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QUANTIFYING THE QUALITY OF PREDICTIONS: G3 MODEL EVALUATION

bakalářská práce

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Prohlašuji na svou čest, že jsem bakalářskou práci vypracoval samostatně a s použitím uvedené literatury.

Marcel Tkáčik
V Praze, dne 18. 8. 2015

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BACHELOR THESIS TOPIC

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Guides to writing a thesis:

1. The purpose of the thesis is to test the quality of predictions provided by G3 model, the dynamic structural model employed by Czech National Bank for economic indicators forecasts.
2. I will summarize the theoretical solution of macroeconomic prediction models focused on dynamic stochastic models of general equilibrium (DSGE). Within this framework, I'm going to study and efficiently describe economic and econometric structure of G3 model.
3. Using econometric methods, I will test the ex post correspondence of data (time series) predicted by the model and the ones actually measured. I will carefully evaluate the test results and discuss their meaning.
4. Data sources: ARAD time series database (available at: http://www.cnb.cz/docs/ARADY/HTML/index.htm); ECB Statistical Data Warehouse (available at: http://sdw.ecb.europa.eu); publicly published forecasts, research outcomes and working papers of the Czech National Bank obtained via official website http://cnb.cz; works of various New Keynesian and other economists and econometrists published in peer-reviewed journals.

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Abstract

Recent developments of New Keynesian models attracted many central banks to develop their own DSGE models for policy analysis and forecasting. The aim of this study is to evaluate the quality of the predictions made by the Czech National Bank which developed its own DSGE model and use it as the core forecasting model from July 2008. The quality of the predictions has been evaluted by comparing it with the Ministry of Finance of the Czech Republic and two commercial banks (Česká spořitelna and Komerční banka). Using the econometrical tests for the structural break and time series analysis, it has been concluded that the Czech National Bank experienced significant improvement in its prediction quality when employing the DSGE model, and surpassed the other three institutions. This study suggests that a well-specified DSGE model may enhance the prediction quality of key macroeconomic indicators compared to non-structural models and expert judgment.

Keywords: New Keynesian models, DSGE, forecasting models, Czech National Bank, prediction quality

JEL: B22, C53, E17

Abstrakt

Nedávný rozvoj Nových keynesiánských modelů motivoval mnoho centrálních bank k vývoji vlastních DSGE modelů pro analýzu měnové politiky a tvorbu prognóz. Cílem této studie je otestovat kvalitu predikcí České národní banky, která vyvinula vlastní DSGE model a používá ho jako jádrový predikční model od července roku 2008. Kvalita predikcí byla vyhodnocena srovnáním s Ministerstvem financí České republiky a dvěma obchodními bankami (Českou spořitelnou a Komerční bankou). Použitím ekonometrických testů pro detekci strukturální změny a analýzu časových řad bylo zjištěno, že Česká národní banka zažila významné zlepšení kvality predikcí, když začala používat DSGE model a předčila ostatní tři instituce. Tato studie navrhuje, že dobře specifikovaný DSGE model může zlepšit kvalitu predikcí klíčových makroekonomických ukazatelů ve srovnání s nestrukturálními modely a odborným úsudkem.

Klíčová slova: Nové keynesiánské modely, DSGE, prognostické modely, Česká národní banka, kvalita predikcí

JEL: B22, C53, E17

Contents

Introduction[1]

As it can be seen in most of the systems which are in the interest of men, the control decisions of any kind have to deal with their consequences. The intent to manage a system as complex as a national economy requires making insight about future developments. Since the future state is not known with certainty, the uncertainty problem can be denoted as:

$$P(y_{t+1} = y_t + x_t) < 1, \tag{1}$$

where y is any measurable indicator and x is knowledge or insight about ex ante changes to y. This knowledge is only available in time t.

This uncertainty problem is very actual both generally and particularly in the last decades. Generally the monetary and fiscal policy needs to manage the uncertainty itself in order to perform the macroeconomic stabilization policy. Particularly, the failure of forecasting methods in predicting recessions in the last decades. Then, research of the forecasting methods (and models employed) of important institutions and evaluation of their forecasts can be an added value of this study. Especially because there is not a lot of papers trying to evalute forecasts of different institutions and comparing them with respect to the forecasting models they use.

In the last decade, the majority of central banks started to use models based on the dynamic stochastic general equilibrium approach (DSGE) as their core prediction model. One central bank is the Czech National Bank, which eventually developed its own DSGE model named g3. This model from the third quarter of the year 2008 is used as the core prediction model where it replaced complex solutions based on the vector autoregression approach. The DSGE model is the only kind of ex ante prediction model which is theoretically able to overcome the concept widely known as the "Lucas critique". Unlike the solutions based on the analysis of previous time series, the DSGE approach tries to simulate the

[1]This study is written in LaTeX and follows the Methodology for writing the final thesis published by Faculty of Economics of University of Economics in Prague available at http://nf.vse.cz/studenti/zaverecne-prace/metodika-pro-psani-bp-a-dp2/. Citation style corresponds to Harvard style (apsr).

real economy using a system of interdependent behavioral equations and national accounting identities, where the final functions are derived from microeconomic principles. Hence, the model is structural.

The aim of this study is to review the theoretical approach of New Keynesian economics, discuss its most important features, link them to the birth of DSGE models and then evaluate the quality of predictions of macroeconomic indicators made by the Czech National Bank, the Ministry of Finance of the Czech Republic and commercial banks in the Czech Republic. This study will contribute to economics science by providing an evaluation of the quality of predictions that comes from different models.

The theoretical part of this work (i) describes a history of mainstream schools of economic thought with respect to their forecasting models, (ii) reviews theoretical assumptions of the New Keynesian economics, modeling of these assumptions and reviews relevant critical reflections, (iii) reviews forecasting methods and models used in the Czech Republic.

The research hypothesis is that predictions of the Czech National Bank made from the 3rd quater of the year 2008 on (when g3 started to serve as core prediction model) increased the prediction quality of the Czech National Bank. This hypothesis is linked to the theoretical part of this study, which states that a DSGE model (or structural model) overcomes non-structural models in forecasting ability (due to its better theoretical underpinning).

This hypothesis will be tested on time series of actually measured data and their predicted counterparts. There will be used a methods of statistical inference and econometrical testing.

Chapter 1

Historical background

1.1 From Keynesianism to New Keynesianism

The publication of the Keynes General theory (1936) which started a "Keynesian revolution" change both theoretical and applied economics forever. After Keynes death in 1946, his followers split themselves into two different schools. The first school, eventually named neo-Keynesian, strived to formalize and interpret Keynes writings and synthesize the with neo-classical economics. The latter school, post-Keynesian economics, then treated Keynes theory in general, while the approach of neo-classical economics being only a specific subtype. They completely rejected classical and neo-classical economics, while treating theory of perfectly competitive markets as not an acceptable approximation of reality, notably Joan Robinson developed a theory of mopolistic competition (Arestic, 1996).

1.1.1 Life and short-comings of neo-Keynesian economics

Neo-Keynesian economics was developed by many of Keynes followers, notably John Hicks, Franco Modigliani and Paul Samuelson. One of their most influential outcomes was Hick's IS-LM which provided a synthesis of neo-classical economics. Another notable instrument was Samuelson's Phillips Curve and the Solow-Swan model of economic growth. The macroeconomic stabilizing methods of neo-Keynesian economics, which eventually became a mainstream school of economics, proved itself to be successful particularly during the 1950's and 1960's (Hayes, 2008). However, events of the 1970's shook neo-Keynesian economics. The developed world suffered from a phenomenom which rejected the relation of Phillips Curve: slow economic growth, high inflation and high rate of uneymployment at the same time (stagflation). The trade-off between inflation and unemployment using a stimulation of aggregate demand was no longer possible.

For more information about the oil crisis, stagflation and crisis of neo-Keynesian economics in 1970's, see Frum (2000).

1.1.2 Birth of New Keynesian economics

Following the 1970's crises, a widening disappointment about neo-Keynesian economics theory, its macroeconometrical models and tools made a large space for both new and old uncommon theories to enrich the mainstrem theory, notably the birth of the Real Business Cycle theory and monetarism (Dixon, 2008) This is when the next wave of Keynesian thinking began, with the attempt to give a rigorous microeconomics foundations for their macroeconomics models and phenomena.The premise of imperfection of free markets, particularly its inablity to assure full employment (perceived as a natural rate of unemployment) has to be supported by a structural model.The result was a series of new ideas to bring tools to Keynesian analysis that would be capable of explaining the economic events of the 1970s. These results will be more explained and discussed in Chapter 2. From the 1980's and following, the new neoclassical synthesis in 1997, the New Keynesian economics became a mainstream school of economic thought and provided both a theoretical and a practical framework for most of central banks all over the world, particularly for Fed and European Central Bank.

1.2 From large-scale models to more sophisticated framework

1.2.1 Non-structural models

The pioneer of macroeconometrical modeling before WWII was Jan Tinbergen, who created a macroeconometrical model of the Dutch economy in the 1936. The main purpose of the model was to help the Dutch Central Planning Bureau in specifying optimal macroeconomic policy. A course of his method in dividing the variables into targets and instruments. Later, he extended his model to the United States and the United Kingdom (Dhaene and Barten, 1989).

The first attempts to create a sophisticated and structural makroeconometrics models can be seen after WWII, when there were very fast developments of computers. Without computers, it would not have been possible to solve computationally demanding algorithms even only with 60 equations, in sufficient time.

With the development of computers and econometrical methods, supported by the success of Keynesian stabilizing policy, national economies started to be modelled by systems of simultaneous equations, which get its solution together. These equations were in a core derived by Keynes General Theory, but eventually they were accompanied by equations of somewhat observed relations in national economy. Together, they were aimed to simulate a national economy in accordance with the system of national accounting (the first formal national accounts were published by the United States in 1947). The observed relations were to specify relatively general behavioral equations subjected to the national accounts identity (for a example of this relation, one equation tried to mathematically express a response of capital accumulation in Austin, Texas to government purchases in Boston, Massachusetts). Then, these empirically observed relations, only observed in limited time and limited location, were put into the system of simultaneous equation. It is important to say, that model enhanced with this equations was not supported by any economic theory. There have even been networks of large-scale models which tried to consolidate partial models in order to make a complex single model of bigger systems (even the economy of the entire world in one model). The most prominent network was propably the LINK Project housed by Wharton Econometric Forecasting Associates. For examples of other models build on this approach, see Klein and Goldberger (1955).

