure 5.1: Behavior of savings in the Czech Republic



Note: On the left-hand figure, the saving rate relates to the left axis and the output gaps to the right axis.
Source: Czech Statistical Office; own computations.

Estimated elasticity of money demand to other domestic assets bearing non-zero interest rate is low and smaller than one. As a consequence, economic agents usually differentiate the money from other assets. This result is important for the usefulness of open market operations. When the monetary policy uses them to fine-tune the economy, it simultaneously assumes a low rate of substitutability between money and bonds. In the situation of zero nominal interest rates the rate of substitutability reaches infinity and the monetary policy is caught in the liquidity trap. It generally

[3]It is the rate from the national accounts.

[4]We present our estimations from Kalman filter (based on the small structural state space model), Cobb-Douglas production function, and Hodrick-Prescott filter (with lambda equals to 1,600).

holds that the lower is the rate of substitutability between domestic assets, the lesser amount of reserves is necessary for required movement in the interbank interest rate. Low rate of substitutability between domestic assets in the Czech Republic is thus a good message for the operability of monetary policy. Within the money demand research, we have distinguished between the narrow money (aggregate M1) and the broader money (aggregate M2). We found two differences in the behavior of these demands, which deserve a mention. Firstly, the narrow demand is sometimes disturbed for a time from the equilibrium by external shocks, but the broader demand remains stable and easily predictable. We explained this difference by the portfolio re-optimization effect, when the broader demand has a lower elasticity to interest rate. Second noticeable difference consists in the fact, that the broader money exerts a connection to the level of output. This can be surprisingly justified by the speculative demand, rather than by the transactions demand. It goes because of the greater internal heterogeneity of broader money demand, including also term deposits, providing more space for the working of speculative demand. As we said, speculative demand correlates with economic development and there is therefore more space for the linkage to the output to be significant. Of course, it is also possible that this linkage is only indirect in nature, what the simple analysis based on the correlation coefficients cannot recognize.

Weakening of the Czech koruna leads initially into a deterioration of the Czech trade balance, which is shortly replaced by its improvement. Post-devaluation dynamics of the trade balance therefore resemble the J-curve. The deterioration is short-lived especially when the agents consider the weakening as temporary; it only takes at most two quarters. Consecutive positive effects then last for a year or two. As a result, foreign trade flows of the Czech Republic seem to be relatively elastic with respect to a movement of the terms of trade. Nevertheless, there is a delay in the improvement of the trade balance if agents expect the devaluation to be permanent. In this case, the deterioration persists up to two years. This could be due to a time that the agents need for an assurance that the devaluation is really long-standing. After that, it takes another time to assess a new situation, to bargain new contracts and finally to adjust the production. Regarding quantitative effects, estimated models predict the improvement of the trade balance of about 0.6 %, if the long-run value of currency depreciates by 1 %. Consequently, while temporal weakening of the currency represents a disturbance from the equilibrium, the permanent devaluation imposes the transition to a new equilibrium. Whereas the former does not require an optimization, the optimization is necessary for the latter. Improvement of the trade balance following temporal currency depreciation is thus based rather on the spot foreign-trade contracts; it is also in line with the rapid increase in the trade balance.

One-side exchange rate peg introduced by the Czech National Bank in November 2013 seems to be successful unconventional measure. Although we found some evidence of the structural break with respect to a policy change, the results confirm the usefulness of the Czech koruna as a monetary policy tool. At least, the devaluation of the Czech koruna in November 2013 improved the competitiveness of Czech exporters on foreign markets, increased the demand for their products and so restore their profitability. It is visible from the top-left part of Figure 5.2, where the annual growth rates of book value added and operating profit in the sector of non-financial corporations is shown. Accordingly, exporters began to demand more labor and were able to pay higher wages; see the top-right part of Figure 5.2. It as well formed the basis for a future growth in household consumption. Moreover, they enjoyed more than three years without exchange-rate risk and thus saved money on hedge payments.[5] The Czech economy started to grow again; see the bottom-left part of Figure 5.2. Our money demand research emphasized the forward guidance as an important aspect of the CNB's exchange rate commitment. It significantly strengthens the effectiveness of usual foreign exchange interventions.[6] Transparency and credibility of the Czech National Bank likely fostered the faster recovery of the Czech economy; see the bottom right part of Figure 5.2 with annual dynamics of real export. There was therefore a shorter lag in the improvement of the trade balance than our models predicted. Whilst the research shed light on the effect of exchange rate commitment on the real economy, it let outside the implications for price dynamics. Investigation of these would require an extra assessment regarding the Phillips curve, the Balassa-Samuelson effect or the effect of positive supply shock which was in play during 2014 and 2015.[7] As there is a real possibility that the liquidity trap was not an event which will not occur again in the future, it would be a good reason to have some effective unconventional measure, as the exchange rate for a small open economy obviously is, able to support the economy in this unorthodox situation. Furthermore, the usage of other unconventional measures such as

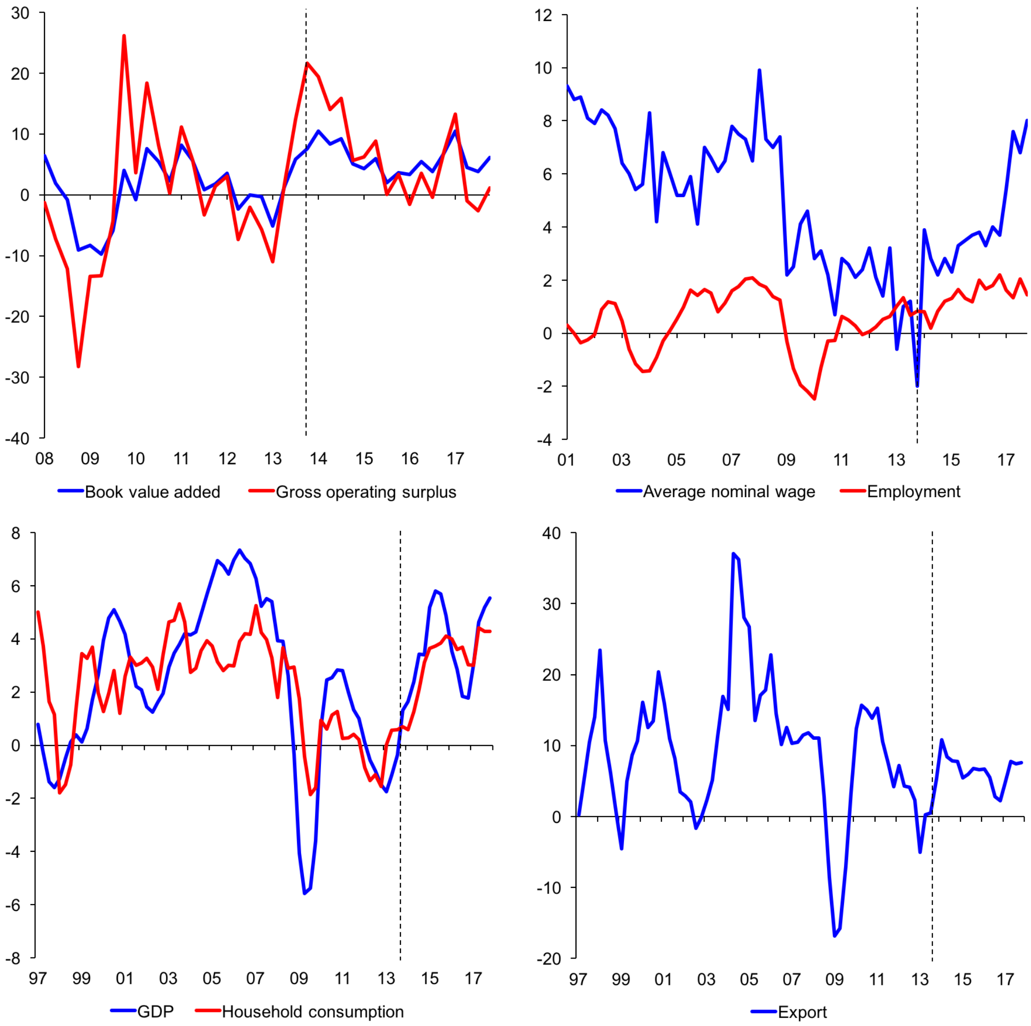
[5] Czech National Bank decided to exit from the exchange rate commitment on 6 April 2017.

[6] Effectiveness of the foreign exchange interventions without forward guidance to set growth in the Czech economy is bounded by the high rate of substitutability between domestic and foreign assets.

[7] In this period the price of Brent oil fell down from more than 100 USD per barrel to less than 40 USD.

quantitative and qualitative easing is tricky for the Czech Republic, because of its less-liquid capital market on one hand and over-liquid banking sector on the other hand.

Figure 5.2: Czech exchange-rate commitment



Note: All figures capture the annual growth rates in %. GDP, household consumption and export are stable-price quantities. Other variables are in nominal terms. Vertical dashed line indicates the introduction of exchange rate peg in the fourth quarter of 2013. Source: Czech Statistical Office.

Long-lasting devaluation of the Czech koruna gives rise to trade-balance improvement in most sectors of the Czech economy. Yet, there is a difference between the impact on two most important sectors of the Czech foreign trade; namely automotive and electrical engineering industry. Whereas the reaction of automotive to currency devaluation is positive, the electrical engineering industry reacts negatively. It has a link to the fact that both industries are mutually connected, as electrical engineering industry delivers the components for the car production. And so, increased foreign demand for car production[8] implies a need for higher inputs from the electrical engineering industry. It is not a surprise, that a part of these inputs is produced abroad and so increased imports induce a trade balance deterioration in the electrical engineering industry. That the electrical engineering industry does not experience an improvement in the trade balance could therefore easily be due to a very high share of automotive on the Czech exports. Moreover, foreign demand for electrical engineering products is mostly price inelastic; opposite to the demand for cars. It is mainly the case of various components, which are adapted for a completion of some final good and therefore cannot be used for any other production. Actually, the similar holds for the rest of manufacturing industries. So, when the industry supplies the goods for final consumption, it should also benefit from the exchange-rate devaluation. The opposite applies for industries producing just the intermediate goods.

Economic growth in the Czech economy changes the structure of its foreign trade towards the products with higher added value. As a consequence, Czech Republic exports more manufactured goods, including means of transport, machinery, and chemical products. There is a further increase in the importance of automotive for the Czech exports and so increased share of the components for car production in the Czech imports. As the Czech economy grows, it is more dependent on import of fuels and raw materials. This is especially evident on the worsening of trade balance with Russia, from where it comes a huge amount of crude oil and gas. On the other hand, foreign trade with agricultural products remains almost intact by economic growth. While the estimated models point to the positive effects of domestic economic growth on the trade balance, they also revealed the negative effects of the growth in foreign economies. However, this result is a kind of statistical peculiarity and by no means conforms the stylized facts of the Czech economy. As was stated many times in the thesis, the Czech economy can be characterized as a small open economy, and its production is thus strongly and positively correlated with the foreign economic activity.

[8] Due to its better price in foreign currency.

Negative effects of foreign economic growth predicted by estimated models could be for two reasons. At first, strong correlation between domestic and foreign aggregate production leads into multicollinearity of these explanatory variables within the estimated models; it is supported by statistical insignificancy of most parameters for foreign GDP. Secondly, it could be due to the usage of unweighted measure for foreign demand (usual GDP for EU-27), which does not take into account a different importance of EU countries for the Czech exports. As regards other factors influencing the Czech trade balance, we also tested the role of intertemporal substitution. We realized that it is very limited, when the discrepancies between domestic and foreign interest rate are promptly wiped out by a movement of exchange rate (as the uncovered interest rate parity predicts).

The most important macroeconomic covariate for the Czech business investment is foreign demand. Increase in foreign demand promotes the investment in most sectors of the Czech economy, especially in manufacturing and tourism. Within manufacturing, automotive and electrical engineering industries have the greatest response. This relates to high export intensity of these industries. Business investment depends not only on the currently observed demand, but also on the demand expected in the future. Moreover, expectations played a greater role recently, which was due to a higher uncertainty. Business investment are also significantly influenced by the evolution of real exchange rate and real interest rate. Based on the results, it can be concluded that the monetary policy has a power over the private investment. Depreciation of the real exchange rate causes an increase in investment of export-oriented enterprises, therefore mainly those in manufacturing and also in tourism. On the other hand, increase in interest rate leads to a decrease in the investment of smaller firms highly dependent on the credit; these firms can be found in trade, services and agriculture. What should be also noticed is the fact that we did not see any indication of the laziness in investment, which could be induced by a long-lasting depreciation of the real exchange rate. That type of reasoning was frequently used in the policy debate against the CNB's devaluation of the Czech koruna.

Public investment crowds out private investment on macroeconomic level, but there are also industries with crowding in. While private investment in manufacturing and agriculture are crowded out by public investment, the crowding in was observed in construction, services and trade. Crowding in is connected to the positive externalities of public goods arising from government investment, such as better infrastructure, education, or health care. On the contrary, the most probable explanation for the crowding out effect is the interaction of monetary policy with frequently procyclical fiscal policy. Finally, the research confirmed that the EU funds encourage the business investment. Although the influence of EU funds on business investment is rather marginal from the long-run perspective, its intensity can be turn up in some specific periods (as was the year 2015). In fact, the same holds for the government investment.

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Appendices

A Estimated VECM for money demand

Table A.1: Estimate of the VEC system - part 1

Cointegration vectors					
	constant	trend	u	i	REER
Vector for M/P (CV-1)	-4.5995	-0.0084	0.0708	0.1987	-2.0728
		(0.0017)	(0.0638)	(0.0266)	(0.1403)
Vector for Y (CV-2)	-14.0159	-0.0171	0.0024	-0.1486	0.2317
		(0.0022)	(0.0830)	(0.0346)	(0.1824)
Loading parameters					
	M/P	Y	u	i	REER
CV-1	-0.4306	0.0256	-0.3666	0.4247	0.2439
	(0.1128)	(0.0359)	(0.1636)	(0.4250)	(0.0716)
CV-2	-0.0493	0.0776	-0.0045	0.9097	0.2357
	(0.0995)	(0.0317)	(0.1444)	(0.3750)	(0.0632)

Note: Standard errors in parentheses.

Source: Own computations.

