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HOW DOES THE NEW KEYNESIAN PHILLIPS CURVE FORECAST THE RATE OF INFLATION IN THE CZECH ECONOMY?

diplomová práce

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

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DIPLOMA THESIS TOPIC

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Guides to writing a thesis:

1. In the thesis, I will focus on the behaviour of the rate of inflation, captured by the so-called New Keynesian Phillips Curve which is a crucial element of modern dynamic stochastic general equilibrium models. I will assess the issue in a broader framework given the relatively long history of the study of the relationship between the rate of inflation and the real economy within standard macroeconomic theory. I will use the generalised method of moments to estimate this relationship, following relevant theoretical and empirical literature. I will answer the headline question both in terms of statistical significance and instrumentality of the New Keynesian Phillips Curve in forecasting the rate of inflation in the Czech Republic, while handling with various specifications of the new Keynesian Phillips Curve, namely several ways of incorporating marginal costs into the model.

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Abstract

This analysis studies the phenomenon of the New Keynesian Phillips Curve – its inception from the RBC theory and DSGE modelling via incorporation of nominal rigidities, and its various specifications and empirical issues. The estimates on Czech macroeconomic data using the Generalised Method of Moments show that the hybrid New Keynesian Phillips Curve with the labour income share or the real unit labour cost as driving variables can be considered as an appropriate model describing inflation in the Czech Republic. Compared to other analyses, we show that the inflation process in the Czech Republic exhibits higher backwardness vis-a-vis other researchers' estimates based on US data.

Keywords: Inflation, New Keynesian Phillips Curve, Generalised Method of Moments

JEL classification: E31, E52

Abstrakt

Tato analýza se zabývá fenoménem nové keynesiánské phillipsovy křivky – jejím vznikem z teorie reálného hospodářského cyklu a DSGE modelů zakomponováním nominálním rigidit, jejími různými specifikacemi a empirickými problémy. Odhady na českých makroekonomických datech metodou zobecněných momentů ukazují, že hybridní novou keynesiánskou phillipsovu křivku používající jako řídící proměnné poměr příjmu práce a reálné mzdové náklady lze považovat za model, který je vhodný pro popis inflace v České republice. V porovnání s jinými analýzami, které odhadují novou keynesiánskou křivku na amerických datech, vykazuje inflační proces v České republice větší vliv vzadhledícího chování.

Klíčová slova: inflace, nová keynesiánská phillipsova křivka, metoda zobecněných momentů

JEL klasifikace: E31, E52

Contents

Introduction

Inflation has long stood in the centre of economic research. The original Phillips curve that in a simple and graphical manner related the price dynamics to real economic activity (the rate of unemployment) used to be one of holy grails of economics. However, the significance of the original Phillips curve sharply diminished in 1970's, as it was unable to deal with new economic phenomena due to its atheoretical nature.

The New Keynesian Phillips Curve (NKPC) that emerged from a combination of the Real Business Cycle theory with the existence of nominal rigidities in an environment of state-of-the-art Dynamic Stochastic General Equilibrium (DSGE) models brought new life into the study of relationship between inflation and the real economy. The NKPC is based on microeconomic grounds, i.e. decision making (optimising) of economic agents who are maximising their utility.

Several different specifications of the NKPC have been subject to study. In our analysis, we focus on the most important three versions of the NKPC: (1) the pure forward-looking NKPC that assumes current inflation is dependent on expected future inflation and a measure of real activity, (2) the hybrid NKPC that incorporates backward-looking components into the inflation equation, and (3) the open-economy NKPC with terms-of-trade as another driving variable.

We describe the three NKPC specifications and test them on Czech quarterly macroeconomic data to see, if – and how – they are able to explain the inflation process in the Czech Republic. Our findings support the hybrid NKPC as an apt model of inflation. On the other hand, results of our analysis in terms of the pure forward-looking NKPC and the open-economy NKPC are unfavourable.

The basic insight into the NKPC theory can be found in Galí and Gertler (1999), where the authors present both the pure forward-looking NKPC and the hybrid NKPC. The open-economy NKPC emerged from the analysis of Galí and Monacelli (2004). An interesting insight into the theoretical and empirical issues related with the NKPC might be found in Nason and Smith (2008).

This analysis is structured as follows: section 1 delivers discussion regarding the original Phillips curve and the challenges it struggled with. Then it presents the theoretical background of the New Keynesian Phillips Curve and its various specifications. Section 2 introduces the empirical issues that researchers – and this analysis, too – face in dealing with the NKPC. It focuses also on the Generalised Method of Moments that is used in the estimation process. Section 3 shows results of our estimates of the three different specifications of the NKPC. Conclusion sums up our findings.

1 Theoretical Background

1.1 The Classical Phillips Curve

1.1.1 Inception of the Phillips Curve

The original Phillips curve was presented in Phillips (1958), where Phillips described statistically detected links between unemployment and wage inflation in the United Kingdom in the years 1861-1957. Phillips stated that this confirmed the hypothesis that the rate of unemployment explains wage inflation. Phillips based this hypothesis on a simple, yet robust, idea of demand for labour meeting supply on a labour market with wage being the price. Ceteris paribus, excess (or increasing) demand for labour (say, in times of an economic expansion) should drive the price (wage) higher. This relationship between unemployment and wage inflation proved to be non-linear, with downward nominal wage frictions being the reason behind the convex shape of the estimated curve.

Although Phillips presented rather just a statistical and technical evidence of the relationship between unemployment and wage level in the corresponding period of time, in his concluding remarks he suggested that economic policy could manage or influence the rate of unemployment, i.e. a policy maker may set a level of demand which would lead to the desired rate of unemployment (and the wage rates appropriate to the Phillips curve relationship).

However, it was only an analysis by Samuelson and Solow (1960), which came with the well-known form of the Phillips curve as a relationship between price inflation and the rate of unemployment. It is this Samuelson’s and Solow’s specification that is mostly referred to as the classical Phillips curve. Samuelson and Solow first fitted the Phillips curve to the US data and found results, which were almost similar (although less stable) to the original Phillip’s curve that was based on English data. Also, Samuelson and Solow transformed the original Phillips curve into a relationship between unemployment and a change in a price index. And perhaps most importantly, they presented their findings to be an outright policy tool. According to Samuelson’s and

Solow's view, a policy maker can choose a level of inflation of, say, 4-5% in order to reduce the rate of unemployment toward 3%. On the other hand, a stable price level is consistent with some 5.5% unemployment.[1] It is worth noting though, that Samuelson and Solow warned that such a Phillips-curve-related trade-off would only hold in the short term (a few years, according to the authors). In the long term, the Samuelson's and Solow's Phillips curve could shift or alter its shape (due to institutional changes in the labour market or economic agents' adjusting expectations), losing its viability of an effective policy tool, the authors say.

1.1.2 The Critique of the Phillips Curve

The Phillips curve and the alleged possibility of the policy-invoked trade-off between inflation and unemployment soon started to be criticised. Notably, Milton Friedman (1968) spoke against using the Phillips curve as a long-run policy option and introduced the idea of natural rate of unemployment. According to Friedman, a policy maker may reduce the rate of unemployment via monetary-policy tools, but only in the short-run. Monetary easing (increase in the money supply) comes with costs, i.e. accelerating inflation. The definitive effect of a monetary stimulus is only a higher price level, as soon as the real variables return to their pre-shock levels. In Friedman's view, there is simply no long-run Phillips curve (or more precisely, Friedman's long-run Phillips curve is a vertical line), as economic agents are adapting their expectations to the changing environment. In the long run, the economy operates on its potential output and with its natural rate of unemployment, which depends mostly on institutional factors (e.g. flexibility of the labour market).