This phenomenom of models build on observed equations without theoretical support is then discussed by Robert Lucas (see Lucas, 1976). His critique, eventually known as the "Lucas critique" lies in an argument, that past expectations of economic subjects about behaviour of policy makers (i.e. central bank and government) are already absorbed in these empirical equations. So the past expectations, made for time t are already absorbed in the parameters of these equations. These parameters have their explanatory power only for a behaviour at time t. However, they can not be used for simulations and forecasts for period $t+1$ (or basically ex-ante periods), because the expectations of economic subjects have already changed (which works both for adaptive and rational expectations). Since the expectations have changed, the parameters of equations have changed alsol, even the specification of equation may change as well. The findings of the "Lucas critique" made an impulse for a development of structural models where the parameters of the equations should be a function of some deep parameters which would be independent of monetary and fiscal policy. This way would be also in live with a theory of rational expectations (Muth, 1961). This theory basically suggests that economic subjects can make a best guess of the future (optimal forecasts) and so their predictions do not differ systematically from market equilibrium results. The theory of rational expectations was a response to the widely used theory of adaptive expectations, which was not in theoretical conflict with the phenomenom of "observed equations" But the theory of rational expectations implies that the observed relations made into an equation can not be a good approximation of reality and lacks explanatory power. (Shiller, 1978)

The further development of macroeconometrical models, then, follows the events of the 1970s: the failure of neo-Keynesian large-scale macroeconometric models as forecasting tools and the widening disappointment of economists with theoretical underpinning of this models. The reason was obvious: the phenomenom of stagflation, that occured in the 1970s, when the key trade-off between inflation and rate of unemployment (as present by the Phillips Curve) stopped working, the neo-Keynesian models built on this paradigm were not able to explain the empirical data, and not at all make acceptable forecasts. Plenty of empirical studies in the 1970's researched the predictive power of neo-Keynesian models and concluded that even a very simple statistical extrapolation of time series connected with the hypotheses testing based on statistical inference, gives a way better prediction about future outcomes than this neo-Keynesian model. For the example of this study, see Nelson (1972).

1.2.2 Optimizing agents framework

An effort to create a model which would be immune to Lucas critiques, therefore containing kind of deep parameteres (for example households discount factor, elasticities of substition, and so on) had first account in work of Lucas and Prescott (1971) and Lucas (1972). Even though some authors, for example Diebold (1998), consider this early work as a first type of a DSGE model (and labels it as New Classical DSGE model), there is a problem of non-complexity of presented models. For example in Lucas (1972) there is a well-specified supply side (with real marginal costs) but is put against an ad-hoc demand which is not the outcome of a structural model. Following Gali (2008), they can not be assumed to be the first DSGE models, because, even though working in the optimizing agents framework, all agents optimizing functions were not a function of a complex structural model.

The first real DSGE model was formed by Kydland and Prescott (1982). This model because the core of the real business cycle theory (RBC). After their influential paper had been published, many other RBC models appeared, for example, Long and Plosser (1983). See Valadkhani (2004) for a review. Their important common feature was that they all assumed a perfect competition on markets of goods and labor, and also assumed flexible prices and wages without nominal rigidities. Empirically, RBC models were succesful in explaining some features of macroeconomic time series, namely, unconditional second moments. See King and Rebelo (1999) for a study about fitness of RBC models to historical technological shocks.

However, RBC models have very serious and controversial implications for a monetary policy, where holding a classical dichotomy, monetary policy has no effects on real variables even in the short run. This was not acceptable for the majority of economists since there was a widely held belief that monetary policy is empowered to influence the output and employment, at least in the short run, given the evidence of Friedman and Schwartz, (1963) and more recently by Christiano, Eichenbaum and Evans (1998). Also, Summers (1986) gave an excellent discussion about the aproach to calibration (parametrization) of model presented in Prescott (1986). For example, a parameter of average real interest rates and parameters of elasticity labor supply is calibrated to extremely unrealistic values. Due to presented conflict with mainstream macroeconomic thought the RBC models were not widely accepted. (Slanicay, 2014)

The reasons for a shortcoming of RBC models mentioned above led to an evolution of New Keynesian DSGE models. They absorbed a methodology and underlying structure of RBC models (most importanly, the principle of economic agents optimizing their utility subjected to numerous constraints). Nevertheless, they enhanced the RBC structure with Keynesian features, particularly monopolistic competition in the markets of goods and/or labor and the nominal rigidities in prices and wages. The first to introduce this framework were Rotemberg and Woodford (1997).

Finally arriving to the state of past two decades when New Keynesian economics became a mainstream economic theory (as discussed in previous section), employed by almost all central banks, DSGE models have been subjected to great attention and development. From the New Keynesian DSGE framework presented in late 90's, there have been plenty of DSGE models built, among them the most important are Smets and Wouters (2003), Christiano et. Al (2005), An and Schorfheide (2007) , Smets and Wouters (2007) and Galí (2008). An excellent study of current DSGE models employed for forecasting can be found in Negro and Schorfheide (2012).

Chapter 2

Theoretical assumptions of the New Keynesian economics

New Keynesian economics strives to explain the nominal and real rigidities observed in the real economy by the microeconomics foundations of aggregated phenomena. Evenhough some of these theoretical assumptions, or at least their macroeconomic effects, can be found in introductory economics courses and basic textbooks, I provide a brief overview, since these assumptions are a crucial part of New Keynesian DSGE models and nominal rigidities are the point when classical dichotomy breaks down - if nominal values can affect real values.

2.1 Theories of nominal and real rigidities

Sticky Nominal Wages and Prices

The first phenomenom examined by New Keynesian economists was nominal rigidity due to long-term contracts. Firstly, Fischer (1977) examined implications of long-term wage contracts on the effectivity of monetary policy and Phelps and Taylor (1977) examined implications of long-term price contracts on effectivity of monetary policy. They both concluded, that existence of long-term wage and/or price contracts can generate significant nominal rigidity and makes a space for monetary policy to be effective in stimulating output (and potentially welfare). According to Phelps (1990), the long-term wage contracts exist due to costs associated with time required to frequently negotiate wage between employees and employers (to find an equilibrium price (wage) between labor supply and labor demand.

Similiar arguments can hold for long-term price contracts, particularly for price negotiations between producers and retailers. If the negotiations are costly, it can be very convenient for both subjects to make a long-term contract.

Sticky Real Wages

In the New Classical economics, the labor market is cleared at the market-clearing real wage, which cannot explain involuntary unemployment. New Keynesian economics tries to explain involuntary unemployment resulting from the real wage rigidity, a situation where agents of labor supply (workers or employees) are not paid the market-clearing real wage.

The real wages rigidity can be explained in the New Keynesian economics framework primarily by three theories.

The first one is the Assymetric Information Model, where workers and firms enter into contract when managers of the firms have better information about firm's position in the market and then can pay workers a rigid real wage. For more, see Grossman and Hart (1981).

The second one is the Efficiency Wage Theory, where a portion of employers can pay to particular employees wage above the market-clearing wage in order to (i) raise their productivity, (ii) attract better workers (due to the Adverse Selection Model), (iii) reduce labor turnover (since searching for new staff is costly), and (iv) reduce workers slacking in situations when the costs of monitoring workers productivity are prohibitedly costly. All of the above mentioned reasons can be at least partly effectively assured by paying the worker real wages above the market-clearing level in order to generate incentives (efficency wage). The basic idea of efficency wages can be found in Solow (1979) and has been greatly expanded by Shapiro and Stiglitz (1984), and Akerlof and Yellen (1990).

The third one is the Implicit Contract Theory as developed in Baily (1974) and Azariadis (1975), which explains why there is lower labor turnover in labor markets even though the market-clearing process suggests much higher turnover. Because it could be very costly to lower real wages of workers and lower number of workers employed according to the competitive wage theory (particularly socially because workers in this model enter the contracts being risk-averse in respect to income and length of employment), most firms, in practice,make workers redundant and pay the unchanged price to remaining workers. Hence, the remaining workers are paid the real wage above the market-clearing level. According to Baily and Azaridis such practice (and contracts) leads to rigidity in real wage.

Mankiw Sticky Price Model: Menu Costs

A "menu costs" term is linked with Mankiw (1985). It is concerned with the idea of flexible price setting by firms and it is costs. Since optimality in means of setting a price which maximizes profit (or, at least, increases profit) requires a very frequent price changes which can be particularly costly. As it can be derived from the name of the phenomenom itself, to print a new menu in a restaurant can be costly and when optimality demands very frequent changes, costs can be prohibitedly high. As stated in Mankiw (1985) and further examined by Blanchard and Kiyotaki (1987), such nominal price rigidity due to menu costs generates negative aggregate demand externality which leads to "significant" loss of agrregate output and employment, that generates large business cycle fluctuations.

2.2 Modeling the Inflation Dynamics

The New Keynesian model of an economy can be, following Brissimis and Maginas (2006), represented basicly by three equations: the New Keynesian Phillips Curve, the New Keynesian IS-Curve and the Taylor Rule. Since it is not the aim of this study to examine and derive equations from the New Keynesian models (which is very advanced topic), I only briefly present a formal representation of the New Keynesian Phillips Curve and the Taylor Rule. Derivation of the New Keynesian IS-Curve from the DSGE model can be found in Galí (2008).

The new Keynesian Phillips Curve

Following Galí and Gertler (1999) and Galí (2005), the standard New Keynesian Phillips Curve is based on a model of price setting by monopolistically competitive firms, namely staggered price setting following Calvo (2007) . The Curve takes the form:

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \lambda\widehat{mc_t} \tag{2.1}$$

where current expectations of the next period's inflation are incorporated in $\beta E_t\{\pi_{t+1}\}$, which makes the standart New Keynesian Phillips Curve forward-looking. The second component $\widehat{mc_t}$ adds deviations of marginal cost from their steady state value with λ being a smoothing parameter.

For full derivation, see Galí (2008), for a review, see Roeger (2012).

Taylor Rule

Central bank behaviour is usually reduced to the Taylor Rule, according to which monetary policy succesfully holds the nominal interest rate at a target level (in "inflation targetting regime"). Hence:

$$i_t = \pi_t + r_t^* + a_\pi(\pi_t - \pi_t^*) + a_y(y_t - \bar{y}_t) \tag{2.2}$$

where i_t is the targeted nominal rate (e.g. the federal funds rate in the United Stated), π_t is the inflation rate (measured by the GDP deflator), π_t^* is the targeted inflation rate, r_t^* is the equilibrium real interest rate. y_t is the logarithm of real

GDP and $\bar{y}_t$ is the logarithmic value of potential output (estimated by linear trend or more sophisticated tools, i.e. Kalman filtering).

2.3 Criticism

There are number of critical reflections from various schools of economic thought regarding the New Keynesian economics (some of them were described in Chapter 1, namely Neo-Classical, New Classical economics, and post-Keynesian economics). Interestingly, the Austrian School of Economics critisized the New Keynesian economics and its models, but Nell (2010) assume a challenging for Austrian economists to begin the development of heterogenous agents in the general equilibrium models.