Table A.2: Estimate of the VEC system - part 2

VAR part					
	Δ M/P(t)	Δ Y(t)	Δ u(t)	Δ i(t)	Δ REER(t)
Δ M/P(t-1)	-0.1469	-0.0129	0.2795	-0.9606	-0.0294
	(0.1296)	(0.0412)	(0.1880)	(0.4883)	(0.0823)
Δ M/P(t-2)	-0.0185	0.0339	-0.1654	-0.3071	0.0571
	(0.1221)	(0.0388)	(0.1772)	(0.4602)	(0.0775)
Δ Y(t-1)	0.2343	0.1402	-2.9593	1.5597	-0.0391
	(0.5209)	(0.1657)	(0.7556)	(1.9626)	(0.3306)
Δ Y(t-2)	-1.0286	-0.1490	-0.1980	-0.6867	-1.3174
	(0.5331)	(0.1696)	(0.7733)	(2.0086)	(0.3383)
Δ u(t-1)	-0.1318	-0.0066	0.0589	-0.7268	-0.0349
	(0.0977)	(0.0311)	(0.1417)	(0.3681)	(0.0620)
Δ u(t-2)	-0.0959	-0.0085	0.2783	-0.2240	-0.0264
	(0.0872)	(0.0278)	(0.1266)	(0.3287)	(0.0554)
Δ i(t-1)	0.0208	0.0181	0.0259	0.1648	0.0093
	(0.0382)	(0.0122)	(0.0554)	(0.1440)	(0.0243)
Δ i(t-2)	0.0266	-0.0112	0.1281	-0.2102	-0.0133
	(0.0364)	(0.0116)	(0.0528)	(0.1372)	(0.0231)
Δ REER(t-1)	-0.0888	0.0874	-0.8947	-0.0212	0.4457
	(0.2173)	(0.0691)	(0.3152)	(0.8188)	(0.1379)
Δ REER(t-2)	-0.4555	-0.0686	0.0132	-0.9204	0.0833
	(0.2224)	(0.0707)	(0.3227)	(0.8380)	(0.1412)
constant	0.0464	0.0060	0.0261	-0.0217	0.0084
	(0.0095)	(0.0030)	(0.0138)	(0.0357)	(0.0060)

Note: Standard errors in parentheses.

Source: Own computations.

B Granger causality of money demand

Table B.1: Granger causality testing - part 1

Granger causality tests for M/P			
	Chi-square statistic	Degrees of freedom	Probability
M/P	5 459 925.96	3	< 0.0001
Y	39 251.37	3	< 0.0001
u	241.40	3	< 0.0001
i	599.75	3	< 0.0001
REER	1 366 538.32	3	< 0.0001
Granger causality tests for Y			
	Chi-square statistic	Degrees of freedom	Probability
M/P	105 112.53	3	< 0.0001
Y	183 791 338.18	3	< 0.0001
u	-5.62	3	1
i	97.90	3	< 0.0001
REER	21 698.29	3	< 0.0001

Source: Own computations.

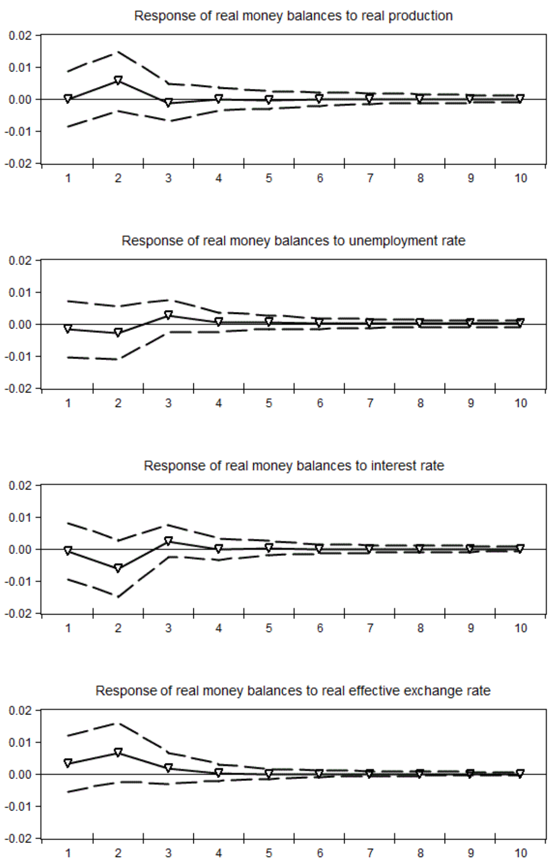
Table B.2: Granger causality testing - part 2

Granger causality tests for u			
	Chi-square statistic	Degrees of freedom	Probability
M/P	1 167 844.77	3	< 0.0001
Y	294.36	3	< 0.0001
u	168 941.50	3	< 0.0001
i	321.04	3	< 0.0001
REER	525 036.35	3	< 0.0001
Granger causality tests for i			
	Chi-square statistic	Degrees of freedom	Probability
M/P	201 541.61	3	< 0.0001
Y	917 501.89	3	< 0.0001
u	8.58	3	0.0354
i	6 786.61	3	< 0.0001
REER	55 173.56	3	< 0.0001
Granger causality tests for REER			
	Chi-square statistic	Degrees of freedom	Probability
M/P	1 762 631.24	3	< 0.0001
Y	1 591 076.35	3	< 0.0001
u	60.58	3	< 0.0001
i	2.96	3	0.3978
REER	931 247.06	3	< 0.0001

Source: Own computations.

C Impulse responses for money-demand growth

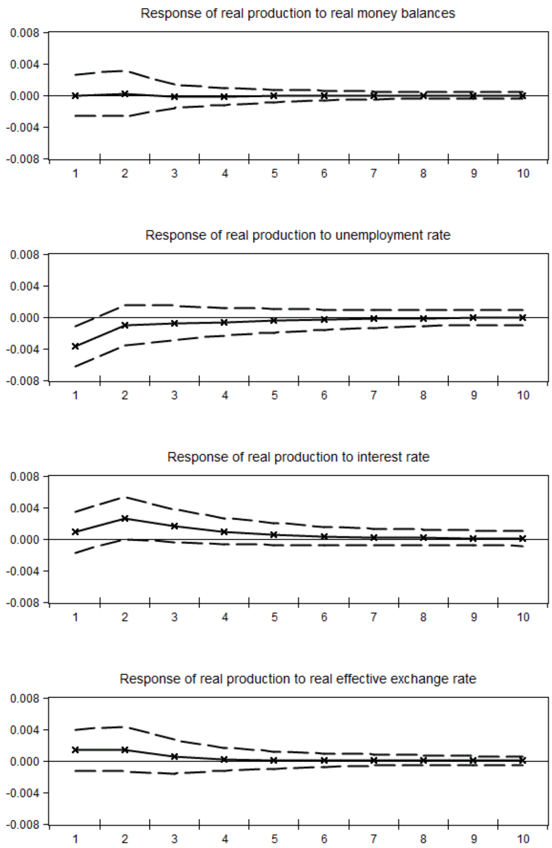
Figure C.1: Impulse responses for the growth rates - M/P



Note: Responses to one-standard-deviation shock. Standard errors are computed by the Monte Carlo simulation with 10,000 replications. Confidence intervals reflect 0.95 probability.

Source: Own computations.

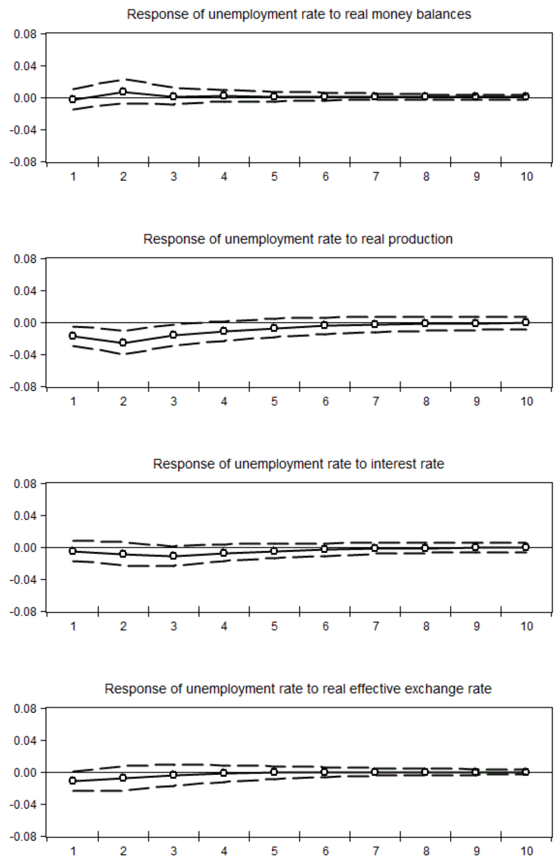
Figure C.2: Impulse responses for the growth rates - Y



Note: Responses to one-standard-deviation shock. Standard errors are computed by the Monte Carlo simulation with 10,000 replications. Confidence intervals reflect 0.95 probability.

Source: Own computations.

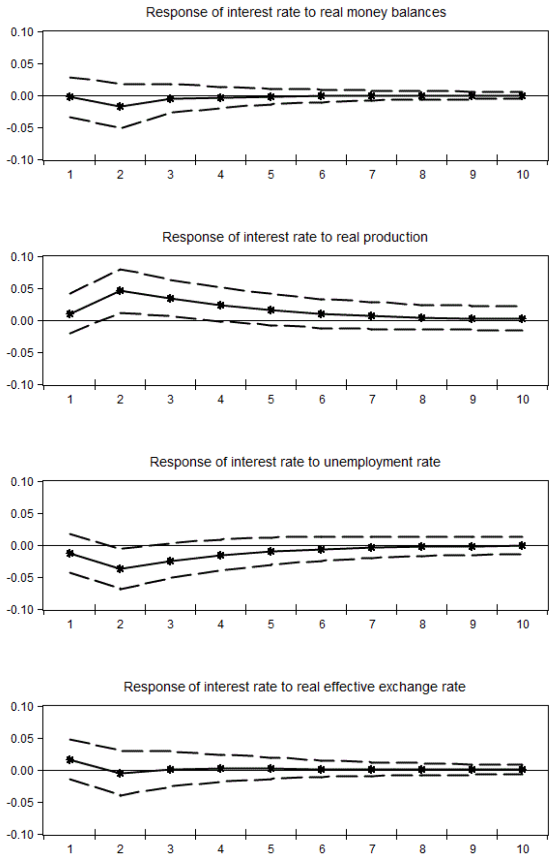
Figure C.3: Impulse responses for the growth rates - u



Note: Responses to one-standard-deviation shock. Standard errors are computed by the Monte Carlo simulation with 10,000 replications. Confidence intervals reflect 0.95 probability.

Source: Own computations.

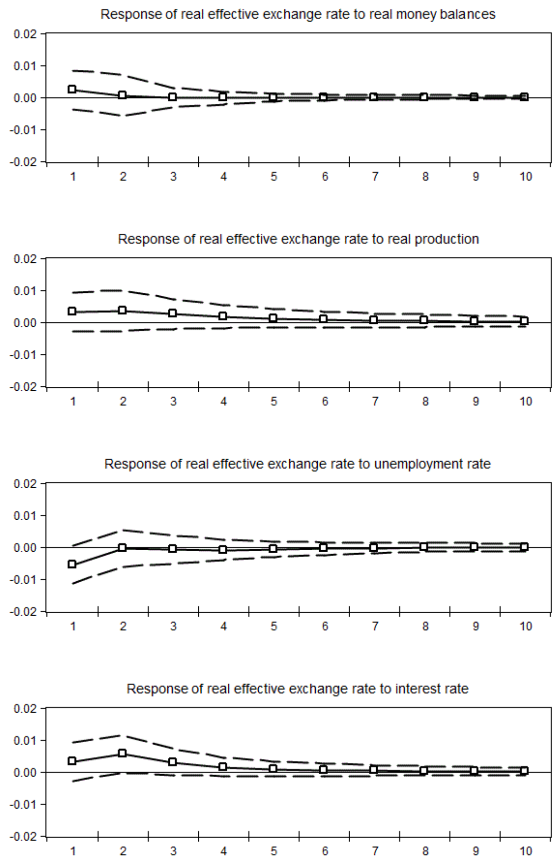
Figure C.4: Impulse responses for the growth rates - i



Note: Responses to one-standard-deviation shock. Standard errors are computed by the Monte Carlo simulation with 10,000 replications. Confidence intervals reflect 0.95 probability.

Source: Own computations.

Figure C.5: Impulse responses for the growth rates - REER



Note: Responses to one-standard-deviation shock. Standard errors are computed by the Monte Carlo simulation with 10,000 replications. Confidence intervals reflect 0.95 probability.

Source: Own computations.

D Derivation of IRF for exchange rate

In derivation, maximal order of lag length of the data-generating process (4.24) and (4.25) is symmetrically restricted to $p = q = r = s = u = v = 3$. In order to simplify the following expressions, $\mathbb{E}_{0\,(j)}$ is used instead of $\mathbb{E}_0(\Delta\, tb_j \,|\, \hat{\beta}, \Theta_j)$ and $\mathbb{E}_{1\,(j)}$ instead of $\mathbb{E}_1(\Delta\, tb_j \,|\, \hat{\beta}, \Theta_j, \Sigma)$.

$$
\begin{aligned}
IRF(0) &= \mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right) = \\
&= \hat{\beta}_{40}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) - \hat{\beta}_{40}\,\Delta\, reer_j = \hat{\beta}_{40}\hat{\sigma}_{reer}
\end{aligned}
\tag{D.1}
$$

$$
\begin{aligned}
IRF(1) &= \mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) = \\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) + \hat{\beta}_{41}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) + \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) - \\
&- \hat{\beta}_{11}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right) - \hat{\beta}_{41}\,\Delta\, reer_j - \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right) = \\
&= \hat{\beta}_{41}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) - \hat{\beta}_{41}\,\Delta\, reer_j + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right)\right] = \\
&= \hat{\beta}_{41}\hat{\sigma}_{reer} + \left(\hat{\beta}_{11} + \hat{\rho}\right)\hat{\beta}_{40}\hat{\sigma}_{reer} = \\
&= \left[\hat{\beta}_{41} + \hat{\beta}_{40}\left(\hat{\beta}_{11} + \hat{\rho}\right)\right]\hat{\sigma}_{reer}
\end{aligned}
\tag{D.2}
$$

$$
\begin{aligned}
IRF(2) &= \mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) = \\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \hat{\beta}_{12}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) + \hat{\beta}_{42}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) + \hat{\rho}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \\
&- \hat{\beta}_{11}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\beta}_{12}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right) - \hat{\beta}_{42}\,\Delta\, reer_j - \\
&- \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right) - \hat{\rho}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) = \\
&= \hat{\beta}_{42}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) - \hat{\beta}_{42}\,\Delta\, reer_j + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_j\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_j\right)\right] = \\
&= \hat{\beta}_{42}\hat{\sigma}_{reer} + \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\hat{\beta}_{41} + \hat{\beta}_{40}\left(\hat{\beta}_{11} + \hat{\rho}\right)\right]\hat{\sigma}_{reer} + \left(\hat{\beta}_{12} + \hat{\rho}\right)\hat{\beta}_{40}\hat{\sigma}_{reer} = \\
&= \left\{\hat{\beta}_{42} + \hat{\beta}_{41}\left(\hat{\beta}_{11} + \hat{\rho}\right) + \hat{\beta}_{40}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer}
\end{aligned}
\tag{D.3}
$$