Phelps (1967) delivered an analogous critique of the classical Phillips curve, which he summarised as follows: *"[It] is reasonable to suppose that the participants in product and labour markets will learn to expect inflation (and the concomitant money wage trend) and that, as a consequence of their rational, anticipatory behaviour, the Phillips curve will gradually shift upward (in a uniform vertical displacement) by the full amount of the newly expected and previously actual rate of inflation."* (pp. 255)

[1] These figures are used by Samuelson and Solow.

Indeed, the "classical" Phillips curve soon started to exhibit several significant inconsistencies vis-a-vis the economic reality. In 1970's, the relationship between the rate of inflation and real economic variables decisively diverted from the predictions of the Phillips curve. Namely, the oil crises of 1973 and 1979 brought about elevated inflation, while economic activity remained subdued. The phenomena of accelerating inflation and stagflation started to challenge the classical Phillips curve, as it was unable to face and explain these new issues due to the purely static and atheoretical nature of the relationship and its underlying idea. In terms of practical use, the Phillips curve lost ground in evaluating economic policies. The trade-off between inflation and real economic variables – as was described by the classical Phillips curve – broke apart.

Lucas (1976) addressed this issue in his broader critique of purely econometrical models with no theoretical (microeconomic) background and specifically targeted the Phillips curve. Lucas argues that economic policies (e.g. a stimulus aiming to reduce unemployment) necessarily affect behaviour and expectation of economic agents, thus causing a change in parameters of aggregate macroeconomic policy-evaluating models (that lead to e.g. a shift of the Phillips curve or a change in its slope). Therefore, such models that are based only on ad hoc macroeconomic and statistical relationships are incompetent for policy making, in Lucas' view.

In result of its inability to explain the economic phenomena of 1970's and the onset of models based on rather microeconomic foundations and Lucas' rational expectations approach, the popularity of the original Phillips curve largely diminished.

1.2 The New Keynesian Phillips Curve

1.2.1 DSGE Modelling and RBC Theory

Contrary to the original Phillips curve, the New Keynesian Phillips curve is (in most of its specifications) derived from theoretical models based on microeconomic decisions of economic agents with rational expectations. Therefore, it is not subject to the aforementioned Lucas critique, and takes into account some ideas of Friedman and Phelps, too. The NKPC arises from the state-of-the-art DSGE economic modelling approach, which is anchored in the real business cycle theory and the new Keynesian economics.

The influential paper by Kydland and Prescott (1982) resulted in a formation of the real business cycle theory. RBC models feature microeconomic framework of economic agents' dynamic decisions that are aimed at maximising utility and are based on rational expectations. This environment with microeconomic characteristics underlies the aggregated (macroeconomic) behaviour of a hypothetical economy in the real business cycle theory. RBC models lack any frictions (wages and prices are fully flexible) and, in most cases, converge (or should converge) to a dynamic stochastic general equilibrium (therefore these models started to be labelled as DSGE models).

The absence of nominal rigidities, however, results in full neutrality of money and impotence of monetary policy – indeed, this is one of the most important conclusions in the RBC theory. Simultaneously, real business cycle theory suggests an economy is always in equilibrium, i.e. that it operates on its full potential. Fluctuations of the economic output (business cycles) are being explained as fluctuations of the very potential output itself, given the absence of frictions in the economy. An economy thus cannot suffer from an output gap. For these reasons, RBC models cannot include any kind of relationship between inflation and real variables (any kind of a 'Phillips curve'). Consequently, RBC models' application for monetary and fiscal policy evaluation is somewhat limited, too.

1.2.2 The New Keynesian Approach

The New Keynesian framework emerged as a synthesis of the RBC and some of the traditional elements of the Keynesian approach. Imperfect competition (mainly monopolistic competition) and inelastic prices and/or wages are the most important extensions of RBC theory in the new Keynesian economics with respect to the policy-related implications, while the building blocks (utility-maximising economic agents, dynamic equilibrium) of the real business cycle models have remained virtually intact. The incorporation of the nominal rigidities allows for a possibility that an economy may operate with a positive or negative output gap in the short run.

Various ways of implementing nominal rigidities into economic models emerged over time in the New Keynesian framework. Roberts (1995) distinguishes two basic approaches: time-dependent and state-dependent stickiness of prices or wages. *"In state-dependent models, firms change prices when underlying determinants, such as demand and costs, reach certain bounds. In time-dependent models (...), firms set their prices for fixed period of time."* (pp. 976) According to Roberts, state-dependent models often lack closed and stable solution, and even may not guarantee the desired inflexibility of prices. Therefore, in line with Roberts and most work in the NKPC field, this analysis further deals only with time-dependent models.

From a different perspective, Nason and Smith (2008) point that the NKPC might be used either as a single-equation description of nature and dynamics of inflation, or it might constitute a part of a broader macroeconomic (DSGE) model. As we focus specifically on inflation characteristics, we take into account the former approach, i.e. the NKPC as a single equation.

Understanding the inflation process via the New Keynesian Phillips Curve framework can be beneficial for evaluation of various monetary-policy measures. Certain specifications of the NKPC incorporate structural parameters that take into account behavioural aspects of economic agents. If these specifications fit economic data well, policy makers get useful information regarding the very building blocks of economy, and thus can fine-tune e.g. policy responses to adverse economic shocks, Nason and Smith (2008) argue.

1.2.3 Models of Time-Dependent Price Stickiness

1.2.3.1 Taylor's Approach

Taylor (1979, 1980) builds on the ideas of Phelps (1970) and shows that existence of labour contracts may be the source of nominal rigidities. Taylor assumes that (nominal) wages are not being set in a continuous manner due to often costly and lengthy negotiations between employers and employees. Instead, wages are being adjusted only once in a specific period of time (e.g. most frequently on semi-annual or annual basis). In Taylor's model, wage contracts are valid for two periods of time; however, a half of the contracts are reset every period, so that contracts are overlapping themselves (for instance, this is corresponding to contracts that are valid for a year, of which a half is reset every six months). Wages are determined by their past level, the expectations over the wage level in the following period, and also by some measure of real activity (like excess demand in Taylor (1979), but output gap or the rate of unemployment may be used instead), with parameters defining the backwardness (stickiness) of the model or its forward-looking and demand-driven components.

The inertia of prices is caused by the fact that they are given either directly by the wage level or as a fixed mark-up over the wage costs of firms. Every time a half of the contracts is able to change, the new level of wages is set with respect to the actual price level, which incorporates also wages of the preceding period (due to the mark-up relationship between prices and wages).

Walsh (2009) puts the equation driving inflation in Taylor's model as follows:

$$\pi_t = E_t\pi_{t+1} + 2k(y_t + y_{t-1}) + \varepsilon_t \tag{1}$$

where the rate of inflation $\pi_t = p_t - p_{t-1}$ is given as the difference between (log) price level p in periods t and $t-1$. It is dependent on the expected rate of inflation π_t (with E_t being the expectations operator), and the change in log output y. The symbol ε_t denotes the error term.

Walsh (2009) also argues that Taylor's model implies there may not be persistence in the inflation rate, which is in opposition to the behaviour of inflation as seen in macroeconomic data. In other words, disinflation might be easy and relatively harmless in Taylor's model, which is often not the case in reality.