I have chosen to pin two critical reflections which are, in my own opinion, very interesting.

The first critical reflection comes from Robert Solow, who, being a neo-Keynesian economist, rejected the DSGE models with homogenous agents living for the infinitely long time. He, instead, proposes a heterogenous agents framework and calls for "empirically based macroeconomics" (see Solow, 2006).

The second reflection comes from Groessl and Fritsche (2010) and is summarized in the next section.

New Keynesian DSGE model and the IS-LM paradigm

In most of the literature describing the general or particular DSGE model, authors refer their dynamic IS-LM model to a static version of Hicks model. But it can be shown that the New Keynesian IS-Curve does not represent the equality of saving and investment.The basic feature of the Keynesian IS-Curve is an observable (and measurable) combination of interest ratse and aggregate outputs, where this combination bilance saving and investment. Considering the aggregate Euler equation of infinitely living households being used in DSGE models, it can be shown that it does, in fact, only express the ratio of future and current diferrence between the equilibrium level of national income and investments depends on the discount factor of a household (representative agent) , its parameter of risk-aversion and the real interest rate, r. This idea is further developed in Groessl and Fritsche (2010), where the authors concluded that this problem can be resolved by using an Overlapping Generations Model, where households lives at least for two periods with different behaviour in each of them, instead of Representative Agent Model, where households live for infinite time.

Chapter 3

Forecasting models

Forecasting models are, besides expert judgment, an important part of the forecasting process conducted by various institutions. The structure of these models vary from basic time series linear regression models, through autoregressive models and their expanded versions as vector autoregression models up to the optimizing agents framework which is today mostly represented by the dynamic stochastic general equilibrium models (DSGE). Over the past 15 years there has been remarkable development in DSGE models. Many central banks and international institutions have responded with an interest to build (or specify) their own DSGE model to support their forecasting process, policy analysis and monetary policy conduction. Some of these banks are: the Bank of Canada (ToTEM), the Bank of England (BEQM), the Central Bank of Chile (MAS), the Central Reserve Bank of Peru (MEGA-D), the European Central Bank (NAWM), the Norges Bank (NEMO), the Sveriges Riksbank (RAMSES), the US Federal Reserve (SIGMA) and the International Monetary Fund (GEM, GFM). Multilateral institutions like the IMF have developed their own DSGE models for policy analysis (ie GEM, GFM). For review, see Tovar (2008).

3.1 DSGE models in the Czech Republic

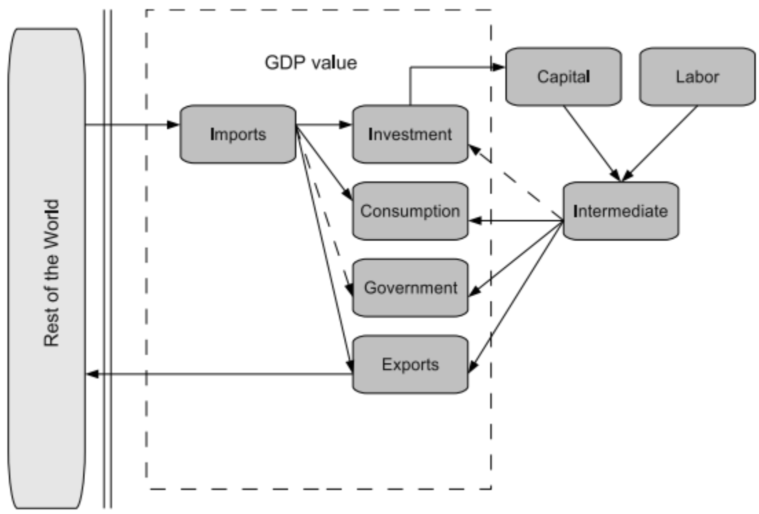
3.1.1 g3 model of the Czech National Bank

The forecasting and policy analysis system (FPSA) of the Czech National Bank is an important part of its monetary policy operation. FPSA consists of two components: expert judgment (being personally conducted by an analyst team) and forecastings tools compounded from formal economic and econometric models. These models can be split regarding the horizon of demanded forecast. For the short term forecast (usually one quarter ahead), the institution employs mostly expert judgment and econometric models based on autoregression, particularly Vector autoregression models. For near-term and medium-term forecasts, the forecasting process is centered on a core structural model. Until July 2008, the institution used the Quarterly Projection Model, which was a New Keynesian gap model oriented to support the inflation-targeting regime. Although the Quarterly Projection Model was in some way structural, there were still some ad-hoc equipped features and it is not possible to recognize it as a DSGE model (for detailed analysis see Coats et al. (2003). In July 2008, it had been replaced by the g3 model in the role of the core model. The g3 model is from the family of DSGE models, being generally structural and allowing complex policy analysis. The g3 model has been built particularly on the work of Christiano et al. (2005) and Smets and Wouters (2007).

The model is built on the model-consistent national accounting of all stock and flows (as summarized in Figure 3.1. Using the g3 model, changes of all GDP components are predicted. A very detailed description of the model structure can be found in Andrle et. al (2009).

Since the switch from the QPM to the g3 model can be a very significant advantage in the forecasting process of the CNB, I will test the accuracy of predictions of the CNB in Chapter 4.

Figure 3.1: Flow of goods and components in the g3 model



Source: the Czech National Bank

3.1.2 HUBERT model of the Ministry of Finance of the Czech Republic

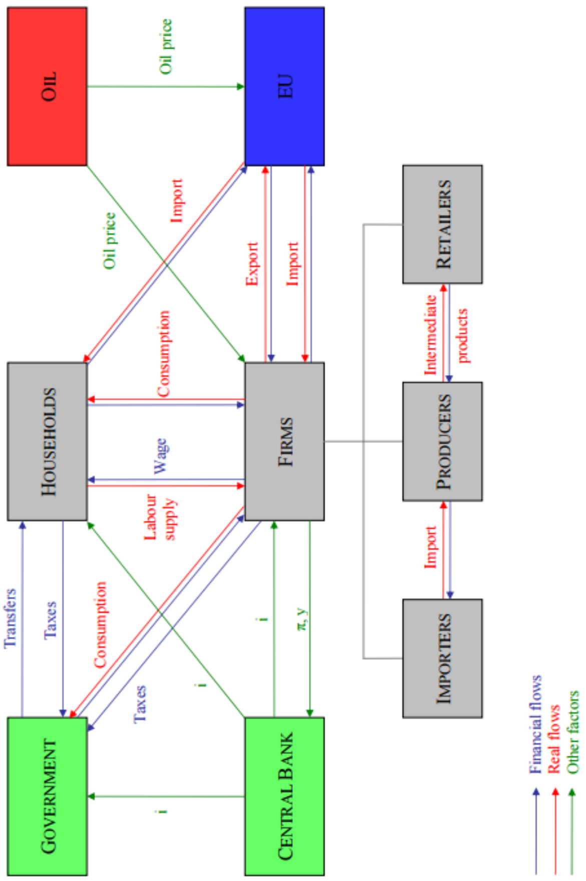
The Ministry of Finance of the Czech Republic (MFCR) developed its first DSGE model, named HUBERT, in 2009. Its specification can be found in Štork, Závacká and Vávra (2009). The first version was a relatively simple DSGE model (international trade has been modelled only by net exports). In 2012, the model has been extended and now international trade is divided into export and import sides. The model is also structural, similarly to the g3 model. Its structure is summarized in Figure 3.2. HUBERT is also used as a core prediction model, but is more oriented on predictions of government behaviour in the economy and is not so complex in modelling households and firms (Alyiev, Bobková and Štork, 2012).

Interestingly, the MFCR organizes some kind of a forecasters meeting which is called "Kolokvium" and takes a place twice a year. The MFCR invites 17 main institutions that makes forecasts about future macroeconomical development (notably the Czech National Bank, Česká spořitelna, Komerční banka, Uni Credit Bank, OECD, IMF and CERGE-EI).

These meetings are not public, and the results are only published in very reduced form, where they only presents the highest prediction, the lowest prediction of given macroeconomical variables and the prediction of the MFCR. The results can be found at "http://www.mfcr.cz" Although the results are not presented in its full form, I suppose it could be a significant advantage in the forecasting process of the MFCR.

Since the MFCR may have a significant advantage in employing the DSGE model in its forecasting process, I will test the accuracy of predictions of the MFCR in Chapter 4.

Figure 3.2: Flow of goods and components in the HUBERT model



Source: the Ministry of Finance of the Czech Republic

3.2 Non-DSGE models in the Czech Republic

The commercial banks and other institutions doing their own research and forecasting do not employ the DSGE models (or, at least, not officially). Searching for information about its forecasting process was very diffiicult, because researched commercial banks, namely Česká spořitelna (ČSAS), Komerční banka (KB) and Raiffeisen bank do not officially publish such information. Looking at the official materials, they only present very general information about their forecasting process (mostly emphasizing expert judgment and "some models"). Most probably they use a combination of expert judgment and autoregression models. Eventhough this technical background is not known, I can still perform tests based on acquired predictions of CSAS and KB, evalute their accuracy and compare them. Then it will be possible to see if these two commercial banks have a disadvantage in their forecasting process since they do not employ a DSGE model. This will be performed in Chapter 4.

Chapter 4

Econometrical testing

4.1 Research hypothesis

The research hypothesis states that the prediction error of key macroeconomic indicators has a statistically significantly improvement after the switch to the g3 model in the forecasts of the Czech National Bank, which happened in July 2008 and that the g3 model is a forecasting advantage (producing lower prediction errors) compared to commercial banks, represented by Česká spořitelna (CSAS) and Komerční banka (KB). Taking into account a horizont in which the predictions are made, meaning that prediction made in 1Q2008 may influence the mean error of prediction for the period up to 4Q2010. The prediction errors will be also computed for the Ministry of Finance of the Czech Republic, since the institution uses a DSGE model (named HUBERT) from the year 2009. Then, the results will be compared and evaluated. This hypothesis is based on theoretical assumptions presented in Chapter 1, namely that the structural model (DSGE model) theoretically and pratically overcomes non-structural models.

4.2 Data

There are two types of data which will be used in the analysis. First are economic indicators in time t, as measured by the Czech Statistical Office. Second are predictions of these indicators. These predictions are taken from the official documents released by particular institutions. For the Czech National Bank, predictions are taken from the Inflation report ("Zpráva o inflaci") which is released quarterly and contains predictions up to the period $q + 10$ (where q represents a quarter of the year, hence $q(1, 2, ..., 40)$, where $1 =$ 1st quarter of year 2005 (1Q2005) and $40 =$ 4th quarter of year 2014 (4Q2014). For the Ministry of Finance, predictions are taken from the Macroeconomic prediction ("Makroekonomická predikce") which is also released quarterly, but presents predictions for a entire year up to the period $t+4$, where t represents a year, hence $t(1,2,...,10)$. It is obvious, that $t=4q$.