$$
\begin{aligned}
IRF(3) &= \mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right) = \\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) + \hat{\beta}_{12}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \hat{\beta}_{13}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \\
&+ \hat{\beta}_{43}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) + \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \hat{\rho}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \hat{\beta}_{11}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \hat{\beta}_{12}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \\
&- \hat{\beta}_{13}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \hat{\beta}_{43}\,\Delta\, reer_j - \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \\
&- \hat{\rho}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\rho}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) = \\
&= \hat{\beta}_{43}\left(\Delta\, reer_j + \hat{\sigma}_{reer}\right) - \hat{\beta}_{43}\,\Delta\, reer_j + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right)\right] + \\
&+ \left(\hat{\beta}_{13} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right)\right] = \\
&= \hat{\beta}_{43}\hat{\sigma}_{reer} + \left(\hat{\beta}_{11} + \hat{\rho}\right)\left\{\hat{\beta}_{42} + \hat{\beta}_{41}\left(\hat{\beta}_{11} + \hat{\rho}\right) + \right. \\
&\left. + \hat{\beta}_{40}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer} + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\hat{\beta}_{41} + \hat{\beta}_{40}\left(\hat{\beta}_{11} + \hat{\rho}\right)\right]\hat{\sigma}_{reer} + \left(\hat{\beta}_{13} + \hat{\rho}\right)\hat{\beta}_{40}\hat{\sigma}_{reer} = \\
&= \left\{\hat{\beta}_{43} + \hat{\beta}_{42}\left(\hat{\beta}_{11} + \hat{\rho}\right) + \hat{\beta}_{41}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right] + \right. \\
&\left. + \hat{\beta}_{40}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^3 + 2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{13} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer}
\end{aligned}
\tag{D.4}
$$

$$
\begin{aligned}
IRF(4) &= \mathbb{E}_{1\,(j+4)}\left(\Delta\, tb_{j+4}\right) - \mathbb{E}_{0\,(j+4)}\left(\Delta\, tb_{j+4}\right) = \\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) + \hat{\beta}_{12}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) + \hat{\beta}_{13}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \hat{\rho}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \hat{\rho}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \hat{\beta}_{11}\mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \hat{\beta}_{12}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \\
&- \hat{\beta}_{13}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \hat{\rho}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \\
&- \hat{\rho}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \hat{\rho}\mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right) = \\
&= \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right)\right] + \\
&+ \left(\hat{\beta}_{13} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right)\right] + \\
&+ \hat{\rho}\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right)\right] = \\
&= \left(\hat{\beta}_{11} + \hat{\rho}\right)\left\{\hat{\beta}_{43} + \hat{\beta}_{42}\left(\hat{\beta}_{11} + \hat{\rho}\right) + \hat{\beta}_{41}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right] + \right. \\
&\left. + \hat{\beta}_{40}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^3 + 2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{13} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer} + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left\{\hat{\beta}_{42} + \hat{\beta}_{41}\left(\hat{\beta}_{11} + \hat{\rho}\right) + \hat{\beta}_{40}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer} + \\
&+ \left(\hat{\beta}_{13} + \hat{\rho}\right)\left[\hat{\beta}_{41} + \hat{\beta}_{40}\left(\hat{\beta}_{11} + \hat{\rho}\right)\right]\hat{\sigma}_{reer} + \hat{\rho}\hat{\beta}_{40}\hat{\sigma}_{reer} = \\
&= \left\{\hat{\beta}_{43}\left(\hat{\beta}_{11} + \hat{\rho}\right) + \hat{\beta}_{42}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right] + \right. \\
&+ \hat{\beta}_{41}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^3 + 2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{13} + \hat{\rho}\right)\right] + \\
&+ \hat{\beta}_{40}\left[\left(\hat{\beta}_{11} + \hat{\rho}\right)^4 + 3\left(\hat{\beta}_{11} + \hat{\rho}\right)^2\left(\hat{\beta}_{12} + \hat{\rho}\right) + \right. \\
&\left.\left. + 2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{13} + \hat{\rho}\right) + \left(\hat{\beta}_{12} + \hat{\rho}\right)^2 + \hat{\rho}\right]\right\}\hat{\sigma}_{reer}
\end{aligned} \tag{D.5}
$$

We will not continue to write down exact analytic formulas in parametric form for further period responses, because due to the irregular pattern of the above stated this would be troublesome. But the numerical computation is relatively simple using the formula

$$
\begin{aligned}
IRF(w) &= \\
&= \left(\hat{\beta}_{11} + \hat{\rho}\right) \left[\mathbb{E}_{1\,(j+w-1)} \left(\Delta\, tb_{j+w-1}\right) - \mathbb{E}_{0\,(j+w-1)} \left(\Delta\, tb_{j+w-1}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right) \left[\mathbb{E}_{1\,(j+w-2)} \left(\Delta\, tb_{j+w-2}\right) - \mathbb{E}_{0\,(j+w-2)} \left(\Delta\, tb_{j+w-2}\right)\right] + \\
&+ \left(\hat{\beta}_{13} + \hat{\rho}\right) \left[\mathbb{E}_{1\,(j+w-3)} \left(\Delta\, tb_{j+w-3}\right) - \mathbb{E}_{0\,(j+w-3)} \left(\Delta\, tb_{j+w-3}\right)\right] + \\
&\qquad + \hat{\rho} \sum_{i=j+w-4}^{j} \left[\mathbb{E}_{1\,(i)} \left(\Delta\, tb_{i}\right) - \mathbb{E}_{0\,(i)} \left(\Delta\, tb_{i}\right)\right], \qquad \text{for } w \geq 4 \qquad \text{(D.6)}
\end{aligned}
$$

Of course, not all betas must be non-zero.

E Derivation of CIRF for exchange rate

In derivation, we again use the restriction $p = q = r = s = u = v = 3$ on (4.24) and (4.25). As in the case of IRF, $\mathbb{E}_{0\,(j)}$ is used instead of $\mathbb{E}_0(\Delta\, tb_j \,|\, \hat{\beta}, \Theta_j)$ and $\mathbb{E}_{1\,(j)}$ instead of $\mathbb{E}_1(\Delta\, tb_j \,|\, \hat{\beta}, \Theta_j, \Sigma)$.

$$\begin{aligned} CIRF(0) &= \mathbb{E}_{1\,(j)}\,(\Delta\, tb_j) - \mathbb{E}_{0\,(j)}\,(\Delta\, tb_j) = \\ &= \hat{\beta}_{40}\,(\Delta\, reer_j + \hat{\sigma}_{reer}) - \hat{\beta}_{40}\,\Delta\, reer_j = \hat{\beta}_{40}\hat{\sigma}_{reer} \end{aligned} \tag{E.1}$$

$$\begin{aligned} CIRF(1) &= \mathbb{E}_{1\,(j+1)}\,(\Delta\, tb_{j+1}) - \mathbb{E}_{0\,(j+1)}\,(\Delta\, tb_{j+1}) = \\ &= \hat{\beta}_{11}\mathbb{E}_{1\,(j)}\,(\Delta\, tb_j) + \hat{\beta}_{40}\,(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}) + \hat{\beta}_{41}\,(\Delta\, reer_j + \hat{\sigma}_{reer}) + \\ &+ \hat{\rho}\mathbb{E}_{1\,(j)}\,(\Delta\, tb_j) - \hat{\beta}_{11}\mathbb{E}_{0\,(j)}\,(\Delta\, tb_j) - \hat{\beta}_{40}\,\Delta\, reer_{j+1} - \\ &- \hat{\beta}_{41}\,\Delta\, reer_j - \hat{\rho}\mathbb{E}_{0\,(j)}\,(\Delta\, tb_j) = \\ &= \left[\hat{\beta}_{40}\,(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}) - \hat{\beta}_{40}\,\Delta\, reer_{j+1}\right] + \left[\hat{\beta}_{41}\,(\Delta\, reer_j + \hat{\sigma}_{reer}) - \right. \\ &\left. - \hat{\beta}_{41}\,\Delta\, reer_j\right] + \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j)}\,(\Delta\, tb_j) - \mathbb{E}_{0\,(j)}\,(\Delta\, tb_j)\right] = \\ &= \hat{\beta}_{40}\hat{\sigma}_{reer} + \hat{\beta}_{41}\hat{\sigma}_{reer} + \left(\hat{\beta}_{11} + \hat{\rho}\right)\hat{\beta}_{40}\hat{\sigma}_{reer} = \\ &= \left\{\hat{\beta}_{41} + \hat{\beta}_{40}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer} \end{aligned} \tag{E.2}$$

$$
\begin{aligned}
CIRF(2) &= \mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) = \\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \hat{\beta}_{12}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \hat{\beta}_{40}\left(\Delta\, reer_{j+2} + \hat{\sigma}_{reer}\right) + \\
&+ \hat{\beta}_{41}\left(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}\right) + \hat{\beta}_{42}\left(\Delta\, reer_{j} + \hat{\sigma}_{reer}\right) + \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\beta}_{11}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\beta}_{12}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \\
&- \hat{\beta}_{40}\,\Delta\, reer_{j+2} - \hat{\beta}_{41}\,\Delta\, reer_{j+1} - \hat{\beta}_{42}\,\Delta\, reer_{j} - \\
&- \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \hat{\rho}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) = \\
&= \left[\hat{\beta}_{40}\left(\Delta\, reer_{j+2} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{40}\,\Delta\, reer_{j+2}\right] + \\
&+ \left[\hat{\beta}_{41}\left(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{41}\,\Delta\, reer_{j+1}\right] + \\
&+ \left[\hat{\beta}_{42}\left(\Delta\, reer_{j} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{42}\,\Delta\, reer_{j}\right] + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right)\right] = \\
&= \hat{\beta}_{40}\hat{\sigma}_{reer} + \hat{\beta}_{41}\hat{\sigma}_{reer} + \hat{\beta}_{42}\hat{\sigma}_{reer} + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left\{\hat{\beta}_{41} + \hat{\beta}_{40}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer} + \left(\hat{\beta}_{12} + \hat{\rho}\right)\hat{\beta}_{40}\hat{\sigma}_{reer} = \\
&= \left\{\hat{\beta}_{42} + \hat{\beta}_{41}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right)\right] + \right. \\
&\left. + \hat{\beta}_{40}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right) + \left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer}
\end{aligned} \tag{E.3}
$$

Hereafter, for space saving, we will continue in shorthand notation, excluding the substitution step.

$$
\begin{aligned}
CIRF(3) &= \mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right) = \\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) + \hat{\beta}_{12}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \hat{\beta}_{13}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \\
&+ \hat{\beta}_{40}\left(\Delta\, reer_{j+3} + \hat{\sigma}_{reer}\right) + \hat{\beta}_{41}\left(\Delta\, reer_{j+2} + \hat{\sigma}_{reer}\right) + \\
&+ \hat{\beta}_{42}\left(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}\right) + \hat{\beta}_{43}\left(\Delta\, reer_{j} + \hat{\sigma}_{reer}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \hat{\rho}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \hat{\beta}_{11}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \hat{\beta}_{12}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \\
&- \hat{\beta}_{13}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \hat{\beta}_{40}\,\Delta\, reer_{j+3} - \hat{\beta}_{41}\,\Delta\, reer_{j+2} - \hat{\beta}_{42}\,\Delta\, reer_{j+1} - \\
&- \hat{\beta}_{43}\,\Delta\, reer_{j} - \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \hat{\rho}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\rho}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) = \\
&= \left[\hat{\beta}_{40}\left(\Delta\, reer_{j+3} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{40}\,\Delta\, reer_{j+3}\right] + \\
&+ \left[\hat{\beta}_{41}\left(\Delta\, reer_{j+2} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{41}\,\Delta\, reer_{j+2}\right] + \\
&+ \left[\hat{\beta}_{42}\left(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{42}\,\Delta\, reer_{j+1}\right] + \\
&+ \left[\hat{\beta}_{43}\left(\Delta\, reer_{j} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{43}\,\Delta\, reer_{j}\right] + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right)\right] + \\
&+ \left(\hat{\beta}_{13} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right)\right] = \\
&= \left\{\hat{\beta}_{43} + \hat{\beta}_{42}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right)\right] + \hat{\beta}_{41}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right) + \left(\hat{\beta}_{11} + \hat{\rho}\right)^{2} + \right.\right. \\
&+ \left.\left(\hat{\beta}_{12} + \hat{\rho}\right)\right] + \hat{\beta}_{40}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right) + \left(\hat{\beta}_{11} + \hat{\rho}\right)^{2} + \left(\hat{\beta}_{11} + \hat{\rho}\right)^{3} + \right. \\
&\left.\left. +2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{13} + \hat{\rho}\right)\right]\right\}\hat{\sigma}_{reer}
\end{aligned}
\tag{E.4}
$$