1.2.3.2 Fuhrer and Moore's Approach

Fuhrer and Moore (1995) address the problem of low inflation persistence generated by Taylor's model and develop their own model that tries to explain the inertia in the rate of inflation observed in the US. Walsh (2009) shows that in Fuhrer and Moore's approach, economic agents make decisions about real wages, not nominal wages like in Taylor's model. A part of real wages that is to be set in a given period of time depends on the current and expected level of all wage contracts (and a measure of economic activity or an economy's position in a business cycle, alike to Taylor's model). Therefore, inflation in Fuhrer and Moore's model is given by the following equation:

$$\pi_t = \frac{1}{2}(\pi_{t-1} + E_t\pi_{t+1}) + 2k(y_t + y_{t-1}) + \eta_t \tag{2}$$

where the error term is denoted as $\eta_t = -(\pi_t - E_{t-1}\pi_t)$, as Walsh (2009, pp. 229) shows. Clearly, in Fuhrer and Moore's approach, current inflation is dependent not only on future inflation, but also on past inflation, which provides the desired increased inflation inertia in the model.

However, Galí and Gertler (1999) remark that aggregation of models with deterministic time schedule of price changes, as it is the case in Taylor's and Fuhrer and Moore's staggered wage contracts models, is "cumbersome" with the model having to incorporate the pattern of price-stickiness (i.e. it must be specified that, for instance, a X-portion of firms are able to change their prices every Y periods – this is not very convenient for solving the models' equations). Therefore, Calvo's model has become more popular, as it allows for easier aggregation.

1.2.3.3 Calvo's Approach and the Resulting New Keynesian Phillips Curve

Among the simulations of price-stickiness, it has been the model by Calvo (1983), which has earned the most prominence. Calvo further developed the models of Phelps and Taylor via focusing on other possible microeconomic grounds of nominal rigidities.

Calvo divides his hypothetical economy into a production side and a demand side. The production side consists of infinite number of infinitely small firms filling a $[0, 1]$ interval, whose variable costs are zero – for the sake of simplicity. Firms set their prices that consist of marginal costs and a mark-up over these marginal costs. However, a firm is not allowed to reset its price in every moment of model's continuous time frame but only in case it observes a *signal*. Following Galí and Gertler (1999), this technically means that firms can adjust their prices with some externally-given probability $(1 - \theta)$ (Calvo himself market the probability of receiving the signal allowing changing the price with δ). As the probability is independent through time, $(1 - \theta)$ also denotes the fraction of firms that change price in a specific period. Conversely, θ is a degree of "price-stickiness" with average duration of a price being fixed determined by the term $\frac{1}{1-\theta}$. As an example, Galí and Gertler show that a price-stickiness of $\theta = 0.75$ in a quarterly model implies an average duration of prices of one year (every quarter there is a ¼ probability that a firm is allowed to change its price).

If we aggregate firms' behaviour in the Calvo model, we obtain the following dynamic inflation equation (Galí and Gertler (1999):

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t \tag{3}$$

where current inflation is dependent on expected future inflation and a measure of real activity x_t (marginal costs or an output gap). The coefficient β is a subjective discount factor that is lower than one, as Walsh (2009, pp. 227) argue, and the coefficient λ measuring the effects of real activity on inflation is given as

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta} \tag{4}$$

An increase in price-stickiness measured with θ thus decreases sensitivity of inflation to changes in marginal costs, i.e. to the effects of business cycle.

It is interesting to show along with Galí and Gertler (1999), that it is possible to iterate the inflation equation forward to get:

$$\pi_t = \lambda \sum_{\mathrm{k}=0}^{\infty} \beta^{\mathrm{k}} x_{t+k} \tag{5}$$

According to this baseline Calvo's model, current inflation is given by the sum of discounted future marginal costs. "*[As] firms are (a) monopolistic competitors that mark-up price over marginal costs, (b) forward looking, and (c) must lock into a price for (possibly) multiple periods, they base their pricing decisions on the expected future behaviour of marginal costs,*" Galí and Gertler (1999, pp. 200) state.

Walsh (2009) notes that Calvo's approach incorporates higher persistence of prices when compared to Taylor's approach. In Taylor's model with half of wage contracts being reset every period, no contract is valid for more than two periods. However, given the fact that prices are being changed with a certain probability in Calvo's model, some prices are stable for more than two periods, even with $\theta = 0.5$.

Nevertheless, Calvo's model and the resulting pure forward-looking NKPC experienced significant challenges when faced with actual economic data. The model struggled to explain high inflation persistence (despite Walsh (2009 statements) and its assumption that inflation leads real economic variables was not supported by observations, either. Its implications for monetary-policy analysis were also unsatisfactory, as this theory suggests disinflation can be achieved without any cost, if a central bank delivers a policy that keeps future output gaps at zero, Galí and Gertler (1999) and Vašíček (2009) argue.

1.2.3.4 The Hybrid New Keynesian Phillips Curve

Galí and Gertler (1999) show that the insufficient application of the pure forward-looking NKPC first resulted in a creation of a simple "hybrid" Phillips curve, where past inflation was added as a factor that helped to explain current inflation. The hybrid NKPC would therefore take a form

$$\pi_t = \delta x_t + (1-\phi)E_t\pi_{t+1} + \phi\pi_{t-1}, \tag{6}$$

where $\phi \in (0,1)$ denotes that current inflation is explained by a convex combination of past and expected inflation. However, this equation lacks any structural and/or microeconomic background. Thus, Galí and Gertler introduced a new framework in the Calvo-model space that resulted in an onset of a structural-based hybrid NKPC.

The authors let part of the firms in the model to use a backward-looking pricing mechanism, while the remaining firms stick to the pure forward-looking setting of prices. If the backward-looking firms are given the signal to reset their prices (with the probability of θ similarly to the original Calvo model), they use a simple rule of thumb in the pricing process, simplified e.g. by Vašíček (2009) as follows:

$$p_t^b = p_{t-1}^* + \pi_{t-1} \tag{7}$$

i.e. firms only adjust their previous prices for past realised inflation. As Vašíček argues, with price index being $p_t^* = \omega p_t^b + (1-\omega)p_t^f$ one can aggregate the model into the structural hybrid New Keynesian Phillips curve, and consequently this Galí and Gertler's structural-based hybrid New Keynesian Phillips curve takes shape

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f E_t\pi_{t+1} + \lambda x_t \tag{8}$$

where

$$\lambda = \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta + \omega(1-\theta(1-\beta))} \tag{9}$$

$$\gamma_f = \frac{\beta\theta}{\theta + \omega(1-\theta(1-\beta))} \tag{10}$$

$$\gamma_b = \frac{\omega}{\theta + \omega(1-\theta(1-\beta))} \tag{11}$$

Again, β is a subjective discount factor as an element of $(0,1)$ and θ denotes the price-stickiness (the share of firms that are forbidden from resetting prices in the specific period of time). The new parameter ω describes the share of backward-looking firms.

Clearly, if ω is calibrated to zero, i.e. if there are no backward looking firms, the inflation equation then takes form of the classic pure forward-looking NKPC. Therefore, the hybrid NKPC can be viewed as a generalised form of the classic NKPC.