For CSAS, predictions are taken from "Makroprognóza', which is available online at : http://www.investicnicentrum.cz . This document is not released regularly (but approximately quarterly) and contains predictions up to the period $t+3$,

For Komercni banka, predictions are taken from "Makroekonomická prognóza" which is available online at: http://www.kb.cz/cs/o-bance/tiskove-centrum/tiskove-zpravy/index.shtml . This document is released annualy and contains prediction up to the period $t+4$.

Due to the limited access to predictions of the latter two institutions, I only had been able to find prediction series from the year 2008 to 2014.

The number of acquired predictions for a given institution and period is summarized in Table 4.1 .

Table 4.1: Number of acquired predictions n for period t

Period (years)	Institution			
	CNB	MFCR	CSAS	KB
2005	32	4	3	4
2006	31	4	4	3
2007	29	6	4	2
2008	36	5	3	3
2009	41	4	2	4
2010	35	6	4	4
2011	32	5	3	3
2012	38	8	4	5
2013	36	4	4	4
2014	45	7	5	6

In my research, I evaluate the quality of predictions of key macroenomic indicators, which are described in Table 4.2.

Table 4.2: Key Macroeconomic Indicators

Indicator	Description
GDP	Gross Domestic Product
C^h	Households consumption
C^g	Government consumption
K	Gross capital formation
X	Exports to foreign economies
M	Imports to domestic economy
CPI	Inflation as measured by consumer price index
U	General unemployment rate

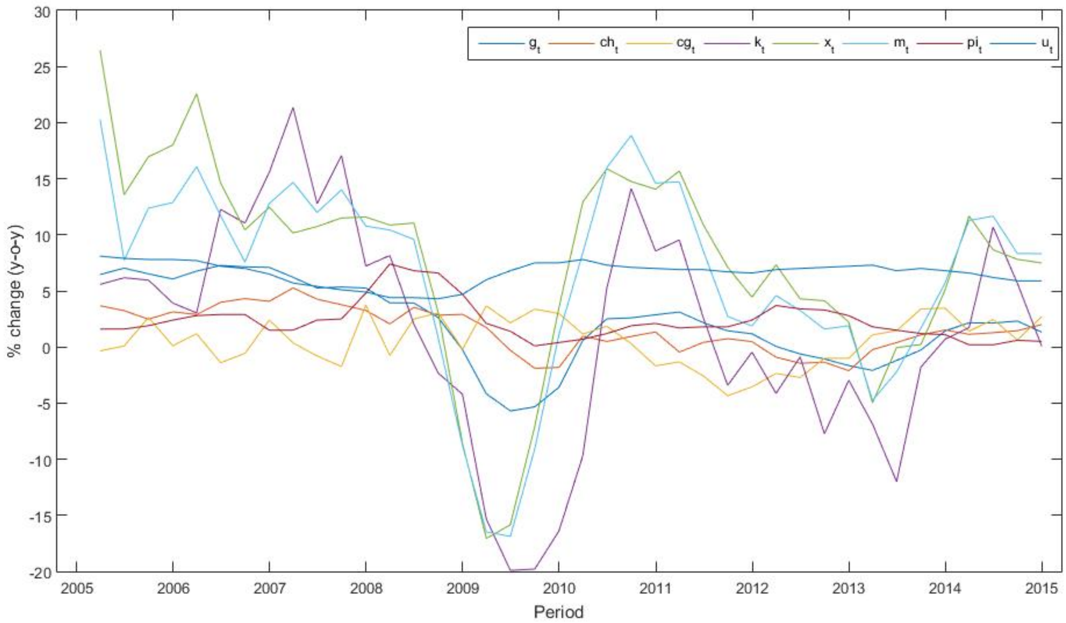
Because the predictions are expressed in percentage growth, indicators need to be expressed in the same way, hence for the research, I will treat indicators as variables and it will be used in the type of measurement described in Table 4.3.

Table 4.3: Used variables

i	Variab.	Description
1	g_t	Percentage change of GDP in time t compared to q-4 (y-o-y index), measured by expenditure in constant prices and seasonally adjusted
2	ch_t	Percentage change of Households consumption in time t compared to q-4 (y-o-y index), measured by expenditure in constant prices and seasonally adjusted.
3	cg_t	Percentage change of Government consumption in time t compared to q-4 (y-o-y index), measured by expenditure in constant prices and seasonally adjusted.
4	k_t	Percentage change of K in time t compared to q-4 (y-o-y index), measured by expenditure in constant prices and seasonally adjusted.
5	x_t	Percentage change of X in time t compared to q-4 (y-o-y index), measured by expenditure in constant prices and seasonally adjusted.
6	m_t	Percentage change of M in time t compared to q-4 (y-o-y index), measured by expenditure in constant prices and seasonally adjusted.
7	π_t	Percentage change of CPI in time t compared to q-4 (y-o-y index).
8	u_t	Unemployment rate as general rate of unemployment according to methodics used by the Ministry of Labor and Social Affairs of the Czech Republic.

Figure 4.1 plots the time series of all variables expressed in Table 4.3. .Perfoming a simple data verification from a look at the graph, it can be seen that gross capital formation is, in time, more volatile than consumption which is, according to Mankiw (2008), coherent with macroenomic theory.

Figure 4.1: Time series of g_t, ch_t, cg_t, k_t, x_t, m_t, π_t and u_t



Source: Czech Statistical Office

4.3 Method

4.3.1 Prediction errors

Prediction errors are computed using the Root Mean Square Error formula:

$$RMSE_{t,i} = \sqrt{\frac{\sum_{k=1}^{n} (\hat{y}_{k,t,i} - y_{t,i})^2}{n}} \tag{4.1}$$

which is a more general version of Hyndman and Koehler (2006) , and where t is the time period for which y_i is predicted, n is the total number of predictions acquired for $y_{t,i}$, the numbers of predictions acquired are summarized in Table 4.1 k is the order of acquired prediction and i is the variable predicted (see i in Table 4.3 for indexation).

For simplicity, $RMSE_{t,i}$ will be referred as $i_{r,t}$ regarding the indexation in Table 4.3. Hence RMSE of g_t, formally $RMSE_{t,1}$ will be referred to as $g_{r,t}$. This holds for all 8 variables in the text. Only in graphical expressions, the $i_{r,t}$ can be referred without a time index, since it is already indexed by its position between the axes (hence in graphical expression $g_{r,t}$ can be in the legend simply noted as g_r).

4.3.2 Test for structural change

Chow test

The Chow test is a widely used technique to test both the robustness of the econometrical model and to test for a structural change (break) in a time series predicted by estimators.

The suggested structural change in the forecasts of the Czech National Bank was to take place in 4Q2008 (the g3 model started to serve as the core prediction model, hence the first available predictions are for 4Q2008). I will perform a Chow test dividing time series of RMSE into two subsets: the first one will represent the RMSE of predictions before the demanded break and the latter will represent errors after the break took a place (beginning then in 4Q2008).

Basically, the Chow test compares residuals (the values not explained) of the regression model when it is left in a full state and when it is split into two models. If the residuals are in lower second case then in the prior model, there is a structural change in the time series and the analysis will perform better if it uses two models for different periods instead of one for the whole period.

The null hypothesis of the Chow test states that the coefficient of splitted models is equal (e.g.: $a_1 = a_2$, $b_1 = b_2$), whereas the alternative hypothesis rejects the null one if at least one coefficient is not equal.

Then, the hypothesis is tested using the equation for Chow statistic:

$$ch = \frac{S_c - (S_1 + S_2)/k}{(S_1 + S_2)/(N_1 + N_2 - 2k} \tag{4.2}$$

Then, ch is compared with F, referring to Fischer's probability distribution with degrees of freedom v:

$$v = N1 + N2 - 2k \tag{4.3}$$

Let the RMSE of g_t be determined by the RMSE of its components:

$$g_{r,t} = \mathbf{a}ch_{r,t} + \mathbf{b}cg_{r,t} + \mathbf{c}k_{r,t} + \mathbf{d}x_{r,t} + \mathbf{e}m_{r,t} + \varepsilon \tag{4.4}$$

where ε is an indepentent and indentically distributed model error from a normal distribution with unknown variance. By dividing both data sets of RMSE for g_t and its components into $t_1 < 1Q2005; 4Q2008 >$ and $t_2(4Q2008; 2014 >$,

I model the dynamics of $g_{r,t}$ in the period t_1 and t_2 using two models (submodels of 4.4 as:

$$g_{r,t} = a_1 ch_{r,t} + b_1 cg_{r,t} + c_1 k_{r,t} + d_1 x_{r,t} + e_1 m_{r,t} + \varepsilon_1 \tag{4.5}$$

for the first period t_1.

And:

$$g_{r,t} = a_2 ch_{r,t} + b_2 cg_{r,t} + c_2 k_{r,t} + d_2 x_{r,t} + e_2 m_{r,t} + \varepsilon_2 \tag{4.6}$$

for the second period t_2.

Following a null hypothesis, all coefficients in both submodels have to be equal so there is no structural break. If the null hypothesis is rejected, there is a structural break in 4Q2008.

4.3.3 Hypothesis testing

Using methods of statistical inference, I can test a research hypothesis using a test for hypotheses about two means (Fay and Proschan, 2010).

The null hypothesis states that there is no difference between average errors in the first and second time periods, formally then:
H_0: $\mu_1 = \mu_2$,
whereas the alternative hypothesis states that the average error is higher in first time period (before the suggested structural change) compared to the second time period (after the structural change took a place, formally then:
H_1: $\mu_1 > \mu_2$,

where μ denotes an average prediction error (computed from all variables) in a given period. The relationship between μ and RMSE is that RMSE is computed from data samples (sample of acquired predictions), hence RMSE represents sample statistic and μ represents error in finite population of errors, this population is not known. Formally then: $\mu = E(\overline{RMSE})$

The most suitable test for statistical hypotheses testing is hypotheses about the fit of two means from two samples. Since the length of time series is not in first period higher than 30, nor it is in the second period, the test will follow a Student's probability distribution. Also, the equality of variance in both sets is not known, nor is the actual value of variance in finite population. This will be substituted by using the variance of data sets.

The test statistic is then computed using the equation:

$$t = \frac{\bar{x_1} - \bar{x_2}}{\sqrt{\frac{s_1^{'2}}{n_1} + \frac{s_2^{'2}}{n_2}}} \tag{4.7}$$

where n_1 and n_2 are the sample sizes, $\bar{x_1}$ and $\bar{x_2}$ are the sample means, and $s_1^{'2}$ and $s_2^{'2}$ are the sample variances.