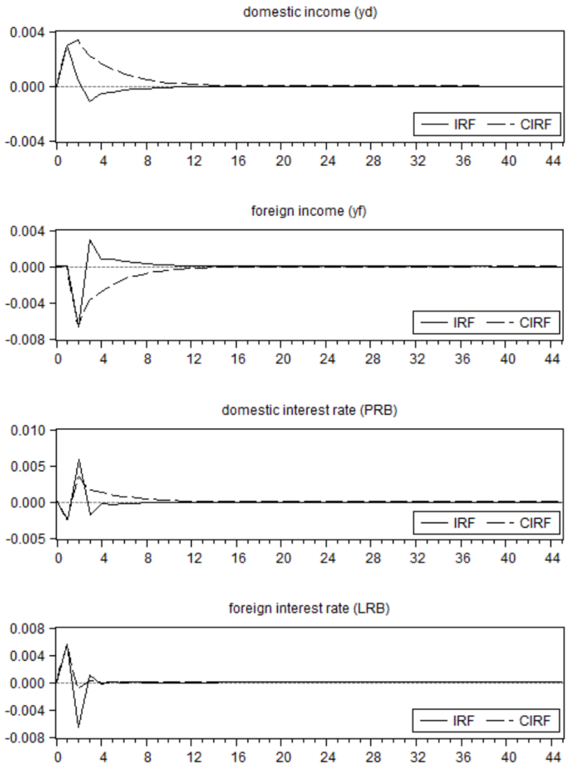
$$
\begin{aligned}
CIRF(4) &= \mathbb{E}_{1\,(j+4)}\left(\Delta\, tb_{j+4}\right) - \mathbb{E}_{0\,(j+4)}\left(\Delta\, tb_{j+4}\right) = \qquad\qquad \text{(E.5)}\\
&= \hat{\beta}_{11}\mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) + \hat{\beta}_{12}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) + \hat{\beta}_{13}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \\
&+ \hat{\beta}_{40}\left(\Delta\, reer_{j+4} + \hat{\sigma}_{reer}\right) + \hat{\beta}_{41}\left(\Delta\, reer_{j+3} + \hat{\sigma}_{reer}\right) + \\
&+ \hat{\beta}_{42}\left(\Delta\, reer_{j+2} + \hat{\sigma}_{reer}\right) + \hat{\beta}_{43}\left(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) + \hat{\rho}\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) + \hat{\rho}\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) + \\
&+ \hat{\rho}\mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \hat{\beta}_{11}\mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \hat{\beta}_{12}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \\
&- \hat{\beta}_{13}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \hat{\beta}_{40}\,\Delta\, reer_{j+4} - \hat{\beta}_{41}\,\Delta\, reer_{j+3} - \hat{\beta}_{42}\,\Delta\, reer_{j+2} - \\
&- \hat{\beta}_{43}\,\Delta\, reer_{j+1} - \hat{\rho}\mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right) - \hat{\rho}\mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \\
&- \hat{\rho}\mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \hat{\rho}\mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right) = \\
&= \left[\hat{\beta}_{40}\left(\Delta\, reer_{j+4} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{40}\,\Delta\, reer_{j+4}\right] + \\
&+ \left[\hat{\beta}_{41}\left(\Delta\, reer_{j+3} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{41}\,\Delta\, reer_{j+3}\right] + \\
&+ \left[\hat{\beta}_{42}\left(\Delta\, reer_{j+2} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{42}\,\Delta\, reer_{j+2}\right] + \\
&+ \left[\hat{\beta}_{43}\left(\Delta\, reer_{j+1} + \hat{\sigma}_{reer}\right) - \hat{\beta}_{43}\,\Delta\, reer_{j+1}\right] + \\
&+ \left(\hat{\beta}_{11} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+3)}\left(\Delta\, tb_{j+3}\right) - \mathbb{E}_{0\,(j+3)}\left(\Delta\, tb_{j+3}\right)\right] + \\
&+ \left(\hat{\beta}_{12} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+2)}\left(\Delta\, tb_{j+2}\right) - \mathbb{E}_{0\,(j+2)}\left(\Delta\, tb_{j+2}\right)\right] + \\
&+ \left(\hat{\beta}_{13} + \hat{\rho}\right)\left[\mathbb{E}_{1\,(j+1)}\left(\Delta\, tb_{j+1}\right) - \mathbb{E}_{0\,(j+1)}\left(\Delta\, tb_{j+1}\right)\right] + \\
&+ \hat{\rho}\left[\mathbb{E}_{1\,(j)}\left(\Delta\, tb_{j}\right) - \mathbb{E}_{0\,(j)}\left(\Delta\, tb_{j}\right)\right] = \\
&= \left\{\hat{\beta}_{43}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right)\right] + \hat{\beta}_{42}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right) + \left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \right.\right.\\
&+ \left.\left(\hat{\beta}_{12} + \hat{\rho}\right)\right] + \hat{\beta}_{41}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right) + \left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{11} + \hat{\rho}\right)^3 + \right.\\
&\left. +2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{13} + \hat{\rho}\right)\right] + \\
&+\hat{\beta}_{40}\left[1 + \left(\hat{\beta}_{11} + \hat{\rho}\right) + \left(\hat{\beta}_{11} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{11} + \hat{\rho}\right)^3 + \left(\hat{\beta}_{11} + \hat{\rho}\right)^4 + \right.\\
&+3\left(\hat{\beta}_{11} + \hat{\rho}\right)^2\left(\hat{\beta}_{12} + \hat{\rho}\right) + 2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{12} + \hat{\rho}\right) + \\
&\left.\left. +2\left(\hat{\beta}_{11} + \hat{\rho}\right)\left(\hat{\beta}_{13} + \hat{\rho}\right) + \left(\hat{\beta}_{12} + \hat{\rho}\right)^2 + \left(\hat{\beta}_{12} + \hat{\rho}\right) + \left(\hat{\beta}_{13} + \hat{\rho}\right) + \hat{\rho}\right]\right\}\hat{\sigma}_{reer}
\end{aligned}
$$

For further elements of CIRF, we give only the formula for numerical computation (the reason is the same as for IRF)

$$\begin{aligned} CIRF(w) = & \sum_{i=0}^{3} \left[\hat{\beta}_{4i} \left(\Delta\, reer_{j+w-i} + \hat{\sigma}_{reer} \right) - \hat{\beta}_{4i}\, \Delta\, reer_{j+w-i} \right] + \\ & + \sum_{i=1}^{3} \left(\hat{\beta}_{1i} + \hat{\rho} \right) \left[\mathbb{E}_{1\,(j+w-i)} \left(\Delta\, tb_{j+w-i} \right) - \mathbb{E}_{0\,(j+w-i)} \left(\Delta\, tb_{j+w-i} \right) \right] + \\ & + \hat{\rho} \sum_{i=j+w-4}^{j} \left[\mathbb{E}_{1\,(i)} \left(\Delta\, tb_i \right) - \mathbb{E}_{0\,(i)} \left(\Delta\, tb_i \right) \right], \qquad \text{for } w \geq 4 \end{aligned} \tag{E.6}$$

F Impulse responses for trade balance model - model with the best SBC criterion

Figure F.1: IRFs for trade balance model with the best SBC

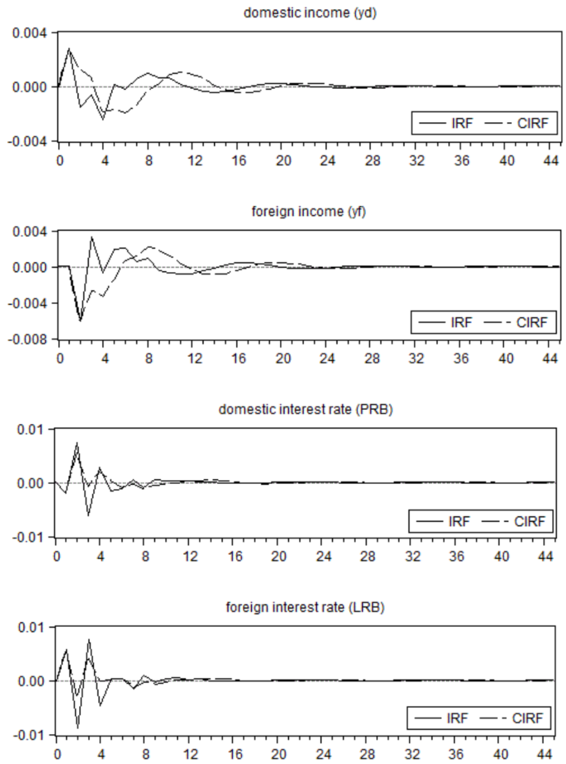


Note: In all cases, the solid line represents the IRF and the dashed line the CIRF. Impulse responses are based on the model with the best Schwarz Bayesian criterion, chosen from models in Table 4.7 and Table 4.10, i.e. Model 4. Responses measure the effect on trade balance of plus-one-standard-deviation shock in selected variable, where the standard deviations computed on first differences are $\hat{\sigma}_{yd} = 0.0162$, $\hat{\sigma}_{yf} = 0.0075$, $\hat{\sigma}_{PRB} = 0.3388$ and $\hat{\sigma}_{LRB} = 0.5043$. Horizontal axis is dated in the same manner as in Figure 4.8.

Source: Own computations.

G Impulse responses for trade balance model - model with the best AIC criterion

Figure G.1: IRFs for trade balance model with the best AIC



Note: In all cases, the solid line represents the IRF and the dashed line the CIRF. Impulse responses are based on the model with the best Akaike information criterion, chosen from models in Table 4.7 and Table 4.10, i.e. Model 2. Responses measure the effect on trade balance of plus-one-standard-deviation shock in selected variable, where the standard deviations computed on first differences are $\hat{\sigma}_{yd} = 0.0162$, $\hat{\sigma}_{yf} = 0.0075$, $\hat{\sigma}_{PRB} = 0.3388$ and $\hat{\sigma}_{LRB} = 0.5043$. Horizontal axis is dated in the same manner as in Figure 4.8.

Source: Own computations.

H CEC models for bilateral trade

Table H.1: CEC models for bilateral trade - part 1

	Wald statistic	Johansen test	KED test	J-curve
Austria	1.6522	NO	NO	YES
Belgium	3.8216	YES	YES	YES
France	3.0426	YES	YES	NO
Germany	8.7272	YES	YES	YES
Hungary	3.9005	YES	YES	NO
Italy	3.5758	YES	YES	NO
The Netherlands	1.3868	NO	YES	NO
Poland	2.6910	NO	YES	YES/NO
Slovakia	4.2963	YES	YES	YES/NO
United Kingdom	2.5392	YES	YES	NO
United States	3.4952	YES	YES	YES/NO
Russia	3.5788	YES	YES	YES
China	4.3629	YES	YES	YES

Note: Cointegration was considered through the following three tests: Bounds test - see Wald statistic in the table; Johansen test; and Kremers-Ericsson-Dolado test - in the table as KED test. Corresponding references are Pesaran et al. (2001), Johansen (1988, 1991), and Kremers, Ericsson and Dolado (1992). The conclusion for Johansen test and KED test was inferred at the 10 percent significance level; YES means the presence of cointegration. Finally, in the table the J-curve is verified only under the direct parameters; YES means the presence of J-curve and YES/NO means that there is a mixed result dependent on the definition of J-curve.

Source: Own computations.

Table H.2: CEC models for bilateral trade - part 2

	Austria	Belgium	France	Germany	Hungary
constant	0.0147	0.0082	0.0125	0.0129	-0.0014
	(0.0072)	(0.0145)	(0.0126)	(0.0032)	(0.0154)
tb(t-1)	-0.0630	-0.7579	-0.7523	-0.4893	-0.6525
	(0.1072)	(0.1968)	(0.2066)	(0.0892)	(0.1733)
yf(t-1)	0.1120	-1.0576	-0.1846	-0.0488	1.8496
	(0.3188)	(0.9535)	(0.4781)	(0.0949)	(0.9099)
yd(t-1)	-0.0808	0.9096	0.4543	0.1824	-1.1322
	(0.2570)	(0.6616)	(0.4177)	(0.0824)	(0.6426)
rer(t-1)	0.0321	0.7515	-0.3543	0.1368	-0.1104
	(0.1986)	(0.4822)	(0.4239)	(0.0928)	(0.3033)
irdf(t-1)	0.0265	-0.0428	0.0328	0.0144	0.0408
	(0.0107)	(0.0258)	(0.0219)	(0.0054)	(0.0267)
Δ yf(t)	-0.3962	-3.2821	2.3972	-1.1720	3.1634
	(0.6621)	(2.4217)	(2.1968)	(0.2817)	(1.4352)
Δ yf(t-1)	-1.1748	2.5397	0.4759	-0.5020	-4.6001
	(0.6020)	(2.2105)	(2.0836)	(0.3233)	(1.6753)
Δ yd(t)	0.4992	1.4430	-0.8527	0.1223	0.1523
	(0.4791)	(1.0267)	(0.8246)	(0.2026)	(1.1661)
Δ yd(t-1)	-0.0039	-0.1342	-0.3943	-0.6304	1.8138
	(0.4190)	(0.9289)	(0.7555)	(0.1969)	(0.9948)
Δ rer(t)	-0.0897	-0.4330	0.0038	-0.0464	0.0082
	(0.2209)	(0.5340)	(0.4106)	(0.0950)	(0.2597)
Δ rer(t-1)	-0.2475	-0.7622	0.1997	-0.0613	0.0444
	(0.2674)	(0.6532)	(0.4553)	(0.1124)	(0.2430)
Δ irdf(t)	0.0767	-0.0313	-0.0246	-0.0210	0.1194
	(0.0388)	(0.0684)	(0.0606)	(0.0152)	(0.0750)
Δ irdf(t-1)	-0.0831	0.0222	0.0301	-0.0118	-0.1385
	(0.0351)	(0.0707)	(0.0650)	(0.0151)	(0.0773)
Δ tb(t-1)	-0.5044	0.0806	-0.0886	-0.2058	0.0062
	(0.1601)	(0.1665)	(0.1666)	(0.1131)	(0.1573)

Note: Standard errors in parentheses.

Source: Own computations.

Table H.3: CEC models for bilateral trade - part 3

	Italy	The Netherlands	Poland	Slovakia
constant	0.0088	-0.0132	-0.0113	-0.0081
	(0.0099)	(0.0242)	(0.0137)	(0.0099)
tb(t-1)	-0.6808	-0.2880	-0.4543	-0.5038
	(0.1699)	(0.1461)	(0.1415)	(0.1224)
yf(t-1)	-0.9325	0.6593	0.0917	-0.6945
	(0.4645)	(1.4542)	(0.2202)	(0.4514)
yd(t-1)	1.1676	-0.4353	0.0660	0.6064
	(0.4362)	(1.1684)	(0.1595)	(0.3119)
rer(t-1)	-0.2797	-0.2830	0.1163	0.1398
	(0.2813)	(0.7301)	(0.0566)	(0.1275)
irdf(t-1)	0.0003	0.0665	0.0151	0.0023
	(0.0146)	(0.0630)	(0.0116)	(0.0121)
Δ yf(t)	2.8571	6.7018	0.3069	0.2066
	(1.2820)	(4.5859)	(1.0130)	(0.4882)
Δ yf(t-1)	0.9603	-3.6203	0.2125	1.2155
	(1.3324)	(4.1368)	(1.0225)	(0.5258)
Δ yd(t)	1.2313	-1.4588	0.6145	0.1169
	(0.6636)	(1.8945)	(0.4301)	(0.5372)
Δ yd(t-1)	-0.2875	1.1211	-0.1800	-0.8978
	(0.5862)	(1.7659)	(0.4228)	(0.5325)
Δ rer(t)	-0.5317	1.1494	0.1669	0.4439
	(0.3666)	(0.7179)	(0.0781)	(0.1786)
Δ rer(t-1)	0.9589	-0.3680	-0.0504	-0.0614
	(0.4346)	(0.8831)	(0.0731)	(0.1735)
Δ irdf(t)	0.0094	0.1691	0.0270	0.0469
	(0.0450)	(0.1190)	(0.0318)	(0.0400)
Δ irdf(t-1)	0.0187	0.1792	-0.0473	0.0152
	(0.0466)	(0.1305)	(0.0320)	(0.0423)
Δ tb(t-1)	-0.0314	-0.1571	0.2058	-0.0485
	(0.1443)	(0.1656)	(0.1691)	(0.1278)

Note: Standard errors in parentheses.

Source: Own computations.