1.2.3.5 New Keynesian Phillips Curve in a Small Open Economy

In a small open economy like the Czech Republic, external environment is an important driver of economic developments. Intuitively, cross-border changes in prices have a significant impact on small open economy's domestic price level and economic activity. In order to capture such effects and improve capabilities of the NKPC framework within data from small open economies, Galí and Monacelli (2004) introduce a model that in effect incorporates terms of trade as another driving variable in the New Keynesian Phillips Curve. This is shown in Mihailov, Rumler and Scharler (2008), where the authors rearrange Galí and Monacelli's outcomes into a more intuitive NKPC-like inflation equation:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t + \alpha(\Delta s_t - \beta E_t \Delta s_{t+1}) \tag{12}$$

where the third expression on the right-hand side determines the dependence of inflation on a change in discounted expected terms of trade $\beta E_t \Delta s_{t+1}$ vis-a-vis the realised change in terms of trade Δs_t weighted by the coefficient $\alpha \in [0,1]$ that measures the openness of an economy. In other words, the higher α, the more imported goods are consumed in the small open economy, and the higher effect of foreign price changes onto domestic inflation.

The structural coefficient λ that measures the relationship between inflation and real economic activity takes the form similar to that the traditional Calvo-based NKPC:

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta} \tag{13}$$

The mechanism of terms of trade influence on inflation is described by Mihailov, Rumler and Scharler (2008) as follows: "*[An] expected relative improvement in the terms of trade would stimulate expenditure switching to foreign goods, so that CPI inflation would be under upward pressure arising from the demand for imports. This pressure is stronger the higher is the degree of openness to trade, α.*" (pp. 6)

2 Empirical Issues

2.1 Econometric Specification

In our analysis, we focus on the three baseline specifications of the New Keynesian Phillips Curve – the original one resulting from the Calvo model:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t + \varepsilon_t \tag{14}$$

the hybrid NKPC developed by Galí and Gertler:

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda x_t + \varepsilon_t \tag{15}$$

and the small open economy NKPC presented in Mihailov, Rumler and Scharler (2008) and based on Galí and Monacelli (2004):

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t + \alpha(\Delta s_t - \beta E_t \Delta s_{t+1}) + \varepsilon_t \tag{16}$$

with their respective structural parameters as described above and added error terms.

In the econometric analysis, the focus will mainly be on the estimates of the structural (deep) parameters, and the comparison of these estimates to their expected levels (namely with respect to the subjective discount factor, or the subjective discount rate) or the results of estimations in the available and comparable literature. Also of importance will be the overall quality of the models' fit to data.

2.2 Generalised Method of Moments

In accordance with the most of relevant literature, the Generalised Method of Moments (GMM) is used in the estimation of the NKPCs. The crucial property of the NKPC specification is the presence of the future expected inflation rate $E_t \pi_{t+1}$ which is an unobservable variable. In most cases, it is approximated by the realised inflation π_{t+1}. However, this procedure prevents from employing the ordinary least squares method, as estimates of the NKPC parameters would be inconsistent, Nason and Smith (2008) argue (due to the correlation between π_{t+1} and the residual in the period t).

Nason and Smith (2008) present an intuitive insight into GMM and its application within the NKPC estimation, which we apply here to the original forward-looking NKPC. Rational economic agents forecast inflation $E_t\pi_{t+1}$ using the set of information I_t, a phenomenon that can be formalised as $E_t[\pi_{t+1}|I_t]$. This is an unobservable variable, as stated above. However, we can use a subset of known variables z_t, that are elements of the information set I_t (on the theoretical grounds) to create our own forecasts of inflation $E_t[\pi_{t+1}|z_t]$. Thus, we try to simulate the expectations of economic agents using our forecast $E_t[\pi_{t+1}|I_t|z_t]$ as demonstrated below:

$$E_t[\pi_{t+1}|I_t] = E_t[\pi_{t+1}|I_t|z_t] + \eta_t \tag{17}$$

using law of iterated expectations, we can rewrite:

$$E_t[\pi_{t+1}|I_t] = E_t[\pi_{t+1}|z_t] + \eta_t \tag{18}$$

where the error terms η_t catches the differences between our proxy and the actual expectations of economic agents over inflation (as z_t variables covers an incomplete information of the set I_t).

Incorporating this idea into the NKPC yields

$$\pi_t = \beta E_t[\pi_{t+1}|I_t] + \lambda x_t \tag{19}$$

$$\pi_t = \beta(E_t[\pi_{t+1}|z_t] + \eta_t) + \lambda x_t \tag{20}$$

$$\pi_t = \beta E_t[\pi_{t+1}|z_t] + \lambda x_t + \beta\eta_t \tag{21}$$

which is a formulation that can be estimated using the two-stage least squares method. One would first find the forecasted inflation π_{t+1}, then insert it into the equation and use the least square estimate, Nason and Smith (2008) argue.

The GMM is a generalisation of such an approach, which can be demonstrated using the following regrouped NKPC equation that is subject to estimation:

$$E[(\pi_t - \beta\pi_{t+1} - \lambda x_t)|z_t] = 0 \tag{22}$$

where we identify the whole equation using the set of variables z_t. The residuals of this estimate vis-a-vis the actual data sample should average zero and should be uncorrelated with z_t. These are classical desired attributes of explanatory variables in a regression analysis. In GMM terminology, expressions like the equation (22) are called orthogonality conditions (DeJong, 2011).

Such variables that constitute z_t are called instruments, or instrumental variables. GMM require that they cannot be mutually perfectly correlated (so that they provide a wide scale of information in the estimation process) and there must be at least the same number of instruments as the number of model's parameters. If the number of instruments is greater than the number of parameters, then the model is "over-identified," and it is possible to test its quality, to a certain extent.

More theoretically, Favero (2001) presents the GMM method as solving the problem (a system of orthogonality conditions)

$$E[f(x_{t+i}, \boldsymbol{\theta})\boldsymbol{z}_t] = 0 \tag{23}$$

where $\boldsymbol{\theta}$ is the (p x 1) vector of parameters and $\boldsymbol{z_t}$ is the (n x 1) vector of instruments that should be orthogonal to the estimated function. The existence of a solution is conditioned upon $n \geq p$. If $n = p$, the parameters are just-identified, and if $n > p$, the parameters are over-identified (clearly, if we have $n < p$, i.e. if the model is under-identified; we are unable to find a solution). Over-identification is a common state of affairs in GMM application, as theory usually offers many instruments that help to solve the problem in question. In the estimation process, the sample moments are used to simulate the expectations:

$$\frac{1}{T}\sum_{t=1}^{T}[f(x_{t+i}, \boldsymbol{\theta})\boldsymbol{z}_t] = 0 \tag{24}$$

that leads to n equations containing p unknowns – a situation with more than a single solution. It is desirable to find the best solution via "*minimising the 'Euclidean distance' between* $\frac{1}{T}\sum_{t=1}^{T}[f(x_{t+i}, \boldsymbol{\theta})\boldsymbol{z}_t] = 0$ *and the null vector,*" Favero (2001) states (pp. 220), which in the GMM takes shape:

$$\min_{\theta}\left(\sum_{t=1}^{T}[f(x_{t+i},\boldsymbol{\theta})\boldsymbol{z}_t]\right)'\Psi^{-1}\left(\sum_{t=1}^{T}[f(x_{t+i},\boldsymbol{\theta})\boldsymbol{z}_t]\right) \tag{25}$$

where Ψ is a weighting matrix as presented by Hansen (1982), as Favero (2001) shows:

$$\Psi = \mathrm{Var}\left(\sum_{t=1}^{T}[f(x_{t+i},\boldsymbol{\theta})\boldsymbol{z}_t]\right) \tag{26}$$

There are other weighting matrixes that are possible to employ in GMM, but Hansen's has most likely earned the most prominence. Importantly, the resulting value of the minimisation, again according to Favero (2001):

$$J = \left(\sum_{t=1}^{T}[f(x_{t+i},\boldsymbol{\theta})\boldsymbol{z}_t]\right)'\widehat{\Psi}^{-1}\left(\sum_{t=1}^{T}[f(x_{t+i},\boldsymbol{\theta})\boldsymbol{z}_t]\right) \tag{27}$$

is called J-statistic (with a χ^2 distribution and $n-p$ degrees of freedom). The J-statistic serves a measure of the validity of instruments used for the (over-)identification of parameters, i.e. if a model is constructed correctly (if it emulates well the rational expectations of economic agents). It is possible to compare models with various specifications of instruments, provided we hold the number of instruments against the number of parameters $n-p$. In this case, the smaller p-value, the higher the probability the model is specified wrongly (either in terms of instruments or the estimated equation itself).