The critical region $t > t_{1-\alpha,v}$ rejects the null hypothesis, where v stands for the degrees of freedom and is computed using:

$$v = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{(s_1^2/n_1)^2/(n_1-1) + (s_2^2/n_2)^2/(n_2-1)} \tag{4.8}$$

For using the test, the distribution of values in both data sets has to be from a normal distribution. This will be verified by the Chi-square goodness of fit test, which is an alternative to the Kolmogorov -Smirnow test (for a full equation and comparison see Snedecor & Cochran, 1989), where the null hypothesis states that the data set is from normal distribution and alternative hypothesis rejects accordance of data set with the normal distribution.

If the both data sets are not rejected, they can be tested using the equation above.

4.4 Results

4.4.1 Prediction errors

Czech National Bank

The root mean squared errors for predictions made by the CNB are summarized in Table 4.4.

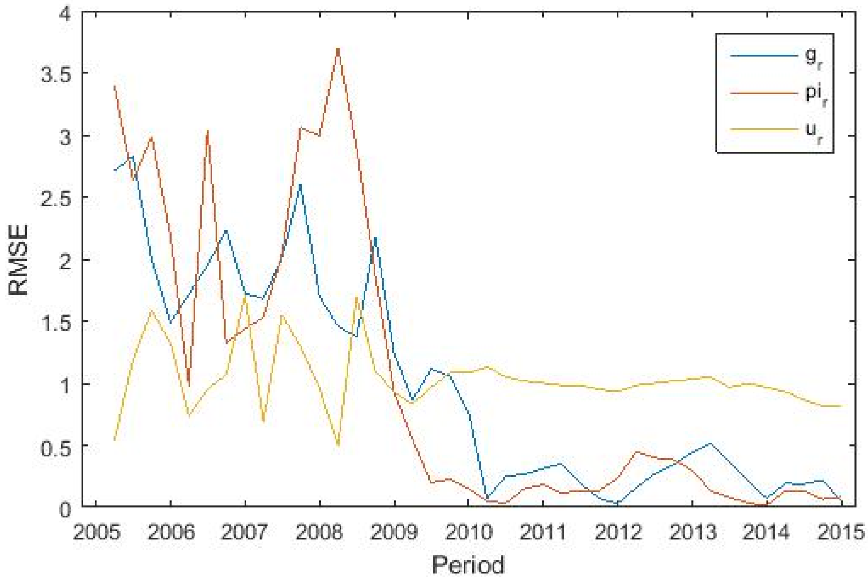
Table 4.4: RMSE of g_t ,c_t^h, c_t^g,k_t, x_t, m_t, π_t and u_t predicted by the CNB

	Period(t)	Root Mean Square Error							
		g_r	ch_r	cg_r	k_r	x_r	m_r	pi_r	u_r
CNB	1Q2005	2,71	0,60	0,52	2,00	2,62	3,83	3,39	0,54
	2Q2005	2,83	0,65	0,64	2,36	3,91	3,42	2,64	1,19
	3Q2005	2,00	0,42	0,93	2,52	3,47	3,09	2,99	1,58
	4Q2005	1,49	0,37	0,69	3,27	3,43	3,04	2,18	1,32
	1Q2006	1,72	0,46	0,68	2,08	4,21	2,40	0,98	0,73
	2Q2006	1,95	0,47	0,51	1,86	3,67	3,37	3,04	0,95
	3Q2006	2,24	0,52	0,66	2,02	3,68	2,38	1,32	1,07
	4Q2006	1,72	0,56	0,46	3,21	4,12	2,42	1,44	1,71
	1Q2007	1,68	0,36	0,77	2,86	4,03	3,12	1,53	0,69
	2Q2007	2,01	0,44	0,61	3,48	3,61	2,46	2,04	1,55
	3Q2007	2,60	0,69	0,59	3,35	2,89	3,58	3,06	1,29
	4Q2007	1,70	0,33	0,95	3,76	3,00	3,58	2,99	0,96
	1Q2008	1,46	0,75	0,40	3,73	4,17	3,43	3,70	0,50
	2Q2008	1,37	0,66	0,89	2,51	2,61	2,54	2,90	1,70
	3Q2008	2,18	0,55	0,91	3,31	3,45	3,34	1,87	1,10
	4Q2008	1,24	0,59	0,84	2,22	2,87	3,12	0,93	0,93
	1Q2009	0,86	0,25	0,44	2,72	3,01	2,91	0,55	0,83
	2Q2009	1,12	0,32	0,19	3,48	2,81	2,98	0,20	0,97
	3Q2009	1,06	0,58	0,40	3,47	1,35	1,68	0,23	1,08
	4Q2009	0,76	0,47	0,33	2,90	0,42	0,02	0,15	1,08
	1Q2010	0,07	0,01	0,02	1,78	1,99	1,23	0,05	1,13
	2Q2010	0,25	0,08	0,14	0,71	2,48	2,50	0,03	1,05
	3Q2010	0,27	0,01	0,12	2,19	2,29	2,98	0,15	1,02
	4Q2010	0,31	0,06	0,45	1,26	2,18	2,27	0,18	1,00
	1Q2011	0,35	0,24	0,39	1,42	2,45	2,29	0,12	0,98
	2Q2011	0,20	0,10	0,60	0,27	1,65	1,26	0,13	0,98
	3Q2011	0,07	0,04	0,89	0,74	1,02	0,29	0,13	0,95
	4Q2011	0,03	0,09	0,76	0,24	0,57	0,15	0,23	0,93
	1Q2012	0,16	0,32	0,56	0,85	1,05	0,60	0,45	0,98
	2Q2012	0,27	0,41	0,62	0,31	0,55	0,38	0,40	1,00
	3Q2012	0,34	0,39	0,33	1,46	0,52	0,10	0,38	1,02
	4Q2012	0,44	0,52	0,33	0,66	0,20	0,15	0,30	1,03
	1Q2013	0,51	0,20	0,02	1,31	1,00	0,96	0,13	1,05
	2Q2013	0,37	0,10	0,07	2,17	0,18	0,54	0,08	0,97
	3Q2013	0,21	0,01	0,40	0,46	0,13	0,11	0,03	1,00
	4Q2013	0,07	0,09	0,41	0,05	0,69	0,79	0,02	0,97
	1Q2014	0,19	0,02	0,07	0,12	1,78	1,71	0,13	0,93
	2Q2014	0,19	0,05	0,24	1,61	1,28	1,78	0,13	0,87
	3Q2014	0,22	0,08	0,06	0,78	1,14	1,22	0,07	0,82
	4Q2014	0,05	0,17	0,29	0,16	1,08	1,22	0,08	0,82

Note: Author's calculations, MATLAB 8

Taking the computed values into the graph, Figure 4.2 shows that there is an observable decrease in erorrs for g_t and π_t but u_t after the 4Q2010, although there is still a linear trend with a length of 4.

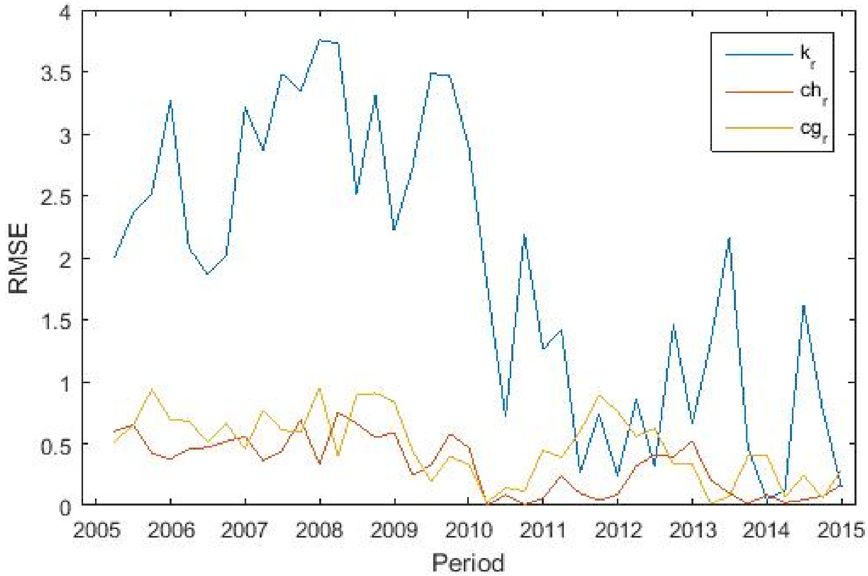
Figure 4.2: RMSE of g_t,π_t and u_t predicted by the CNB



Note: Author's calculations, MATLAB 8

Figure 4.3 plots root mean square errors of predictions of gross capital formation, household consumption and government consumption. It is clearly observable that even predictions for gross capital formation are more volatile then predictions of both consumption indicators. Despite of remaining volatility, there is an strong decrease of error levels between 2Q2009 and 4Q2010. This is in accordance with a research hypothesis where there is a supposed break in the last quarter of year 2010. Looking at RMSE of both consumptions, there is very clear improvement after 2010. Only a dynamics of the government consumption returned back on prior error levels between 4Q2011 and 3Q2013. Presence of a linear trend with a length of $t = 4$ remained even in RMSE of these three variables.

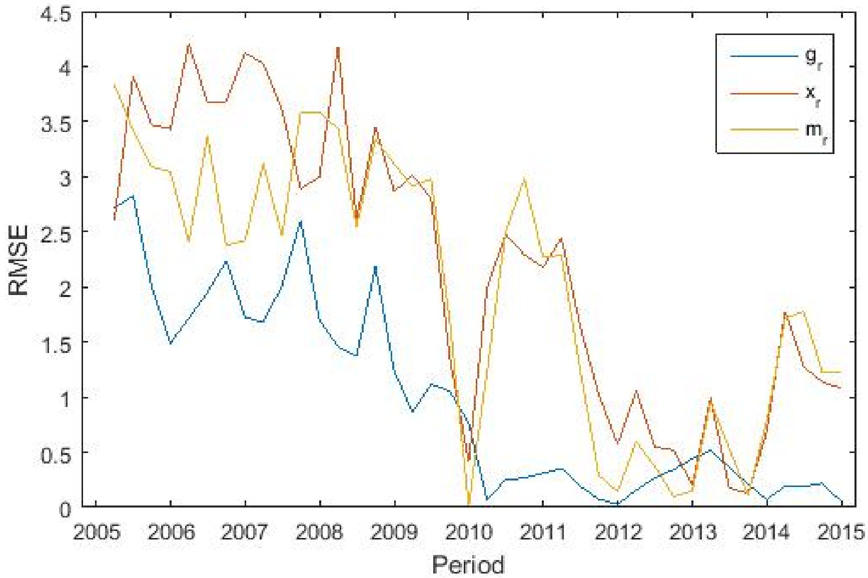
Figure 4.3: RMSE of k_t ,c_t^h and c_t^g predicted by the CNB



Note: Author's calculations, MATLAB 8

Finally, in Figure 4.4, I plot RMSE of remaining variables: real export and real import accompanied by RMSE of gross domestic product for comparison. Despite the presence of a break in 4Q2010, there is an upcoming increase of error levels for x_t and m_t right away between 1Q2011 and 4Q2012 where it returned to the decreased levels in 4Q2010. It seems that even though there was an strict improvement in 4Q2010, there was a process which influenced the behaviour of these two variables between 1Q2011 and 4Q2012 and which was not produced by a change of techniques of predictions but more likely by changes in an real economy. This assumption can be supported by the end of this trend after approximately 8 periods and then both RMSE remained in levels lower than in the period before 4Q2010 and lower than in the above mentioned trend. Similiarl to the Figure 4.3, there remained a presence of a long term linear trend with a lenth of $t = 4$.