Table H.4: CEC models for bilateral trade - part 4

	United Kingdom	United States	Russia	China
constant	0.0144	-0.0011	0.0220	0.0666
	(0.0214)	(0.0266)	(0.0322)	(0.1370)
tb(t-1)	-0.5237	-0.5851	-0.8511	-0.7833
	(0.1787)	(0.1572)	(0.2094)	(0.1783)
yf(t-1)	0.7903	-0.7944	1.4780	0.0450
	(1.3360)	(1.3425)	(1.0119)	(1.8993)
yd(t-1)	-0.4952	0.6710	-1.5058	0.0359
	(1.1598)	(0.8897)	(1.1785)	(1.4178)
rer(t-1)	-0.2625	0.3606	0.6287	0.4585
	(0.3533)	(0.2568)	(0.7236)	(0.4157)
irdf(t-1)	0.0089	-0.0524	0.0309	-0.0074
	(0.0428)	(0.0387)	(0.0809)	(0.0607)
Δ yf(t)	1.6615	-0.7881	1.3199	-0.0900
	(2.1850)	(3.3624)	(1.6342)	(3.6314)
Δ yf(t-1)	-0.1397	2.5906	-0.1719	-1.8544
	(1.9462)	(3.6664)	(1.9135)	(3.8653)
Δ yd(t)	-0.2732	0.4623	-2.7556	-0.4500
	(1.3999)	(1.7577)	(2.1293)	(2.5904)
Δ yd(t-1)	-1.1294	1.9101	0.2822	-0.4179
	(1.2810)	(1.2883)	(2.0052)	(2.4588)
Δ rer(t)	0.6767	0.0618	-0.1565	-0.6022
	(0.3133)	(0.3016)	(0.6205)	(0.7149)
Δ rer(t-1)	-0.4610	-0.5179	-0.3752	-0.5867
	(0.4069)	(0.3913)	(0.6570)	(0.7673)
Δ irdf(t)	0.0738	-0.1108	-0.1079	-0.1386
	(0.1066)	(0.1186)	(0.1529)	(0.1782)
Δ irdf(t-1)	-0.1344	-0.2260	0.0528	-0.0935
	(0.1099)	(0.1108)	(0.1473)	(0.1692)
Δ tb(t-1)	-0.0991	-0.2606	0.3108	0.1333
	(0.1488)	(0.1339)	(0.1803)	(0.1491)

Note: Standard errors in parentheses.

Source: Own computations.

I CEC models for industry trade

Table I.1: CEC models for industry trade - part 1

SITC	Cointeg.		Short-run dynamics		Long-run multipliers			
class	F	KED	Δ reer(t)	Δ reer(t-1)	reer	yd	yf	irdf
00	2.76	YES	-1.0176	2.1477	-2.31	5.49	-4.13	0.23
			(1.8127)	(1.7687)				
01	2.46	YES	-0.0926	-2.8066	1.62	1.90	-1.83	-0.05
			(1.1270)	(1.2126)				
02	4.94	YES	1.5542	-2.7102	4.81	-3.12	1.69	-0.04
			(0.8228)	(1.0187)				
03	3.10	YES	-1.1273	0.6252	-1.60	2.21	-1.17	0.06
			(0.6313)	(0.6944)				
04	8.85	YES	-0.3904	1.7923	-2.19	0.92	0.13	0.01
			(0.7916)	(0.8599)				
05	2.26	YES	0.4502	-0.8784	3.25	-4.38	3.43	-0.01
			(0.4074)	(0.5209)				
06	4.09	YES	0.0271	-0.3588	1.10	-0.78	0.72	-0.16
			(1.6768)	(1.8741)				
07	2.47	YES	-0.1025	0.3914	-0.19	0.34	0.12	-0.04
			(0.7932)	(0.8927)				
08	3.57	YES	-0.8267	-0.1971	2.41	-3.36	2.75	0.01
			(1.0132)	(1.1476)				

Note: Standard errors in parentheses. Value of F is calculated test statistic for the Bounds test. KED test is evaluated at the 10 percent significance level. Some short-run parameters are skipped for space saving.

Source: Own computations.

Table I.2: CEC models for industry trade - part 2

SITC	Cointeg.		Short-run dynamics		Long-run multipliers			
class	F	KED	Δ reer(t)	Δ reer(t-1)	reer	yd	yf	irdf
11	1.89	YES	0.3868	-1.1532	2.00	-0.79	0.40	0.08
			(0.5394)	(0.5897)				
12	5.91	YES	-5.6798	-1.2005	-0.99	1.12	-0.29	-0.28
			(3.5039)	(3.8742)				
21	3.83	YES	1.5829	0.6035	-13.67	17.84	-11.93	0.07
			(1.0680)	(1.4028)				
22	2.16	YES	-0.1755	-3.9684	5.08	-7.57	5.59	0.06
			(2.4924)	(2.7647)				
23	3.07	YES	-0.1230	-1.4459	2.89	1.79	-2.08	-0.01
			(1.1639)	(1.3050)				
24	3.79	YES	1.4241	1.1169	-1.70	2.15	-1.26	0.15
			(0.9189)	(1.0668)				
26	3.76	YES	-1.0318	1.5961	-1.35	-0.34	1.09	0.01
			(0.7578)	(0.8400)				
27	6.37	YES	0.3179	0.8750	0.16	1.03	-0.62	-0.12
			(0.6083)	(0.6572)				
28	11.45	YES	1.1034	1.0709	0.82	-4.01	3.75	-0.07
			(1.4591)	(1.5964)				
32	3.32	YES	1.6703	-1.1514	0.44	-0.41	0.45	-0.01
			(1.5403)	(1.6834)				
33	3.96	YES	-0.8956	-0.3952	-0.10	2.83	-2.05	-0.15
			(0.8983)	(0.9802)				
34	2.36	YES	3.5548	-2.7238	0.73	-8.54	8.17	-0.17
			(2.3757)	(2.2130)				
35	0.95	NO	2.2132	1.5653	1.57	7.07	-6.68	0.03
			(1.3590)	(1.4608)				
41	3.07	YES	3.9628	0.7743	1.27	-9.00	8.22	0.17
			(3.1042)	(3.3750)				
42	3.98	YES	1.5041	-6.1419	19.68	-23.88	16.38	-0.40
			(2.6820)	(2.8707)				
43	1.79	YES	-3.8328	0.1433	1.80	2.65	-2.47	-0.40
			(4.2272)	(4.4976)				

Note: Standard errors in parentheses. Value of F is calculated test statistic for the Bounds test. KED test is evaluated at the 10 percent significance level. Some short-run parameters are skipped for space saving.

Source: Own computations.

Table I.3: CEC models for industry trade - part 3

SITC	Cointeg.		Short-run dynamics		Long-run multipliers			
class	F	KED	Δ reer(t)	Δ reer(t-1)	reer	yd	yf	irdf
51	3.99	YES	0.1315	-0.5787	1.28	-1.04	0.87	-0.07
			(0.2945)	(0.3090)				
52	1.31	YES	-0.3555	-0.3109	0.54	-2.09	2.09	-0.01
			(0.5864)	(0.6079)				
53	2.43	YES	-0.3560	-0.2232	0.38	-0.17	0.41	0.03
			(0.5409)	(0.6208)				
54	2.11	YES	1.5382	-1.0098	1.77	-2.31	1.97	0.05
			(0.6939)	(0.7627)				
55	3.83	YES	-1.7256	-0.3811	-1.59	-0.24	0.99	0.04
			(0.7040)	(0.7543)				
56	3.77	YES	1.4472	1.9527	0.14	-3.40	3.37	-0.02
			(0.8669)	(0.9080)				
57	1.66	YES	-0.6446	1.0471	-2.79	0.92	0.32	0.14
			(0.5230)	(0.6619)				
58	3.10	YES	-0.9122	-0.6677	1.21	-1.84	1.69	-0.02
			(0.3218)	(0.4123)				
61	1.60	YES	0.0984	-1.2658	6.23	-11.20	8.75	-0.06
			(0.8921)	(0.9970)				
62	5.09	YES	-0.8957	0.1851	-1.22	1.33	-0.58	0.07
			(0.5924)	(0.6448)				
63	3.30	YES	0.5449	-0.8544	1.17	-0.69	0.57	-0.01
			(0.3149)	(0.3522)				
64	3.52	YES	-0.3927	-0.0336	-0.30	-0.10	0.49	0.06
			(0.3351)	(0.3456)				
65	5.41	YES	0.2017	-0.6261	0.77	-0.90	0.91	-0.03
			(0.2781)	(0.3418)				
66	4.12	YES	0.1777	-0.5399	1.08	-1.44	1.24	0.01
			(0.4287)	(0.4875)				
67	3.82	YES	-0.7884	0.7971	-1.07	1.60	-0.82	0.02
			(0.4474)	(0.4907)				
68	3.21	YES	0.2504	0.1708	-1.18	4.78	-3.58	0.02
			(0.5831)	(0.6295)				
69	2.30	YES	0.0547	-0.3037	0.89	-0.55	0.53	0.01
			(0.2709)	(0.3563)				

Note: Standard errors in parentheses. Value of F is calculated test statistic for the Bounds test. KED test is evaluated at the 10 percent significance level. Some short-run parameters are skipped for space saving.

Source: Own computations.

Table I.4: CEC models for industry trade - part 4

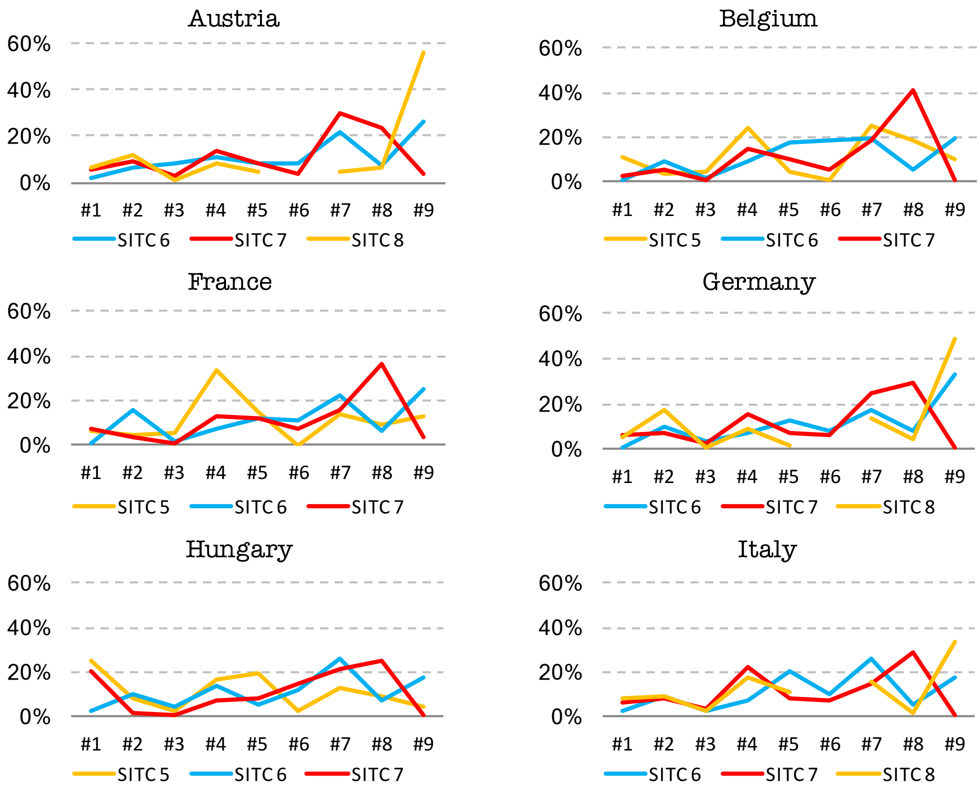
SITC	Cointeg.		Short-run dynamics		Long-run multipliers			
class	F	KED	Δ reer(t)	Δ reer(t-1)	reer	yd	yf	irdf
71	4.23	YES	-1.4129	0.4160	-2.40	1.50	-0.36	0.06
			(0.5424)	(0.6537)				
72	3.94	YES	-0.3543	0.8069	-0.85	0.35	0.24	0.04
			(0.4978)	(0.5681)				
73	1.99	YES	-0.2859	-0.6773	3.17	-5.82	4.67	-0.07
			(0.8964)	(0.9974)				
74	1.68	YES	-0.0817	0.1523	-0.71	-0.32	0.80	0.03
			(0.2848)	(0.2995)				
75	4.77	YES	-1.4870	0.9255	-6.80	8.12	-5.10	0.19
			(0.8418)	(1.0649)				
76	3.84	YES	-0.3924	-0.4704	-1.55	1.20	-0.31	0.01
			(0.9135)	(0.9915)				
77	3.97	YES	-0.2871	-0.0397	-0.41	0.51	-0.04	0.10
			(0.3593)	(0.4013)				
78	2.57	YES	0.3171	-0.2953	3.06	-4.46	3.44	-0.09
			(0.2976)	(0.3396)				
79	7.11	YES	-1.0313	-5.4931	0.70	1.21	-0.95	-0.08
			(2.9222)	(3.1959)				
81	2.15	YES	-0.5913	-0.3983	-1.30	0.43	0.20	0.16
			(0.4208)	(0.4112)				
82	5.52	YES	-0.2336	-0.3376	1.54	0.16	-0.31	-0.13
			(0.3037)	(0.3666)				
83	8.26	YES	0.2126	0.6921	0.17	4.06	-3.38	-0.03
			(0.6268)	(0.6816)				
84	2.60	YES	0.6516	0.0437	1.11	0.68	-0.65	0.02
			(0.5456)	(0.6214)				
85	3.04	YES	0.9030	-0.4364	5.10	-2.13	0.80	-0.08
			(0.4168)	(0.5372)				
87	1.22	NO	0.4435	-0.1067	-3.48	10.57	-8.28	0.19
			(0.4504)	(0.4932)				
88	2.34	YES	0.7494	0.6012	0.69	-1.67	1.61	0.17
			(1.0993)	(1.1850)				

Note: Standard errors in parentheses. Value of F is calculated test statistic for the Bounds test. KED test is evaluated at the 10 percent significance level. Some short-run parameters are skipped for space saving.

Source: Own computations.