Provided there is expected serial correlation in data sample and estimates, which is also our case (we use lagged variables as instruments), it is necessary to use a GMM estimator (weighting matrix) that is heteroscedasticity and autocorrelation resistant, as shown by Favero (2001). Newey-West estimator complies with such criteria, and we use it in our analysis.

The GMM and its application within NKPC modelling has been subject to criticism, however. Mavroeidis (2004) argue that the GMM may produce misleading estimates mainly in the field of rational expectations models (like the NKPC). Mavroeidis targets the original results of Galí and Gertler (1999) and presents his findings showing that the model by Galí and Gertler is mis-specified and weakly indentified. Specifically, the

GMM estimates are skewed toward higher forward-looking component, notwithstanding a possible change in data. The J-statistic is unreliable, Mavrocidis argues, in estimations with large number of instruments and a small sample. Instead of the GMM, Mavrocidis recommends employing the Full Information Likelihood Method (FIML) that would "*require the specification of a completing model for the forcing variables and the derivation of the solution to the model, the restricted reduced form.*" (pp. 2). However, Galí, Gertler and López-Salido (2005) defend the prior estimates by Galí and Gertler (1999) and GMM-based NKPC analyses in general. They admit that single-equation approach like the GMM comes with shortcomings like a high sensitivity to the selection of instrument sets. On the other hand, they also show that many analyses that use FIML or other comparative methods, yield results that are rather similar to the findings by the GMM. Therefore, the GMM may indeed produce robust results, the authors argue.

2.3 Data Issues and Description

2.3.1 Inflation

As a measure of inflation, we employ the (quarter-on-quarter changes in) overall consumer price index measured by the CSO, as it is the most important price-dynamics indicator among the general public. Also, the year-on-year change in the headline CPI is the key target of the Czech National Bank's monetary policy. The natural shortcoming of the CPI is that it does not cover changes of all prices in economy. Still, it is reasonable to put it in the focus of our analysis, given the reasons stated above.

It is possible to incorporate other inflation data in analysing the NKPC. Probably the most common measure of inflation is the GDP deflator which is used for instance by Genberg and Pauwels (2003), Nason and Smith (2006), or Neiss and Nelson (2002). However, GDP deflator might not be the most appropriate measure of inflation in a small open economy.

2.3.2 Driving Variables

2.3.2.1 Labour Income Share and Real Unit Labour Costs

Empirical literature contains several proxies for marginal costs, which is the driving variable in the theoretical concept of the NKPC (denoted x_t in the inflation equations as the measure of real economic activity). The traditional approach, as presented by Galí and Gertler (1999) is to consider a simple economy based on Cobb-Douglas production function

$$Y_t = A_t K_t^{\alpha_k} N_t^{\alpha_n} \tag{28}$$

where output Y_t is created by combining technology, capital, and labour, respectively. In this simple model, real marginal cost takes the following form:

$$MC_t = \frac{W_t / P_t}{\partial Y_t / \partial N_t} \tag{29}$$

After executing the partial differential and some algebra, we obtain

$$MC_t = \frac{S_t}{\alpha_n} \tag{30}$$

where

$$S_t \equiv \frac{W_t N_t}{P_t Y_t} \tag{31}$$

is the labour income share and also real unit labour costs. After linearization around the steady state, we can express the equality:

$$mc_t = s_t \tag{32}$$

and substitute marginal costs by the labour income share (real unit labour costs) in the NKPC equations, as Galí and Gertler (1999) (pp. 205-206) showed.

In our empirical analysis, we employ both labour income share (calculated as fraction of compensation of employees on total GDP at purchaser prices using Czech Statistical Office data) and real unit labour costs (data by Eurostat) time series.

2.3.2.2 Output Gap

Output gap is another intuitive measure of real economic activity that has been incorporated into empirical analyses of the NKPC. For instance, Roberts (1995) assumes from the very beginning that output gap is the driving real economic variable in his tests of NKPC equations. On the other hand, Galí and Gertler (1999) note that output gap enters their NKPC only with a coefficient κ that measures the elasticity of marginal costs to the output gap.

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \kappa x_t + \varepsilon_t \tag{33}$$

where $x_t \equiv (y_t - y_t^*)$ is the output gap measured as a difference of the log of actual output and the log of natural output in an environment in fully-flexible prices. Note that output gap can be incorporated in this way also into the hybrid and open-economy NKPCs.

In their empirical analysis, Nason and Smith (2008) insert the output gap directly into the inflation equation in order to test its viability, i.e. the coefficient κ is omitted.

Several analyses remark that the NKPC with the output gap as a forcing variable suffers from a poor fit with data. Galí and Gertler (1999, pp. 201) show that according to equation (33), "*inflation should lead movements in the output gap.*" Their estimates, however, show the exact opposite (on the other hand, the results may not be statistically significant). Genberg and Pauwels (2003) also report that their NKPC model of Hong-Kong data with the output gap as a driving variable showed results inconsistent with the theory in certain specifications.

Nason and Smith (2008) discuss thoroughly various measures of output gap in their analysis of the hybrid NKPC based on US data: Congressional Budget Office series, linearly and quadratic detrended output, Hodrick-Prescott filter, and others. However, neither of these output gap measures proved to be helpful in identifying the NKPC. Also, ironically, estimated parameters were negative (the opposite of the theoretical suggestions). Furthermore, even the remaining estimated coefficients showed dissatisfactory qualities. All in all, their results put the viability of the output gap as a driving variable in question, notwithstanding how the output gap was measured.

Nevertheless, as the discussion regarding output gap has been an important topic in the NKPC theory, we present the estimates using Czech data here, too. In this analysis, the output gap is calculated as a share of a cycle component on the trend GDP. The Hodrick-Prescott Filter with the smoothing parameter of 1600 was used to separate the trend and cycle GDP series.

Neiss and Nelson (2002), however, argue that output gap might be a satisfactory driving variable within the NKPC after all. Their approach builds on development of a whole DSGE economic model around the NKPC. As theory suggest, the potential output in such a model "*corresponds to the output level that would prevail if there were no nominal rigidities in the economy, i.e. if prices and wages were fully flexible.*" (pp. 6) The authors note that NKPC itself emerges from the DSGE framework, but in many analyses, researchers use data that are not consistent with the DSGE theory. Estimations made by Neiss and Nelson suggest that NKPC incorporating DSGE-based output gap proves to fit data similarly to the marginal cost variants. However, a creation of a whole DSGE model is not a focus of this analysis.

2.3.2.3 Terms of Trade

Terms of trade that enter the open-economy NKPC were calculated as a ratio of import and export deflators within Czech GDP data as presented by the Czech Statistical Office.