Figure 4.4: RMSE of g_t,x_t and m_t predicted by the CNB



Note: Author's calculations, MATLAB 8

Ministry of Finance

Table 4.5 summarizes computed the root mean square errors for the Ministry of Finance of the Czech Republic. RMSE has been computed for 4 variables: g_t , ch_t, cg_t and k_t with its computed RMSE denoted by r appendiced in the name of the variable. All other variables have been omitted because the MFCR does not predict the π_t as measured by the CPI but only predicts an average rate of inflation, which is not predicted by the CNB. MFCR also does not predict x_t and m_t at all, only an average increase of GDP due to a change in international trade (net exports). RMSE of u_t has not been computed because it is predicted via a different method of measurement (MFCR does not predict average rate of unemployment according the MPSV method but according the CSU method) . It is easy to see even from the table that there have been no improvements in the year 2008, where the HUBERT model was officialy in use and not even after. In the next step, this will be also demonstrated graphically.

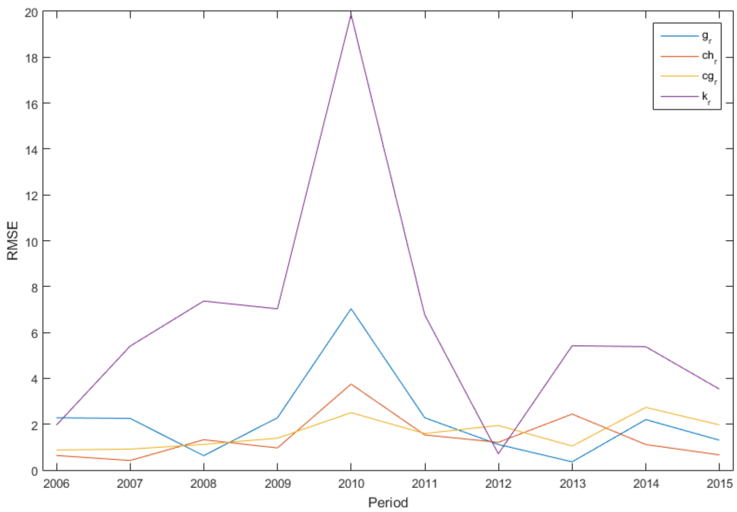
Table 4.5: RMSE for the Ministry of Finance

	Period (t)	Root Mean Square Error			
		g_r	ch_r	cg_r	k_r
MFCR	2005	2.2792	0,64	0,88	1,96
	2006	2.2536	0,42	0,91	5,40
	2007	0.6301	1,32	1,12	7,37
	2008	2.2829	0,97	1,39	7,03
	2009	7.0370	3,75	2,50	19,86
	2010	2.2829	1,54	1,59	6,77
	2011	1.1176	1,21	1,95	0,71
	2012	0.3595	2,44	1,05	5,42
	2013	2.2012	1,11	2,73	5,38
	2014	1.3044	0,66	1,97	3,53

Note: Author's calculations, MATLAB 8

Doing a graphical analysis of RMSE for the Ministry of Finance, I plot g_r ch_r, cg_r and k_r in Figure 4.5. It is graphically observable that there is no sign of overall improvement (decrease of mean errors) for any variable,

Figure 4.5: RMSE of g_t, ch_t, cg_t, and k_t predicted by the MFCR



Note: Author's calculations, MATLAB 8

Commercial banks

RMSE has been computed for Česká Spořitelna (CSAS) and Komerční banka (KB) in the time period from 2008 (included) to 2014 (included). Tables 4.6 and 4.7 summarize computed errors for CSAS and KB respectively.

Table 4.6: RMSE for the CSAS

	Period (t)	Root Mean Square Error				
		g_r	ch_r	k_r	pi_r	u_r
CSAS	2008	0,24	0,94	0,66	0,20	0,8
	2009	3,40	1,48	16,64	0,10	0,6
	2010	0,64	0,04	0,96	0,60	1
	2011	1,43	1,71	3,34	0,60	0,6
	2012	0,38	0,14	0,36	0,20	0,8
	2013	0,57	1,39	1,28	0,20	0,5
	2014	0,48	1,27	5,62	1,20	0

Note: Author's calculations, MATLAB 8

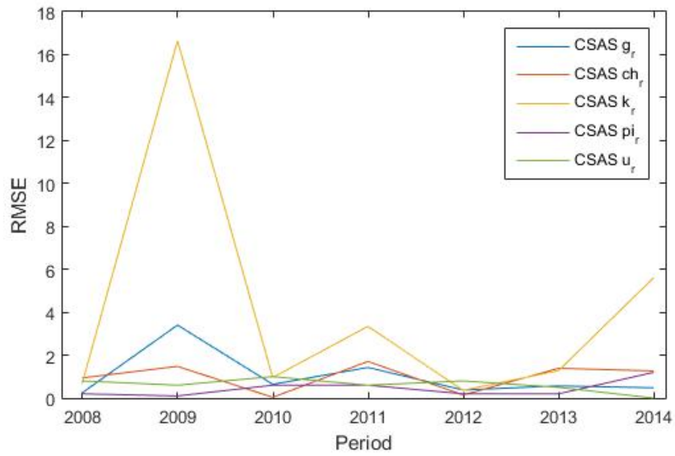
Table 4.7: RMSE for the KB

	Period (t)	Root Mean Square Error				
		g_r	ch_r	k_r	pi_r	u_r
KB	2008	0,26	0,14	0,96	0,1	1
	2009	1,10	2,88	12,34	0,6	1,8
	2010	0,74	1,56	7,56	0,1	2,1
	2011	0,27	0,89	2,76	0,2	1,7
	2012	0,44	0,44	0,84	0,3	1,3
	2013	0,43	0,29	2,98	0,9	0,4
	2014	0,58	0,27	4,62	1,1	0,6

Note: Author's calculations, MATLAB 8

Taking the computed values for CSAS in the graphical expression, Figure 4.6 shows that there is higher volatility in $g_{r,t}$ and $k_{r,t}$, while $ch_{r,t}$, $\pi_{r,t}$ and $u_{r,t}$ remain in stable error levels with an observable linear trend, long 2 periods (years).

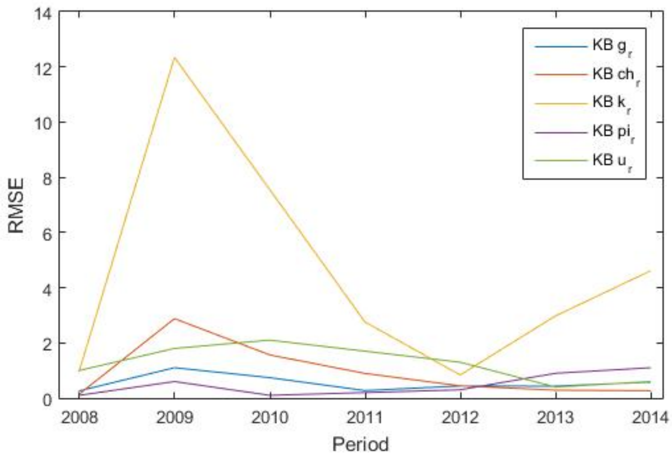
Figure 4.6: RMSE of g_t, ch_t, k_t, π_t and u_t predicted by the CSAS



Note: Author's calculations, MATLAB 8

In Figure 4.7, the computed values for KB shows graphically a higher volatility of $k_{r,t}$ (even the longer deflection of k_r in year 2009). The prediction error of ch_t is higher than in CSAS up to the year 2012, where it shows a decreasing trend and remains in lower levels compared to CSAS. The prediction error of π_t shows a linear trend between 2008 and 2011 where it changes to an increasing trend and continues rising up to 2014. The prediction error of g_t is relatively stable, oscilating between 0.1% and 0.8%. The prediction error of u_t shows a parabolic trend for the entire period.

Figure 4.7: RMSE of g_t, ch_t, k_t, π_t and u_t predicted by the KB

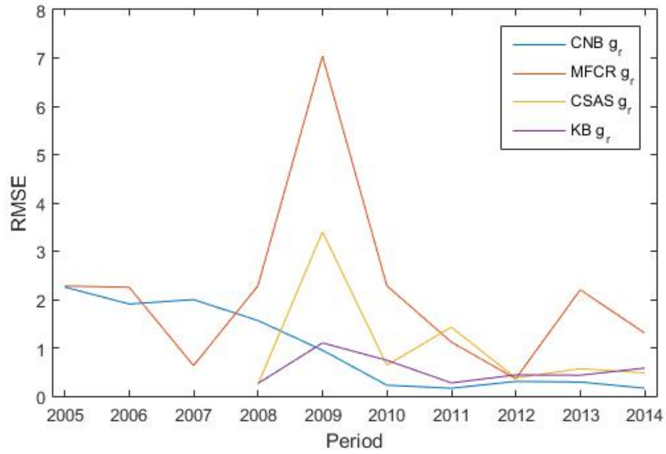


Note: Author's calculations, MATLAB 8

Comparison

Figure 4.8 plots $g_{t,r}$ of the CNB, MFCR, CSAS and KB. It can be easily seen in all institutions, but the CNB experienced a high prediction error in the year 2009. On the contrary, $g_{t,r}$ of the CNB continued decreasing even through the events of 2009. It can be easily evaluated from the graph that the worst predictions for $g_{r,t}$ have been made by the MFCR (even in the period 2012-2014 when HUBERT model was officialy in use).