J Three most important trade classes

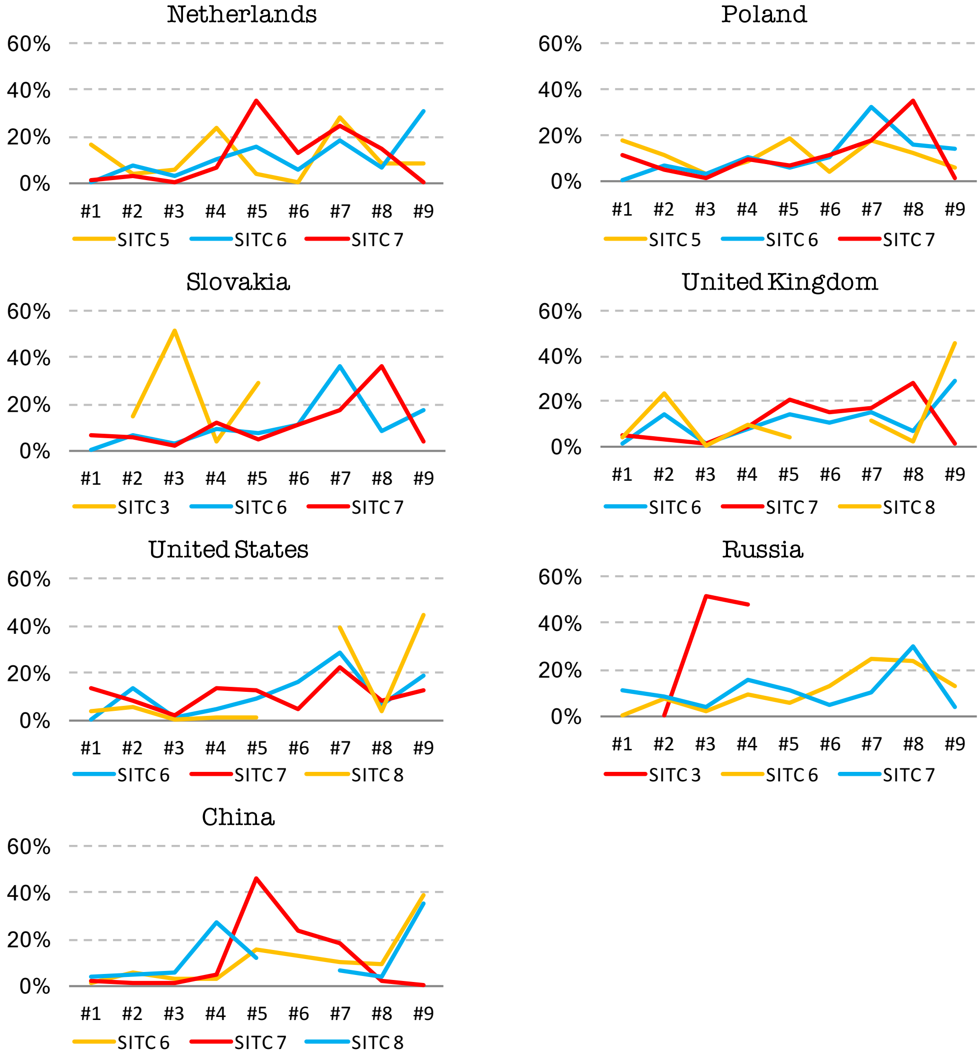
Figure J.1: Three most important trade classes - part 1



Note: Figures present the three most important trade classes in bilateral trade of the Czech Republic with a particular foreign partner. In every case the red line represents the most important trade class for the trade with a country, the blue line represents the second most-important class and the orange line the third most-important trade class. Particularly, shares of the two-digit SITC trade classes on the total volume of corresponding one-digit class are displayed; shares are averaged across the period 2000-2013. Horizontal line then depicts the second number of the two-digit SITC; the first number is given by the color of the line.

Source: Czech Statistical Office; own computations.

Figure J.2: Three most important trade classes - part 2

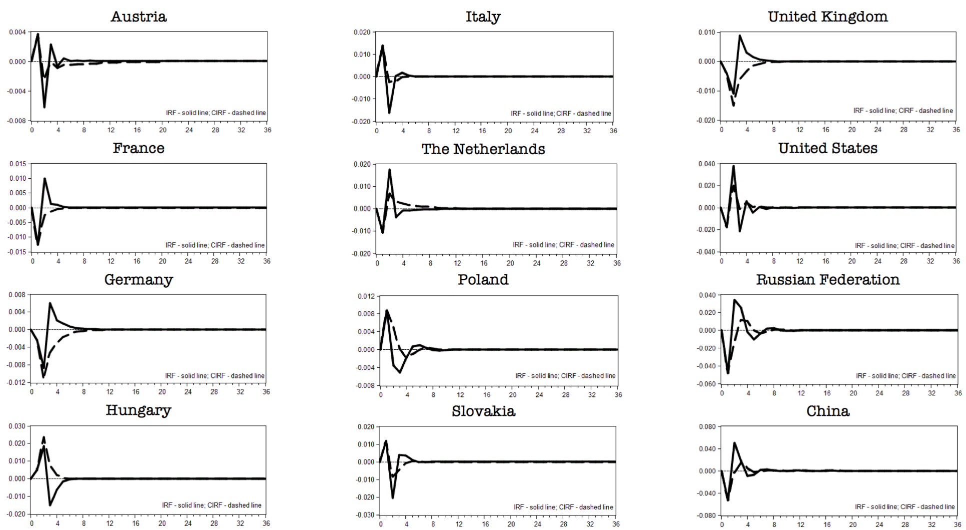


Note: Holds the same as for Figure J.1.

Source: Czech Statistical Office; own computations.

K Country response to domestic income shock

Figure K.1: Country response to domestic income shock

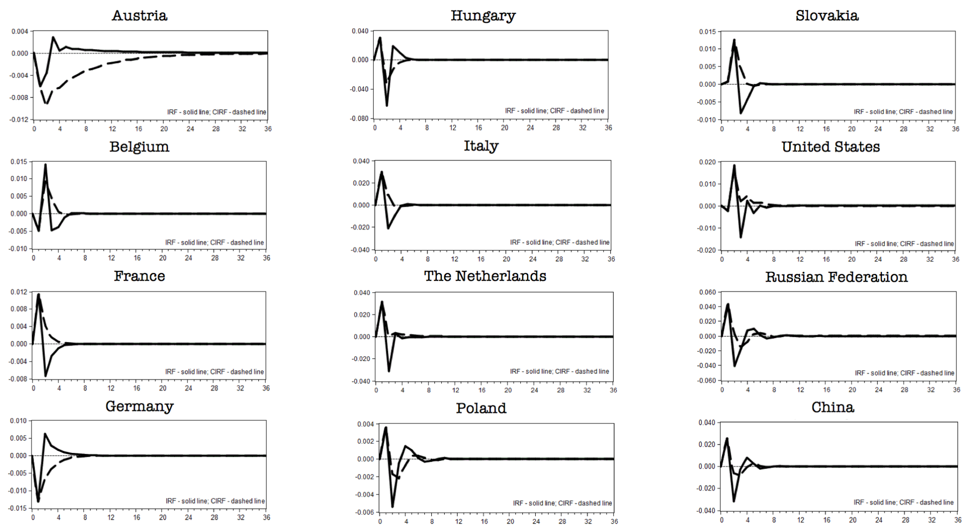


Note: Impulse responses for Belgium are not included, but both the shape and magnitude of these are very similar to the case of Italy. Trade balance is expressed as exports over imports (positive response means improvement in the trade balance) and the responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

L Country response to foreign income shock

Figure L.1: Country response to foreign income shock

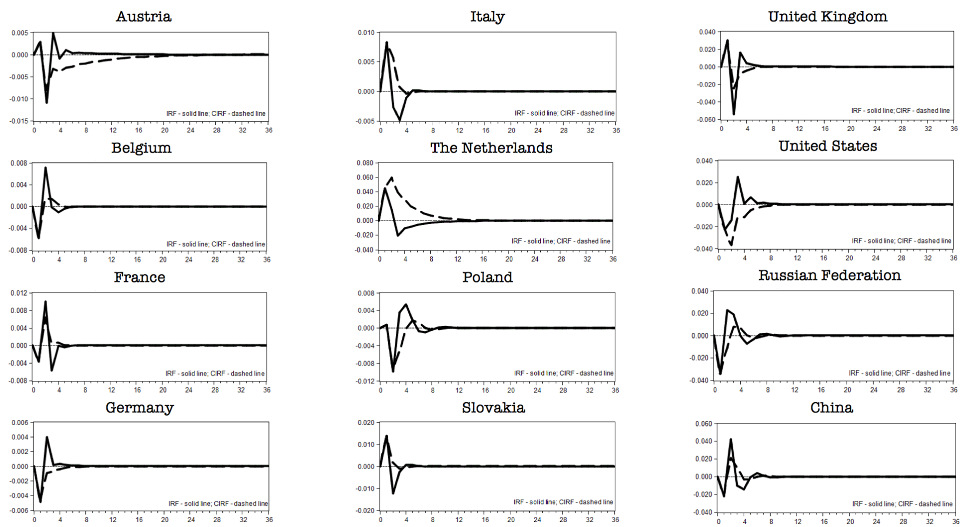


Note: Impulse responses for United Kingdom are not included, but both the shape and magnitude of these are very similar to the case of Italy. Trade balance is expressed as exports over imports (positive response means improvement in the trade balance) and the responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

M Country response to interest rate differential shock

Figure M.1: Country response to interest rate differential shock

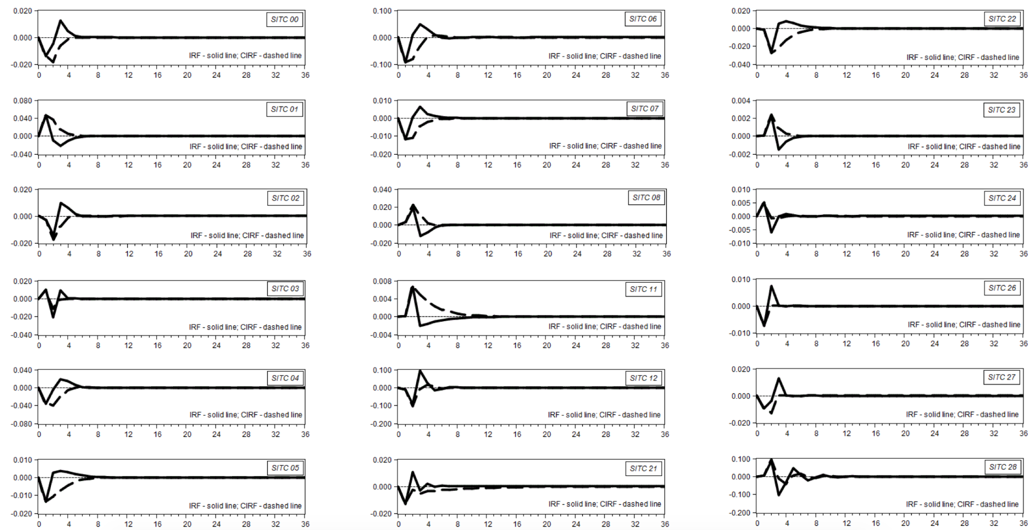


Note: Impulse responses for Hungary are not included, but both the shape and magnitude of these are very similar to the case of United Kingdom. Trade balance is expressed as exports over imports (positive response means improvement in the trade balance) and the responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

N Industry response to domestic income shock

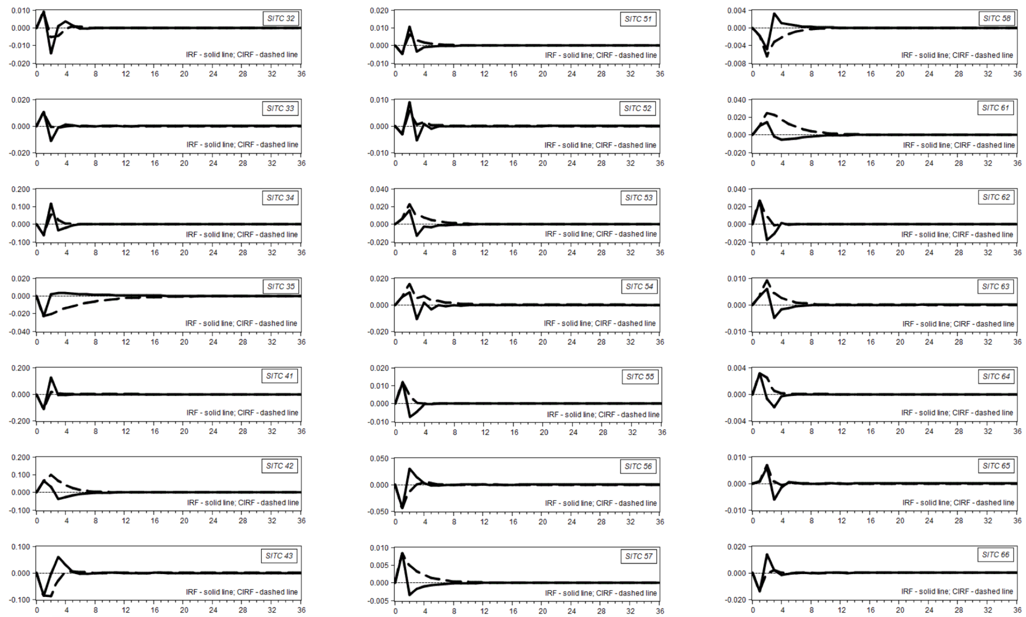
Figure N.1: Industry response to domestic income shock - part 1



Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

Figure N.2: Industry response to domestic income shock - part 2



Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

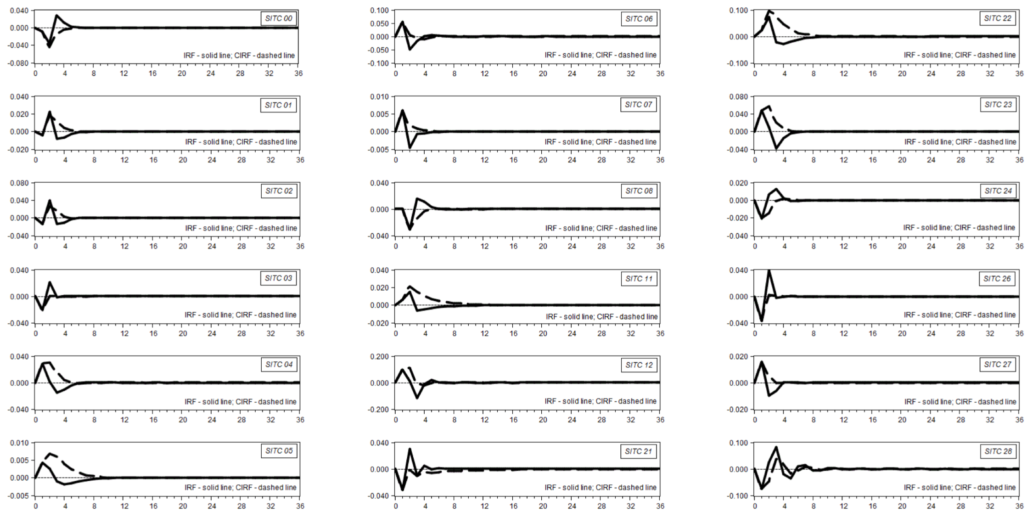
Figure N.3: Industry response to domestic income shock - part 3

Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

O Industry response to foreign income shock

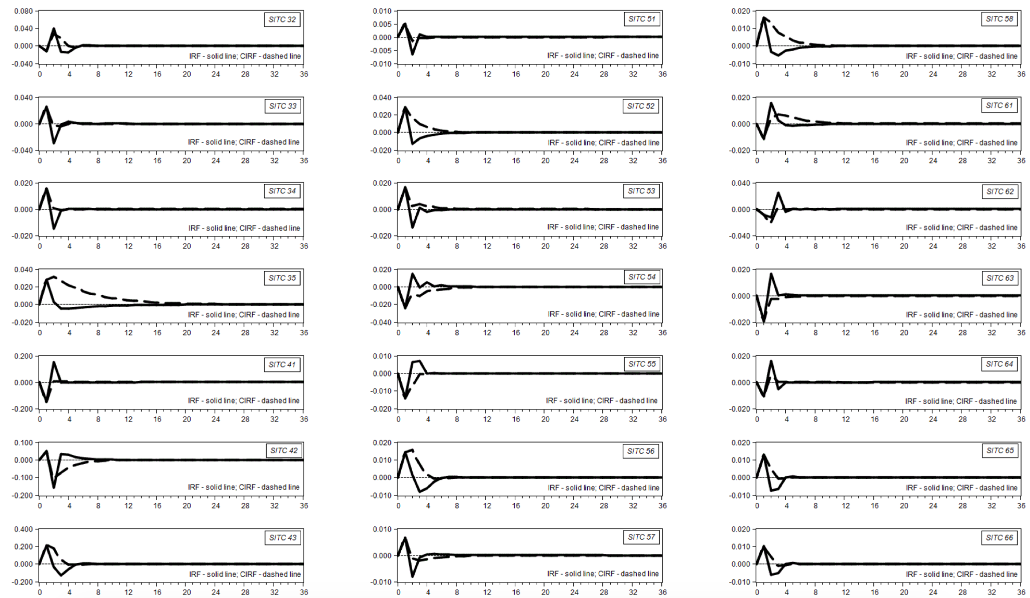
Figure O.1: Industry response to foreign income shock - part 1



Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

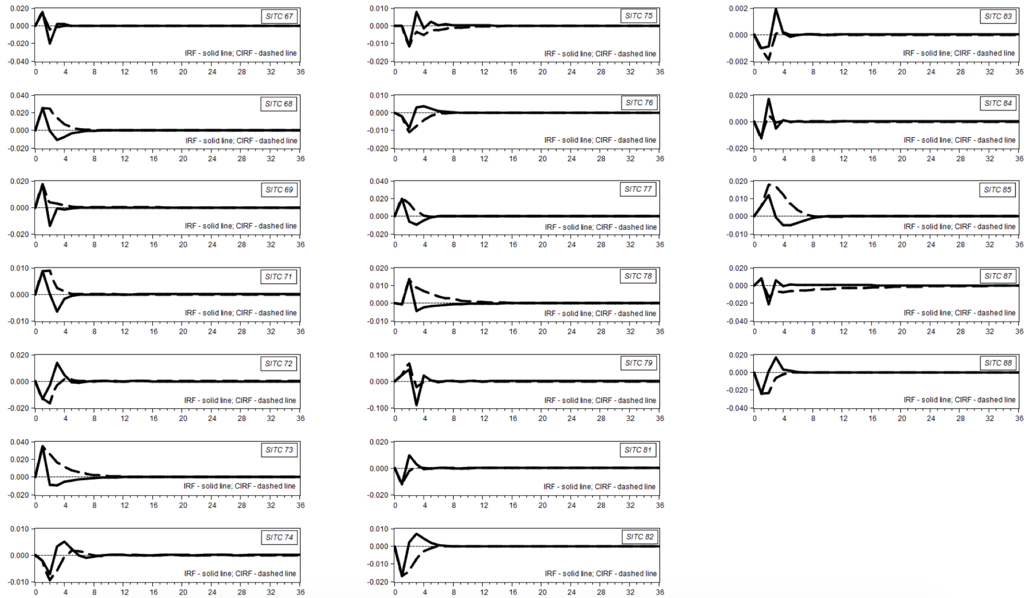
Figure O.2: Industry response to foreign income shock - part 2



Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

Figure O.3: Industry response to foreign income shock - part 3

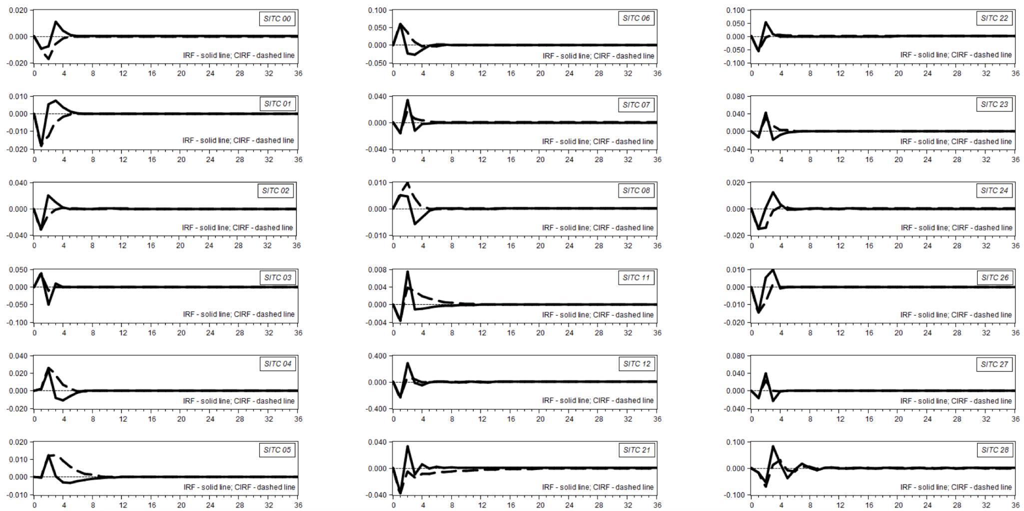


Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

P Industry response to interest rate differential shock

Figure P.1: Industry response to interest rate differential shock - part 1



Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

Figure P.2: Industry response to interest rate differential shock - part 2

Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

Figure P.3: Industry response to interest rate differential shock - part 3

Note: Trade balance expressed as imports over exports. Responses correspond to the one standard deviation shock. IRF = solid line and CIRF = dashed line.

Source: Own computations.

Q Johansen cointegration test for business investment

Table Q.1: Johansen cointegration test for business investment

Trace test			
Number of cointegration vectors under H0	Eigenvalue	Test statistic	Probability
0	0.7826	157.59	0.0001
1	0.7159	110.28	0.0034
2	0.5555	71.27	0.0381
3	0.5184	46.14	0.0719
4	0.4092	23.48	0.2231
5	0.1997	7.17	0.5580
6	0.0085	0.27	0.6063
Maximum Eigenvalue test			
Number of cointegration vectors under H0	Eigenvalue	Test statistic	Probability
0	0.7826	47.31	0.0382
1	0.7159	39.01	0.0657
2	0.5555	25.14	0.3758
3	0.5184	22.65	0.1888
4	0.4092	16.31	0.2070
5	0.1997	6.90	0.5005
6	0.0085	0.27	0.6063

Note: P-values are based on MacKinnon, Haug and Michelis (1999).

Source: Own computations.

R Residuals of aggregate investment model

Figure R.1: Residuals of aggregate investment model

Note: Residuals come from the model estimated on the data for the whole non-financial economy. Two horizontal blue lines indicate ± 2 standard deviation bands of the insignificance.
Source: Own computations.

S Investment responses to one std. dev. shocks

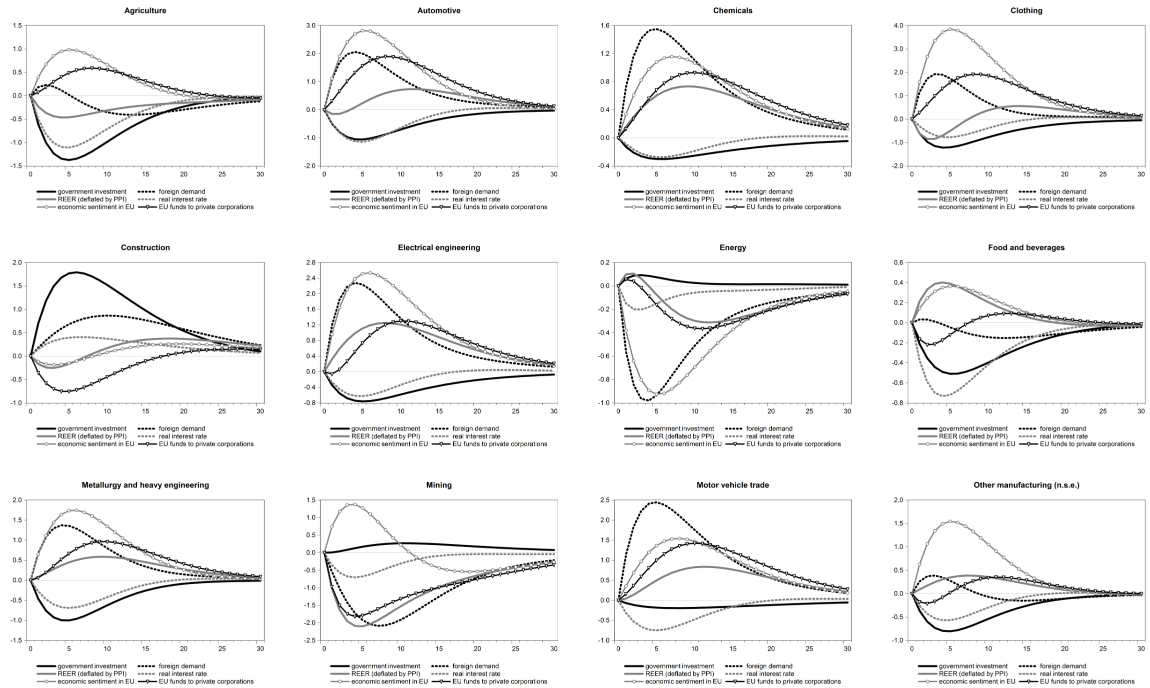
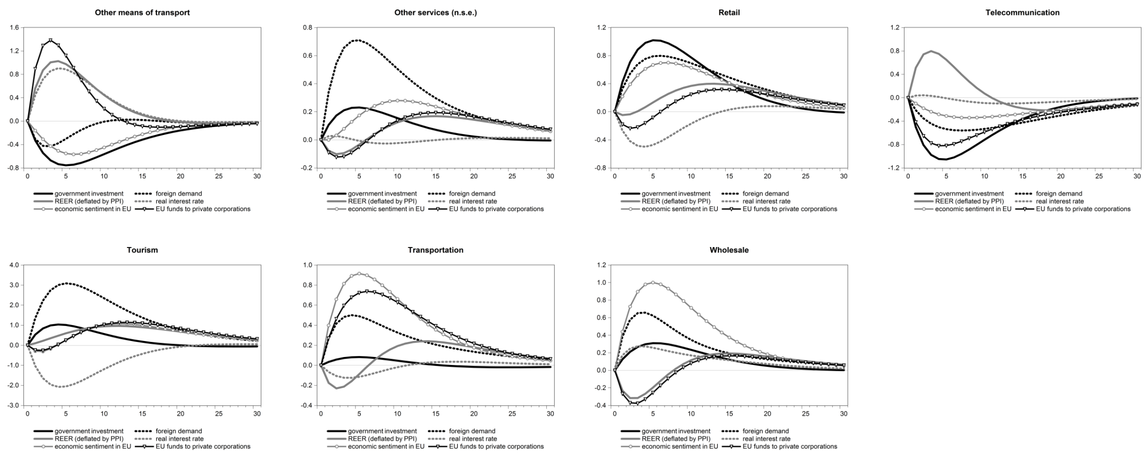


Figure S.1: Investment responses to one std. dev. shocks - part 1

Figure S.2: Investment responses to one std. dev. shocks - part 2

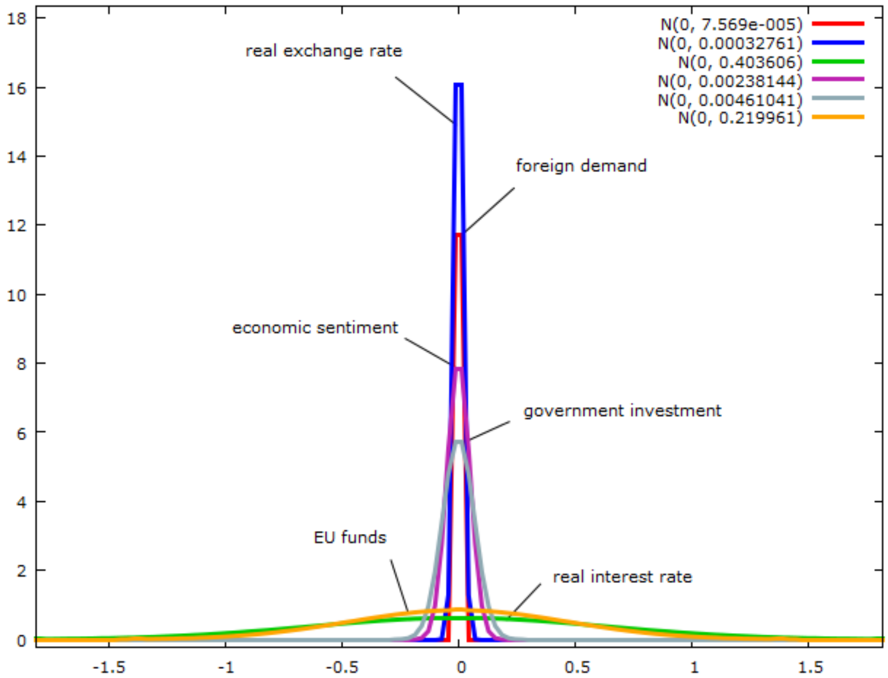


Note: The vertical axis in percentage and the horizontal axis in quarters.

Source: Own computations.

T Distribution of shocks to investment

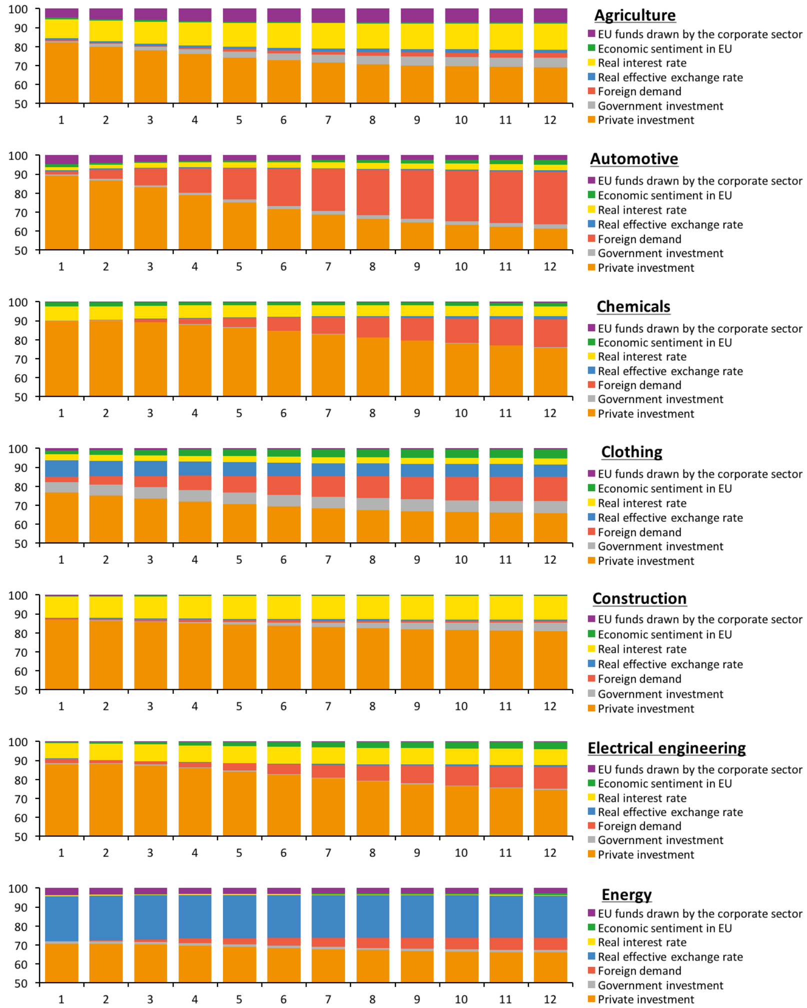
Figure T.1: Distribution of shocks to investment



Source: Own computations.