2.3.3 Instruments

The available literature offers a variety of instruments that can be used in estimating the NKPC. The most obvious one are lagged series of inflation itself and of the driving variables (labour income share, real unit labour costs, or output gap). Nason and Smith (2008) argue that employing only the lagged variables of the inflation equation itself aims to secure that the error terms and these instruments are uncorrelated, and that "many" analyses therefore advances in this way.

On the other hand, Nason and Smith (2008) themselves introduce other variables to test for the properties of the NKPC estimation via GMM, which is based on work by Galí and Gertler (1999). They enlist the spread of long-term and short-term interest rates, wage inflation, and commodity price inflation in their instruments. Furthermore, Genberg and Powels (2003) add lagged world inflation into their list of instruments. Neiss and Nelson (2002) incorporate interest rate (short-term Treasury bill rate).

In our instrument lists, we pick the lagged variables that form the inflation equations (inflation, labour income share, real unit labour costs, output gap, and terms of trade) in various combinations and lags, as the empirical literature suggest.

Also, we test for the possibility that other indicators can help in NKPC estimations. As in Galí and Gertler, we allow for wage inflation to enter the instrument list. Wage inflation is calculated using the series Compensation of employees that are available within Czech Statistical Office's GDP data.

Inspired by Roberts (1995), who incorporates oil prices (they are an important source of variations in the price level and also real economy – as e.g. the oil shocks showed) into his formulation in NKPC, we employ oil prices among our instruments, too. Quarterly averages of Brent oil price in CZK terms obtained from Bloomberg were used in this analysis.

2.3.4 Data Range and Operations with Data

We estimate the NKPC using Czech Republic's quarterly macroeconomic data over the range of Q1 1998 and Q3 2013. Inflation figures (CPI) by the Czech Statistical Office (CSO) are available even for 1997 but we decided to exclude that year on the basis of a different Czech National Bank monetary-policy regime (the CNB adopted the current inflation-targeting regime only as of the beginning of 1998). However, we use the out-of-the-sample (i.e. pre-1998) observations for the seasonal adjustment and other operations (HP Filter) in order to get the highest possible precision of these operations.

All time series are seasonally adjusted either inherently by the Czech Statistical Office (GDP level and the resulting output gap, terms of trade), or by own calculations using Census X12 multiplicative method in EViews. The series are stationarised via log-differentiation or differentiation. Sources of data are the Czech Statistical Office (inflation, GDP, wage inflation, labour income share, terms of trade), Eurostat (real unit labour costs), and Bloomberg (oil price and USDCZK exchange rate).

The table below summarises the medians, standard deviations, Jarque-Bera statistic and augmented Dickey-Fuller test t-statistic of the series.

Table 1: Data description

	Median	St. deviation	JB		ADF	
cpi	0.006881	0.007097	82.20357	***	-4.675179	***
lis	0.000136	0.004934	3.147023		-12.46437	***
rulc	0.002154	0.012292	1.493177		-12.08573	***
gap	-0.004898	0.019237	5.504233	*	-3.109881	**
tot	-0.003347	0.013749	109.0210	***	-11.28698	***
oil	0.044205	0.128782	29.64010	***	-5.456449	***
wage	0.012282	0.011652	0.287500		-2.071935	

Note: The ***, **, and * stand for a rejection of the null hypothesis (JB: series has the kurtosis and skewness of a normal distribution; ADF: series has a unit root) at the 1%, 5%, and 10% significance level, respectively. Cpi denotes inflation, lis: labour income share, rulc: real unit labour costs, gap: output gap, tot: terms of trade, oil: oil price in CZK terms, wage: wage inflation

Furthermore, we estimated separately the subjective discount factor β, using data for the ten-year Czech government bond yield augmented for the rate of inflation over the period Q1 2000 – Q3 2013. Bond yield data were obtained from Bloomberg as quarterly average bid yields, the rate of inflation proxy was year-on-year CPI inflation (measured by the CSO). As result, we estimated the subjective discount factor to reach $\beta = 0.982905$. We use this figure in the assessment process of NKPC identification results, in order to have an anchor that would allow us to identify the best specifications possible.

3 Results

The GMM estimation was run in EViews 8 econometric software. As the estimation weighting matrix, the heteroscedasticity and autocorrelation resistant (HAC) Newey-West with Bartlett kernel and Newey-West fixed bandwidth method was chosen. Each specification of the NKPC (i.e. the pure NKPC, the hybrid NKPC, and the open-economy NKPC) was tested separately. Within each formulation of the NKPC, three possible measures of the real activity and the resulting estimates were examined. Moreover, we employed various sets of instruments so that we could monitor the robustness of the results. As the theory and empirical literature suggest, the core instruments are lagged variables that form the NKPC equations. Also, we employed oil prices and wage inflation in estimating the pure forward-looking NKPC and the hybrid NKPC. In order to operate with a reasonable amount of instruments, we used sets of three, or four lags, respectively. In every estimate, a constant was included. We also watched autocorrelation of residuals, but a presence of autocorrelation does not automatically reject the viability of a GMM-estimated NKPC model, Vašíček (2009) argues.

Where it is possible, we compare our results with research of other authors.

3.1 Pure Forward-Looking NKPC

Now we look at results of estimating the pure forward-looking NKPC. In this exercise, we used the following list of instruments:

Table 2: Instrument lists in the pure forward-looking NKPC estimate

set	instruments
Z1	3 lags of the variables forming the inflation equation (cpi and gap, lis, or rulc)
Z2	4 lags of the variables forming the inflation equation (cpi and gap, lis, or rulc)
Z3	Z1 + three lags of oil prices
Z4	Z2 + four lags of oil prices
Z5	Z1 + three lags of wage inflation
Z6	Z2 + four lags of wage inflation

First we present the estimated parameters of the gap-driven NKPC.

Table 3: Pure forward-looking NKPC with output gap as a driving variable

GAP	β		θ		J-stat	p-value
Z1	1.004186	***	0.868571	***	7.449642	0.189289
Z2	1.025090	***	0.893339	***	9.334555	0.229520
Z3	1.018473	***	0.878943	***	7.766058	0.557883
Z4	1.029598	***	0.894597	***	9.615960	0.565226
Z5	1.046136	***	0.889964	***	9.249775	0.321665
Z6	1.021925	***	0.877693	***	9.552247	0.571054

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

Table 4: Pure forward-looking NKPC with labour income share as a driving variable

LIS	β		θ		J-stat	p-value
Z1	N/C		N/C		-	-
Z2	0.983472	***	0.755475	***	7.324199	0.395923
Z3	1.019127	***	0.792957	**	7.126007	0.788789
Z4	0.947399	***	0.666103	***	8.956545	0.879779
Z5	0.993853	***	0.841342	*	6.756758	0.563090
Z6	0.939831		0.672914		8.722293	0.647509

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively, N/C denotes estimate that repeatedly did not achieve convergence

Table 5: Pure forward-looking NKPC with real unit labour cost as a driving variable

RULC	β		θ		J-stat	p-value
Z1	1.003135	***	0.814193	***	5.498685	0.358090
Z2	0.974541	***	0.777087	***	7.200623	0.408294
Z3	1.016309	***	0.789812	***	6.799650	0.815068
Z4	0.972405	***	0.754044	***	7.897556	0.722450
Z5	0.980128	***	0.805836	***	6.100972	0.635922
Z6	0.942322	***	0.735357	***	8.473590	0.670357

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

In most cases, we obtained statistically significant estimates of the parameters of interest. Somewhat puzzling is the Z1 variant of the NKPC driven by the labour income share that was consistently not able to achieve meaningful convergence. Also rather surprising is the statistical insignificance of the estimated parameters using Z6 instrument set. The other specifications of the pure NKPC did not see any problems with these two sets.