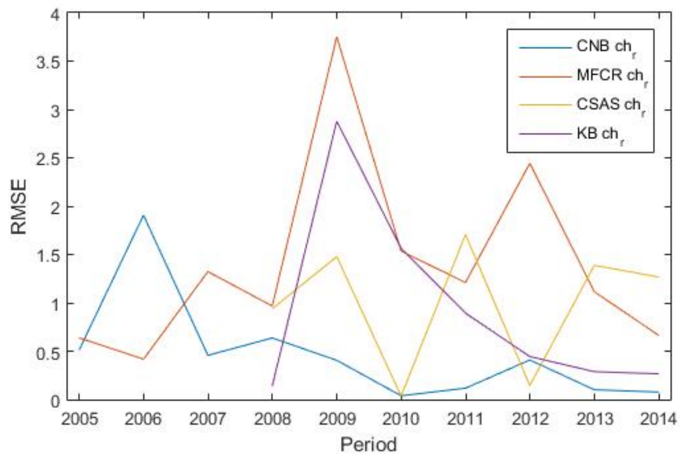
Figure 4.8: RMSE of g_t predicted by the CNB, MFCR, CSAS and KB



Note: Author's calculations, MATLAB 8

Figure 4.9 plots $ch_{t,r}$ of all researched institutions. Whereas the CNB pursues its decreasing trend of prediction error, the absoluted worst is the MFCR the CSAS approximately between the MFCR and the CNB with its linear trend of prediction long 2 periods (years). It is interesting to see that $ch_{t,r}$ of KB fastly decreases from the year 2009. Unfortunately, there are no previous predictions available, so I cannot perform further test for KB.

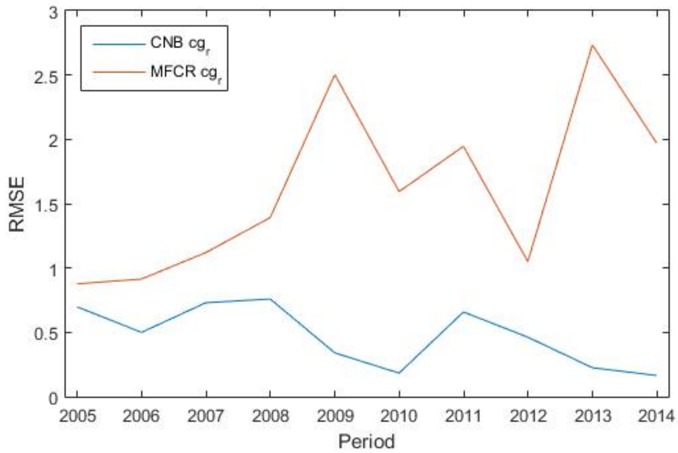
Figure 4.9: RMSE of ch_t predicted by the CNB, MFCR, CSAS and KB



Note: Author's calculations, MATLAB 8

Figure 4.10 plots $cg_{t,r}$ of the CNB and MFCR, which are the only two institutions that predict this variable. Atthough the CNB shows a linear trend with a length of 2, it stays way below the MFCR.

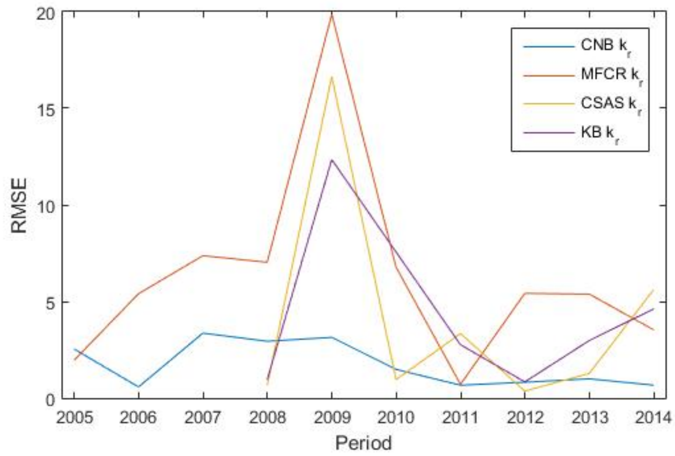
Figure 4.10: RMSE of cg_t predicted by the CNB and MFCR



Note: Author's calculations, MATLAB 8

Figure 4.11 plots $k_{t,r}$ of all institutions. Similar to the previous graph, CNB still pursues decrease of error with a notable decrease in 2009, the latter three institutions experienced a big deflection in the year 2009. Both commercial banks after the year 2009 almost copy their error, but are below the MFCR error (with an exception in 2011).

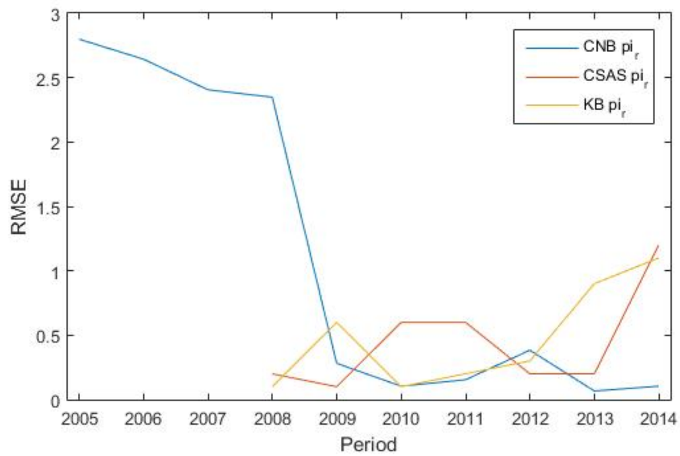
Figure 4.11: RMSE of k_t predicted by the CNB, MFCR, CSAS and KB



Note: Author's calculations, MATLAB 8

Figure 4.12 plots $\pi_{t,r}$ for all institutions except the Ministry of Finance of the Czech Republic. The CNB experience a notable decrease of error between 2008 and 2009. Although commercial banks experience more wild development with some increases and decreases, they mostly stay above the CNB level.

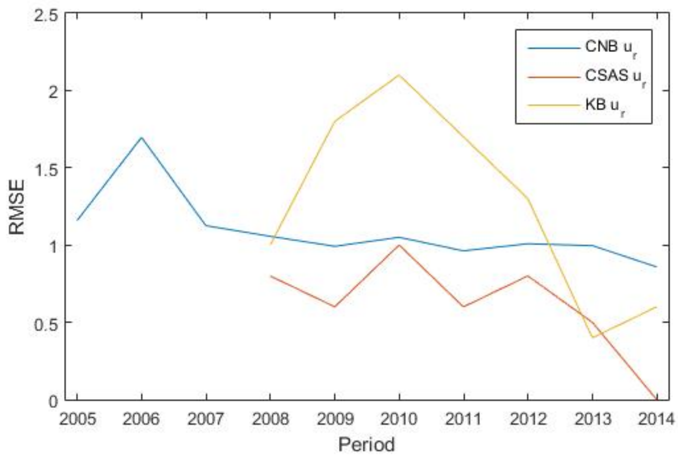
Figure 4.12: RMSE of π_t predicted by the CNB, CSAS and KB



Note: Author's calculations, MATLAB 8

Interestingly, Figure 4.13 plots the first variable, in which comparing its prediction errors, the CNB is not the absolute winner. The dynamics of $u_{t,r}$ shows that the CNB is between the CSAS and the KB, where the CSAS is an absolute winner comparing the period 2008-2014. The KB stayed above the CNB level up to the year 2013, where it experienced notable decrease but immediately there is a sign of rise of the error.

Figure 4.13: RMSE of u_t predicted by the CNB, CSAS and KB



Note: Author's calculations, MATLAB 8

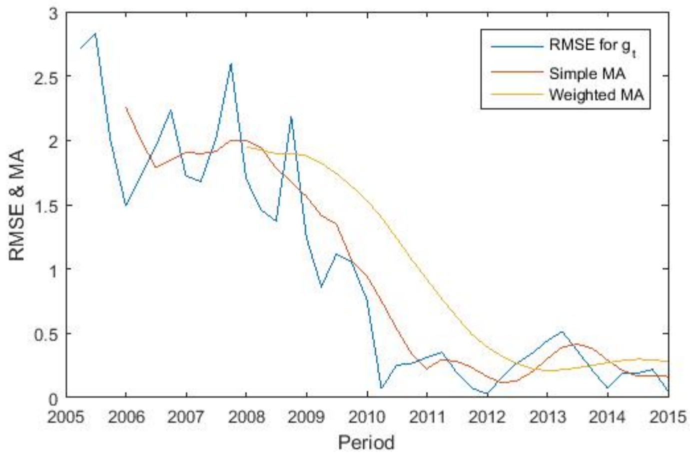
4.4.2 Test for structural change

Filtering

The Czech National Bank

Since the data plotted in Figure 4.2 shows a linear trend with a length of 4 periods (year quarters), I can detrend the data using a basic linear filter, and compute for the simple and weighted moving average of g_t. The root mean square errors and both moving averages are plotted in Figure 4.14:

Figure 4.14: RMSE & Moving Average of g_t for the CNB



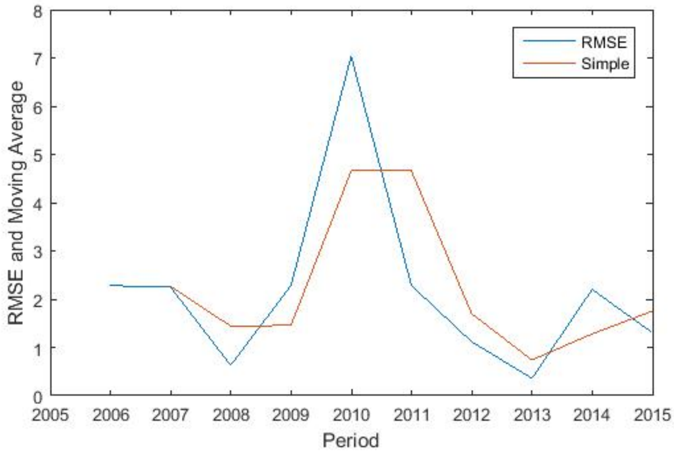
Note: Author's calculations, MATLAB 8

It can be easily seen from the graph that there is a decrease in RMSE after the year 2010, for which there has been still taken into account the predictions made before 3Q2008. This is confirmed both by the simple and weighted moving average, where the simple moving average shows a notable decrease in the 3Q2009 and weighted moving average shows an overall improvement of predictions quality beginning in 2Q2011.

Ministry of Finance of the Czech Republic

Taking the prediction errors of the MFCR in the graphical expression and computing for moving averages, Figure 4.15 demonstrates RMSE for the g_t, . It is clearly graphically observable that there is no structural break in the means of improvement in prediction quality of g_t, even after computing for simple moving average.