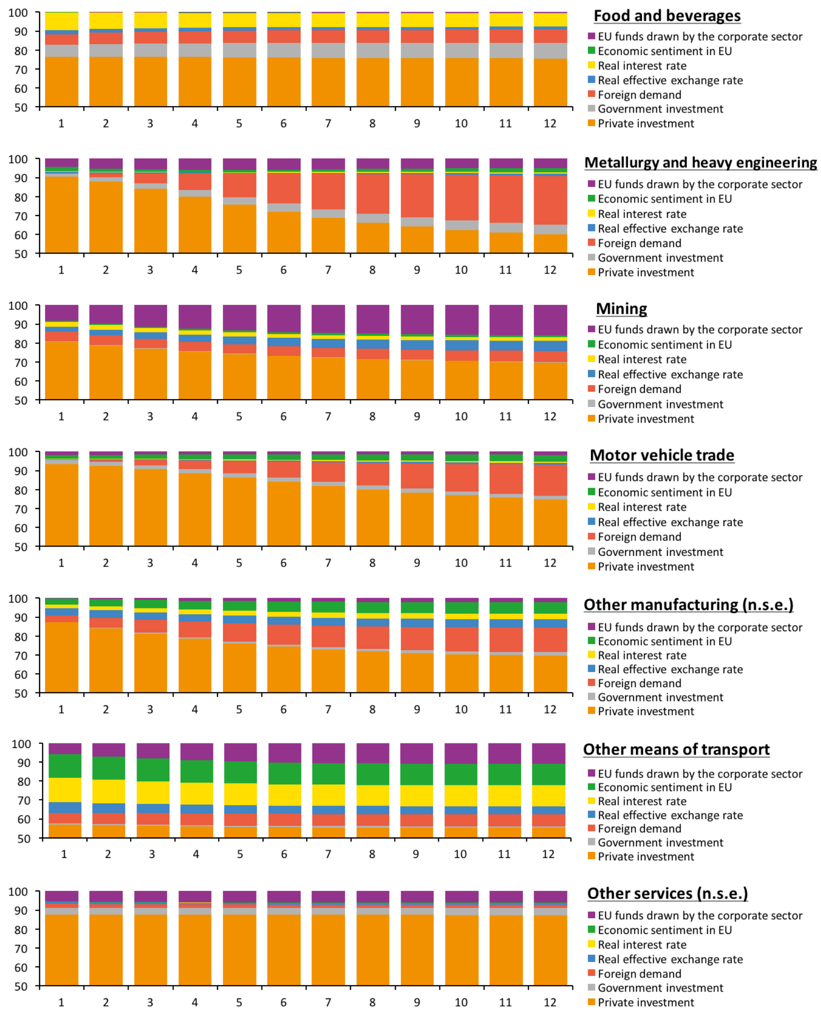
U Investment variance decomposition

Figure U.1: Investment variance decomposition - part 1



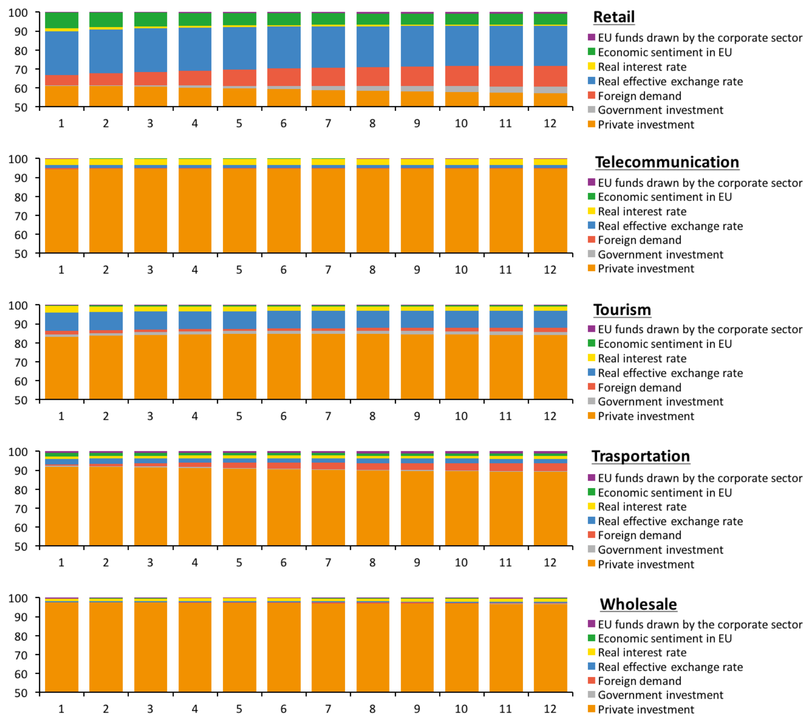
Note: Vertical axis is in percentage and horizontal axis in time periods.
Source: Own computations.

Figure U.2: Investment variance decomposition - part 2



Note: Vertical axis is in percentage and horizontal axis in time periods.
Source: Own computations.

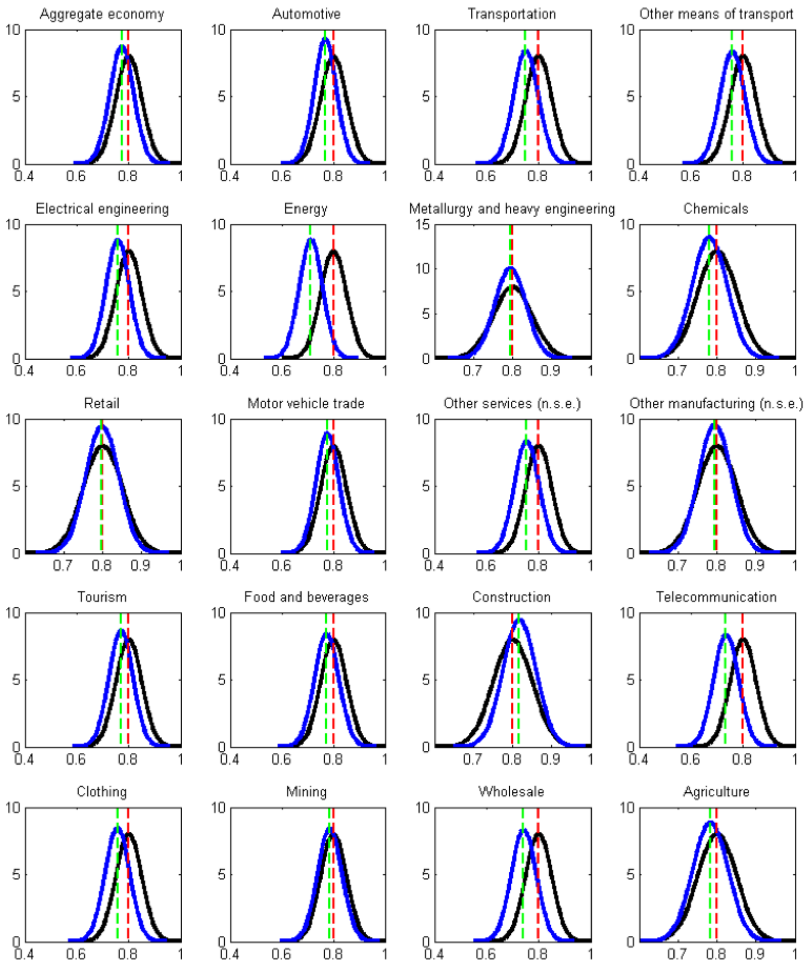
Figure U.3: Investment variance decomposition - part 3



Note: Vertical axis is in percentage and horizontal axis in time periods.
Source: Own computations.

V Posterior distribution of time-to-build coefficients

Figure V.1: Posterior distribution of time-to-build coefficients



Note: Posterior density has the blue color, prior density the black color. Posterior mean is indicated by the green dashed line and prior mean by the red dashed line.
Source: Own computations.

W Definition of industries by the NACE classification

Table W.1: Definition of industries by the NACE classification - part 1

Industry	NACE classification
Agriculture	NACE 01, NACE 02, NACE 03;
Automotive	NACE 29;
Chemicals	NACE 17, NACE 19, NACE 20, NACE 21, NACE 22, NACE 23;
Clothing	NACE 13, NACE 14, NACE 15;
Construction	NACE 41, NACE 42, NACE 43;
Electrical engineering	NACE 26, NACE 27;
Energy	NACE 35, NACE 36, NACE 37, NACE 38, NACE 39;
Food and beverages	NACE 10, NACE 11, NACE 12;
Metallurgy and heavy engineering	NACE 24, NACE 25, NACE 28;
Mining	NACE 05, NACE 06, NACE 07, NACE 08, NACE 09;
Motor vehicle trade	NACE 45;

Table W.2: Definition of industries by the NACE classification - part 2

Industry	NACE classification
Other manufacturing (n.s.e.)	NACE 16, NACE 18, NACE 31, NACE 32, NACE 33;
Other means of transport	NACE 30;
Other services (n.s.e.)	NACE 58, NACE 59, NACE 60, NACE 62, NACE 63, NACE 68, NACE 69, NACE 70, NACE 71, NACE 72, NACE 73, NACE 74, NACE 75, NACE 76, NACE 77, NACE 78, NACE 79, NACE 80, NACE 81, NACE 82, NACE 83, NACE 84, NACE 85, NACE 86, NACE 87, NACE 88, NACE 89, NACE 90, NACE 91, NACE 92, NACE 93, NACE 94, NACE 95, NACE 96, NACE 97, NACE 98, NACE 99;
Retail	NACE 47;
Telecommunication	NACE 61;
Tourism	NACE 55, NACE 56;
Transportation	NACE 49, NACE 50, NACE 51, NACE 52, NACE 53;
Wholesale	NACE 46

Note: The shorthand n.s.e. means not specified elsewhere.

X Distribution of employment over the firms

Table X.1: Distribution of employment in a particular industry

Industry	< 10	$[10, 20)$	$[20, 30)$	$[30, 40)$	$[40, 50)$	≥ 50	Total
Agriculture	8.16	10.65	21.57	15.30	9.91	34.41	100
Automotive	4.19	4.87	10.80	6.82	4.86	68.47	100
Chemicals	4.71	10.94	16.62	10.92	8.57	48.25	100
Clothing	7.81	16.24	21.72	12.26	8.12	33.84	100
Construction	11.93	21.12	26.46	12.11	6.91	21.47	100
Electrical engineering	4.84	12.16	16.89	9.50	7.45	49.16	100
Energy	10.86	13.83	17.33	11.96	7.72	38.31	100
Food and beverages	5.39	13.58	21.09	12.60	8.07	39.27	100
Metallurgy and heavy engineering	4.42	10.89	18.93	12.39	9.17	44.20	100
Mining	6.41	13.66	17.30	10.15	7.44	45.04	100
Motor vehicle trade	7.73	19.06	27.21	12.75	7.98	25.28	100
Other manufacturing (n.s.e.)	6.22	17.79	24.11	11.11	8.34	32.42	100
Other means of transport	3.37	6.19	15.27	9.83	7.86	57.48	100
Other services (n.s.e.)	15.52	19.10	20.37	10.63	6.65	27.72	100
Retail	12.41	28.41	23.40	9.17	5.27	21.34	100
Telecommunication	12.18	20.74	22.49	8.36	5.65	30.57	100
Tourism	11.09	28.12	26.85	11.28	6.25	16.41	100
Transportation	7.62	16.86	22.19	11.73	8.67	32.93	100
Wholesale	17.28	20.83	23.85	11.98	6.98	19.08	100
Total	10.53	17.67	21.81	11.52	7.50	30.98	100

Note: For each industry the table contains a share (in %) of firms with the number of employees in a specified interval, which is defined in the first line of table. For example, 8.16 % of agricultural enterprises in the sample have less than 10 employees and the total number of enterprises with less than 10 employees represents 10.53 % of firms in the sample.

Source: Own computations.

Table X.2: Distribution of firms with a particular number of employees over the industries

Industry	< 10	$[10, 20)$	$[20, 30)$	$[30, 40)$	$[40, 50)$	≥ 50	Total
Agriculture	4.34	3.38	5.54	7.44	7.40	6.23	5.60
Automotive	0.56	0.39	0.69	0.83	0.91	3.09	1.40
Chemicals	2.45	3.40	4.18	5.20	6.27	8.55	5.49
Clothing	1.56	1.93	2.09	2.23	2.27	2.29	2.10
Construction	12.49	13.18	13.37	11.58	10.15	7.64	11.02
Electrical engineering	1.19	1.78	2.01	2.14	2.57	4.11	2.59
Energy	2.54	1.93	1.96	2.56	2.53	3.05	2.46
Food and beverages	1.97	2.96	3.72	4.21	4.14	4.88	3.85
Metallurgy and heavy engineering	4.07	5.97	8.41	10.42	11.84	13.82	9.69
Mining	0.21	0.27	0.28	0.31	0.35	0.51	0.35
Motor vehicle trade	1.85	2.72	3.15	2.79	2.69	2.06	2.52
Other manufacturing (n.s.e.)	3.44	5.86	6.44	5.62	6.48	6.10	5.82
Other means of transport	0.11	0.12	0.23	0.28	0.35	0.61	0.33
Other services (n.s.e.)	30.19	22.14	19.13	18.90	18.15	18.33	20.48
Retail	6.70	9.15	6.10	4.53	4.00	3.92	5.69
Telecommunication	0.33	0.33	0.29	0.20	0.21	0.28	0.28
Tourism	4.43	6.68	5.17	4.11	3.50	2.23	4.20
Transportation	3.87	5.10	5.44	5.44	6.18	5.68	5.34
Wholesale	17.70	12.72	11.80	11.21	10.03	6.64	10.78
Total	100	100	100	100	100	100	100

Note: The table contains a share of the industry in a specified category regarding the number of employees (see the first line of table). For example, 4.34 % of firms with less than 10 employees are in agriculture and the agriculture has the share of 5.6 % on the total number of employees of the firms included in the sample.

Source: Own computations.