Although the coefficient β (the subjective discount factor) might seem to be estimated at or around the expected value, i.e. 0.98 (as shown in the section that deals with data), its variation is rather large, reaching even 0.94 in some cases. Also, all the output-gap specification delivers β above 1.0 (at the 1% level of statistical significance), which is rather problematic from a theoretical standpoint, as it would imply the subjective discount rate is negative.

The parameter θ falls into the expected range of $(0, 1)$ but again the variance is rather big. Most of the estimates point to $\theta \cong 0.8$, which would signal that prices are being fixed for some 5 periods (five quarters). This is roughly in line with the findings of Galí and Gertler (1999) in 1960:1-1997:4 US quarterly data.

Also of interest is the role of the supplementary instrumental variables, oil prices and wage inflation. It cannot be said that adding these variables (their appropriate lags) significantly improves the estimation results. Comparing these two instruments, there is apparently a better performance of oil prices in estimating the NKPC, comparing to wage inflation – as far as the J-stat and its probabilities are concerned. Still, the volatility of estimates incorporating oil prices as instruments is substantial.

Comparing J-stat of estimates using the same set of instruments Z but different driving variables show that the model based on output gap exhibit the poorest fit. On the other hand, measuring the respective J-stats of the LIS and RULC specifications show better results. This is in line with the conclusion of most of the literature that the NKPC based on output gap tends to be inferior to the marginal-cost specifications. Still, even the output-gap J-stats do not reject the hypothesis that such a specification is invalid even at 10% level of significance.

The diagnostic of residual (correlogram of residuals, not shown) reveals that particularly the specifications with instrument lists Z1, Z3, Z5 (containing up to three lags of instruments) might suffer from a modest autocorrelation, namely on the lags two and three. However, this autocorrelation is not strong and can be rejected at 10% level of confidence, in most cases. Therefore, it should not present a significant problem in this case.

All in all, however, we find these results controversial. The stability of parameters is rather low, and the β parameter rather often shows values inconsistent with expectations. Vašíček (2009) briefly discuss the pure forward-looking NKPC, and also shows disappointing results (perhaps most importantly statistically insignificant parameter of real unit labour costs, which he chooses as the driving variable). Also, the viability of the pure forward-looking NKPC is rejected by results of the hybrid NKPC estimates, see below.

3.2 Hybrid New Keynesian Phillips Curve

As stated in the previous sections, the commonly seen poor fit of the pure forward looking NKPC has led researchers to consider an inflation equation that would incorporate some backward backward-looking behaviour of price setters. Such a specification often offers better estimation results, and also present broader discussions opportunities regarding the effectiveness of monetary policy.

In our analysis, we focus on estimating the structural parameters of the hybrid NKPC and the resulting forward and backward looking share of firms. Also of importance is the robustness of estimated parameters in the light of instrument sets used for the identification and the overall quality of the fit.

Again, we tested three specifications of the equation, i.e. output gap, labour income share, and real unit labour costs as driving variables, respectively. We employed a list of instruments similar to the case of the pure forward-looking NKPC, except for the first lag of CPI inflation that was used as a driving variable, in line with the theory.

Table 6: Instrument lists in the hybrid NKPC estimate

set	instruments
Z1	3 lags of the variables forming the inflation equation (gap, lis, or rulc), 2nd and 3rd lags of inflation
Z2	4 lags of the variables forming the inflation equation (gap, lis, or rulc), 2nd to 4th lags of inflation
Z3	Z1 + three lags of oil prices
Z4	Z2 + four lags of oil prices
Z5	Z1 + three lags of wage inflation
Z6	Z2 + four lags of wage inflation

The results of our estimates are summarised in the tables below:

Table 7: Hybrid NKPC with output gap as a driving variable

	$\boldsymbol{\beta}$		$\boldsymbol{\theta}$		$\boldsymbol{\omega}$		$\boldsymbol{\gamma_f}$	$\boldsymbol{\gamma_b}$	**J-stat**	**p-value**
Z1	N/C		N/C		N/C				-	
Z2	1.036326	***	0.752132	***	0.535016	***	0.5961	0.4091	3.715970	0.590989
Z3	N/A		N/A		N/A				-	
Z4	0.953314	***	0.816845	***	0.528345	***	0.5926	0.4021	5.897567	0.750125
Z5	1.090919	***	0.804142	***	0.63859	**	0.5842	0.4253	4.950259	0.838623
Z6	0.949654	***	0.851666	***	0.549966	***	0.5925	0.4029	4.585996	0.868803

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively, N/C denotes estimate that repeatedly did not achieve convergence, N/A denotes defective results

Table 8: Hybrid NKPC with labour income share as a driving variable

	$\boldsymbol{\beta}$		$\boldsymbol{\theta}$		$\boldsymbol{\omega}$		$\boldsymbol{\gamma_f}$	$\boldsymbol{\gamma_b}$	**J-stat**	**p-value**
Z1	0.940906	***	0.436345	**	0.454283	**	0.4669	0.5166	1.548969	0.671015
Z2	0.977437	***	0.409144	***	0.346950	***	0.5316	0.4612	3.489906	0.624915
Z3	1.069596	***	0.422167	**	0.430045	**	0.5223	0.4974	5.049509	0.537479
Z4	0.966202	***	0.438139	***	0.314076	***	0.5677	0.4212	5.228513	0.813951
Z5	1.052822	***	0.491394	***	0.374637	***	0.5887	0.4263	5.657479	0.773649
Z6	0.934204	***	0.426109	***	0.321561	***	0.5411	0.4371	5.068398	0.828305

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

Table 9: Hybrid NKPC with labour income share as a driving variable

	$\boldsymbol{\beta}$		$\boldsymbol{\theta}$		$\boldsymbol{\omega}$		$\boldsymbol{\gamma_f}$	$\boldsymbol{\gamma_b}$	**J-stat**	**p-value**
Z1	0.951837	***	0.544852	***	0.535049	***	0.4867	0.5021	1.917000	0.589811
Z2	0.970803	***	0.562823	***	0.451198	***	0.5438	0.4491	3.506180	0.622453
Z3	1.077053	***	0.527249	***	0.537365	***	0.5229	0.4948	5.382703	0.495745
Z4	0.945003	***	0.592220	***	0.397224	***	0.5769	0.4094	5.399743	0.798163
Z5	0.917988	***	0.601908	***	0.442177	***	0.5447	0.4359	2.800781	0.833403
Z6	0.917979	***	0.575526	***	0.403581	***	0.5550	0.4240	5.024935	0.832129

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

The residual diagnostic (not shown) pointed to possible small serial correlations on the first lags of the presented estimates, but it should most likely not undermine the overall results.

As experience of various researchers suggested, the results of estimating the hybrid NKPC with the output gap as the driving variable are rather poor. Using the set Z1 of instruments, the estimation did not converge, and with the set Z3, estimated parameters were rejected at almost a 100% level of significance (not shown), signalling likely wrong composition of the model. Moreover, the specifications that converged and posted a statistically-significant estimates of the parameters, show very volatile results. Also, the estimated values of β are rather far from the expected value of some 0.98. Despite the relatively solid J-stats, we thus consider this output-gap-based specification as inappropriate.

On the other hand, the results of the LIS-driven and RULC-driven hybrid NKPCs are more promising, and the further discussion will focus only on them. All the estimates are statistically significant at 5% or even 1% level of confidence. The most appropriate estimates were achieved with the Z2 instrument list, as far as the level of β is concerned. The results of estimates using the auxiliary instrumental variables – oil price and wage inflation – did not achieve the quality of the estimates depending solely on the lags of driving variables.