Figure 4.15: RMSE and Moving Average of g_t predicted by the MFCR

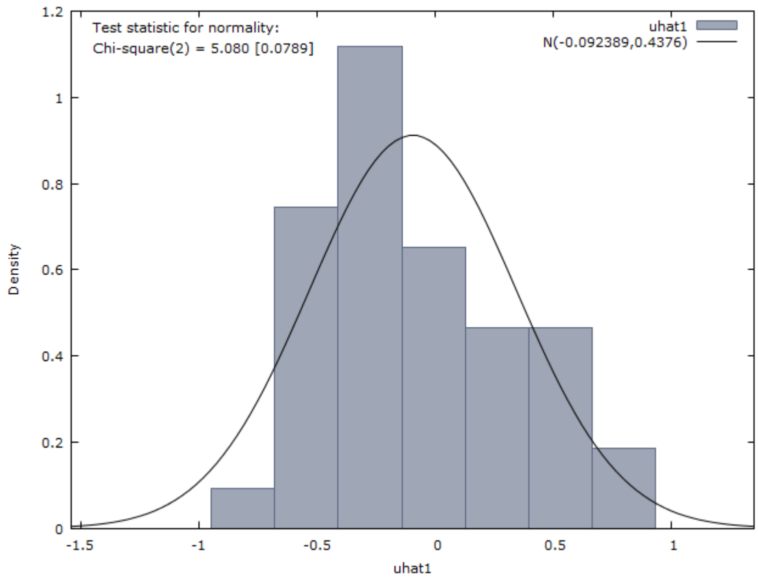


Note: Author's calculations, MATLAB 8

the Chow test

Equation 4.4 is now estimated using an Ordinary least squares method and tested for normality of residuals due to the assumption of the Chow test. The normality of residuals is tested using the Chi-square test for normality of residuals with $P - value$: 0.0789 hence, the null hypothesis of normality of residuals cannot be rejected. The results of the normality test is plotted in Figure 4.16.

Figure 4.16: Test for normality of residuals



Note: Author's calculations, Gretl 1.10

And the estimated equation takes the form:

$$\widehat{\text{g\_r}} = \underset{(0.44)}{1.74}\,\text{ch\_r} - \underset{(0.27)}{0.10}\,\text{cg\_r} - \underset{(0.09)}{0.01}\,\text{k\_r} + \underset{(0.12)}{0.11}\,\text{x\_r} + \underset{(0.13)}{0.17}\,\text{m\_r}$$

(standard errors in parentheses)

The entire estimated model with test results follows in Figure 4.17

Figure 4.17: Estimated model of $g_{r,t}$

Model 1: OLS, using observations 2005:1–2014:4 ($T = 40$)
Dependent variable: g_r

	Coefficient	Std. Error	t-ratio	p-value
ch_r	1.74665	0.439914	3.9704	0.0003
cg_r	−0.102100	0.274381	−0.3721	0.7121
k_r	−0.0134360	0.0910683	−0.1475	0.8836
x_r	0.110286	0.123990	0.8895	0.3798
m_r	0.171095	0.128628	1.3302	0.1921

Mean dependent var	0.982157	S.D. dependent var	0.871434
Sum squared resid	7.043557	S.E. of regression	0.448603
R^2	0.896725	Adjusted R^2	0.884922
$F(5, 35)$	60.77998	P-value(F)	2.91e–16
Log-likelihood	−22.02222	Akaike criterion	54.04444
Schwarz criterion	62.48883	Hannan–Quinn	57.09766
$\hat{\rho}$	0.578191	Durbin–Watson	0.759043

Test for normality of residual –
Null hypothesis: error is normally distributed
Test statistic: $\chi^2(2) = 5.07963$
with p-value = 0.0788811

Chow test for structural break at observation 2008:4 –
Null hypothesis: no structural break
Test statistic: $F(6, 29) = 10.0517$
with p-value = $P(F(6, 29) > 10.0517) = 5.12103\text{e-}006 \approx 0$

Note: Author's calculations, Gretl 1.10

Since the P-value of the Chow test is approximately 0, I reject the null hypothesis of no structural break. Given the result of the Chow test, there is a structural break in 4Q2008.

4.4.3 Hypothesis testing

The Czech National Bank

By dividing both data sets of RMSE of the CNB and computing for a mean value of RMSE of all variables but u_t into $t_1 < 2005; 2010 >$ and $t_2 < 2010; 2014 >$ I get two vectors: $X_1[24, 1]$ and $X_2[16, 1]$.
Variable u has been omitted because it is predicted by the DSGE model in different way (number of hours worked) and it the link between these two types of measurement is not clear. Elements of both vectors are summarized in Table 4.8

Table 4.8: Mean of RMSE(CNB) for g_t ,c_t^h, c_t^g,k_t, x_t, m_t and π_t

t	X1	t	X2
1Q2005	2,238228	1Q2011	1,036521
2Q2005	2,349967	2Q2011	0,598995
3Q2005	2,202357	3Q2011	0,45465
4Q2005	2,0698	4Q2011	0,295914
1Q2006	1,789704	1Q2012	0,570317
2Q2006	2,125368	2Q2012	0,419224
3Q2006	1,830972	3Q2012	0,504688
4Q2006	1,990263	4Q2012	0,372462
1Q2007	2,050671	1Q2013	0,59045
2Q2007	2,09314	2Q2013	0,500457
3Q2007	2,394986	3Q2013	0,194683
4Q2007	2,330427	4Q2013	0,30086
1Q2008	2,521478	1Q2014	0,575726
2Q2008	1,927325	2Q2014	0,754569
3Q2008	2,228755	3Q2014	0,50855
4Q2008	1,684845	4Q2014	0,435064
1Q2009	1,535505		
2Q2009	1,586208		
3Q2009	1,250824		
4Q2009	0,721876		
1Q2010	0,736338		
2Q2010	0,886181		
3Q2010	1,142917		
4Q2010	0,957683		

Note: Author's calculations, MATLAB 8

Both data sets are now tested for normality using a Chisquare goodness of fit test, where for both X_1 and X_2 the null hypothesis about normal distribution is not rejected on $\alpha = 0.05$.

Inserting all 4 variables into equation 4.7 and substituting n_1 and n_2 with the length of X_1 and X_2 respectively, I get the following test result.

Figure 4.18: t-test results for the Czech National Bank

```
Null hypothesis: Difference of means = 0

Sample 1:
 n = 24, mean = 1.77691, s.d. = 0.554225
 standard error of mean = 0.113131
 95% confidence interval for mean: 1.54288 to 2.01094

Sample 2:
 n = 17, mean = 0.533577, s.d. = 0.22013
 standard error of mean = 0.0533893
 95% confidence interval for mean: 0.420397 to 0.646758

Test statistic: t(32) = (1.77691 - 0.533577)/0.125096 = 9.93904
Two-tailed p-value = 2.632e-011
(one-tailed = 1.316e-011)
```

Note: Author's calculations, Gretl 1.10

Since the P-value ≈ 0, I reject the null hypothesis about equality of means on $\alpha = 0.05$ in behalf of H_1. The means are not equal. The mean in the first period is higher than in the second period.

The final result is then that the average prediction error has improved in period t_2 (following after the 4Q2010).

Ministry of Finance of the Czech Republic

By dividing both data sets of RMSE for MFCR and computing for a mean value of RMSE of all variables but u_t into $t_1 < 2005; 2010 >$ and $t_2(2010; 2014 >$ I get two vectors: $Z_1[6,1]$ and $Z_2[4,1]$. Variable u has been omitted due to same reason expressed in previous section.
The elements of both vectors are summarized in Table 4.9

Table 4.9: Mean of RMSE(MFCR) for g_t ,c_t^h, c_t^g and k_t

t	Z1	t	Z2
2005	1,1583	2010	3,2997
2006	2,2442	2011	1,2884
2007	3,2709	2012	2,9705
2008	3,1296	2013	3,0762
2009	8,7046	2014	2,0546

Note: Author's calculations, MATLAB 8

Both data sets are now tested for normality using a Chisquare goodness of fit test, where for both Z_1 and Z_2 the null hypothesis about normal distribution is not rejected on $\alpha = 0.05$.

Figure 4.19: t-test results for the MFCR

```
Null hypothesis: Difference of means = 0

Sample 1:
 n = 6, mean = 3.63455, s.d. = 2.618
 standard error of mean = 1.06879
 95% confidence interval for mean: 0.887127 to 6.38197

Sample 2:
 n = 4, mean = 2.34742, s.d. = 0.841945
 standard error of mean = 0.420973
 95% confidence interval for mean: 1.0077 to 3.68715

Test statistic: t(6) = (3.63455 - 2.34742)/1.14871 = 1.12049
Two-tailed p-value = 0.3053
(one-tailed = 0.1527)
```

Note: Author's calculations, Gretl 1.10

Since the P-value is 0.1527 for one-tailed t-test, I cannot reject the null hypothesis about the equality of means on $\alpha = 0.05$. The means are equal, the average prediction error in first period is equal to the average prediction error in second period.

The final result is, then, that the average prediction error has not improved in period t_2 (following after the 4Q2010). Due to t-test, there is no structural break in the time series of prediction errors of the MFCR between the period t_1 and t_2. Employing the HUBERT model did not statistically significantly improve the average prediction error of the Ministry of Finance of the Czech Republic.

Conclusion

Finishing this study, I have concluded that the research topic is very important in the field of both theoretical and empirical economics. It enhanced my knowledge of theoretical economics, econometrical methods and I have learned new econometrical and research tools.

Even though there is a lot of criticism regarding the New Keynesian economics and DSGE models as described in Chapter 1 and 2, my study proved that the perfomance of a well structured DSGE model overcomes simpler methods based on time series analysis and expert judgment.

It has been evaluated that the Czech National Bank experienced a strong structural break when employed a DSGE model in its practice. Results also strongly suggested that the DSGE model has to be very well specified because for the Ministry of Finance of the Czech Republic, which uses a DSGE model as well, there was no structural break detected and the institution performed very poorly when compared to commercial banks and the Czech National Bank. This poor peformance may result from a poor model specification. This reflection is supported by the institution's official working papers as described in Chapter 3.

For commercial banks, it has been concluded that even though they do not use a sophisticated structural model, their predictions are still better than the predictions of the Ministry of Finance of the Czech Republic. Interestingly, in every variable tested, its prediction error shows a linear trend for commercial banks which may be caused by using models based on time series analysis.

Then the answer for the research hypothesis is that employing the DSGE model in forecasts of the Czech National Bank has statistically significantly improved their prediction performance.

In this study, I have succesfully reviewed and evaluated the theoretical approach of the New Keynesian economics and its models and the quality of predictions of macroeconomic indicators made by the Czech National Bank, the Ministry of Finance of the Czech Republic and commercial banks. This study contributed to economics science by providing an empirical evidence of perfomance of the DSGE models.

If I were not restricted by a very limited availability of forecasts of commercial banks, I would have enhanced my study with more sophisticated time series analysis. It would be also very challenging to test the DSGE model itself, for example, using impulse-response functions and simulated second moments comparison. This would make even better insight into the dynamics of the model, and its microeconomics foundations may be proved both empirically and formally.

List of Figures

List of Tables

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