We will now take a closer look at the estimated values of the parameters, with focus on the results of the Z2 estimates of the LIS and RULC specifications. Note that both LIS and RULC specification achieve roughly the same p-value at J-stat. Although the estimates of θ and ω differ slightly, we may put their estimated values to some $0.5 - 0.6$ and $0.3 - 0.45$, respectively. Therefore, according to this specification of the hybrid NKPC, prices are fixed for two to three periods on average. Galí and Gertler (1999) report that their US hybrid NKPC model put the θ at around 0.8, which would imply that prices are fixed for five periods. However, they also quote surveys that showed prices are indeed actually fixed for some three to four period, which is closer to our estimate.

As the value of ω show, there are roughly 30% to 45% of firms that set their prices according to the backward looking rule of thumb. Such a ratio, along with a statistical significance of this estimate, further rejects the validity of the forward-looking NKPC. Comparing to the results of Galí and Gertler (1999), our results consistently point to relatively high share of backward-looking firms (Galí and Gertler report the value of ω of 0.25 or 0.49, depending on the method chosen – the first one is considered better). This hold true even when compared with Nason and Smith (2008), whose estimates of the ω parameter (also using US data) are very volatile, but consistently lower than ours.

Ceteris paribus, this would indicate higher inflation persistence in the Czech data vis-a-vis the US ones.

If it is really so, let us examine the 'primitive' parameters γ_f and γ_b, the former measuring the influence of expected inflation, the latter quantifies the overall influence of backward-looking behaviour. These two parameters are surprisingly stable across the board. Again focusing on the Z2 estimates, the forward-looking parameter γ_f reaches some 0.54 and the backward-looking parameter γ_b totals roughly 0.45. Most importantly, the backward-looking parameter is significantly higher in comparison with results of Galí and Gertler (1999) (0.25 or 0.38), and of Nason and Smith (maximum level of 0.29). Backward-looking behaviour is apparently more dominant in the Czech economy. This is supported also by findings of Vašíček (2009), who puts the estimated parameter γ_b at 0.42 (in case RULC is the driving variable; note that Vašíček works with year-on-year HICP data but reports results were similar even with quarterly data).

The high-degree of backwardness measured by the parameter γ_b further supports the rejection of the pure forward-looking NKPC as an appropriate model describing inflation dynamics in the Czech Republic. On the other hand, Galí and Gertler (1999) did not refuse the viability of the pure forward-looking model in describing US data, given the relatively small degree of backwardness reported in the hybrid NKPC results.

Implications of these findings in terms of monetary policy are twofold. (1) The existence of significant share of backward-looking firms should make monetary policy less efficient, compared to the pure-forward looking environment. In case monetary policy inflicts a shock on the economy, its effects would be mitigated by this backward-looking nature of almost half of the firms that would not react according to the rational expectations. (2) On the other hand, the estimated deep parameter θ is rather low, implying a relatively high price-flexibility (prices are fixed for some two to three periods). Therefore, the response of both backward-looking and, more importantly, forward-looking firms to a monetary-policy shock can be faster and can somewhat offset the higher degree of backwardness. What is the overall sensitivity implied by the hybrid NKPC to a monetary-policy shock can be subject to further research.

3.3 Open-Economy New Keynesian Phillips Curve

In order to complete the discussion, we present results of the estimates of the open-economy NKPC. In this case, we excluded the auxiliary instrument variables oil prices and wage inflation, and focused only on estimations utilising lagged forcing variables. As shown in the results on the pure forward-looking NKPC and the hybrid NKPC, these two series did not significantly enhance the identification process. Therefore, we use only two sets of instruments:

Table 10: Instrument lists in the open-economy NKPC estimate

set	instruments
Z1	3 lags of the variables forming the inflation equation (cpi, gap, lis, or rulc)
Z2	4 lags of the variables forming the inflation equation (cpi, gap, lis, or rulc)

The identification of the parameter α that should measure the influence of the relative change in terms of trade on the rate of inflation, i.e. the openness of the economy, will be crucial in this section.

Table 11: Open-economy NKPC with output gap as a driving variable

GAP	β		θ		α		J-stat	p-value
Z1	1.019581	***	0.862585	***	-0.192260	**	4.730487	0.692814
Z2	0.995550	***	0.847256	***	-0.003870		8.550112	0.575263

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

Table 12: Open-economy NKPC with labour income share as a driving variable

LIS	β		θ		α		J-stat	p-value
Z1	1.066712	***	0.961101		-0.116400	*	6.799679	0.450031
Z2	0.961033	***	0.637561	***	0.041991		8.616955	0.568800

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

Table 13: Open-economy NKPC with real unit labour cost as a driving variable

RULC	β		θ		α	J-stat	p-value
Z1	N/C		N/C		N/C		
Z2	0.941063	***	1.518035	***	0.068844	8.500072	0.580111

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively, N/C denotes estimate that repeatedly did not achieve convergence

Unfortunately, the estimation results of the open-economy NKPC are particularly poor. In majority of cases, the estimated coefficient α is statistically insignificant. In case the coefficient shows significance, it finds itself in the negative territory, which is in sharp contrast to the theoretically-expected values $[0,1]$. Moreover, identification of other parameters is often cumbersome, too.

We also tested the open-economy NKPC with year-on-year data, hoping for better results. We again used two sets of instruments:

Table 14: Instrument lists in the open-economy NKPC estimate, yoy data

set	instruments
Z1	3 lags of the variables forming the inflation equation (cpi, gap, lis, or rulc)
Z2	4 lags of the variables forming the inflation equation (cpi, gap, lis, or rulc)

The results follow in the tables below:

Table 15: Open-Economy NKPC with output gap as a driving variable, yoy data

GAP	β		θ		α	J-stat	p-value
Z1	0.999556	***	0.939291	**	-0.07111	8.428281	0.296346
Z2	N/C		N/C		N/C		

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively, N/C denotes estimate that repeatedly did not achieve convergence

Table 16: Open-economy NKPC with labour income share as a driving variable, yoy data

LIS	β		θ		α	J-stat	p-value
Z1	0.983700	***	0.692418	***	-0.12205	8.539827	0.287403
Z2	0.955682	***	0.652880	***	-0.04280	9.994885	0.440942

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

Table 17: Open-economy NKPC with real unit labour cost as a driving variable, yoy data

RULC	β		θ		α	J-stat	p-value
Z1	1.002469	***	1.200639	***	-0.10304	8.356042	0.302248
Z2	0.971185	***	1.380022	***	-0.06808	9.738262	0.463749

Note: ***, **, * denote statistical significance at the level of 1%, 5%, and 10%, respectively

We see that even the incorporation of year-on-year data did not improve the results, namely the coefficient α is significant in neither of the specifications. Clearly, this specification of the open-economy NKPC does not fit the data.

These are disappointing results, as we argued that terms of trade play significant role in a small open economy like the Czech Republic. On the other hand, results of analysis by Mihailov, Rumler and Scharler (2008) that focused on eight countries (Austria, Germany, Italy, France, Spain, Netherlands, the UK, Canada, and Sweden) showed somewhat problematic results, too. In their case, an estimate using LIS as a driving variable produced negative α for Austria and France (although statistically insignificant), and statistically insignificant positive α for Spain, Canada, and Sweden. Therefore, our results may not be as surprising after all. Also, we have been estimating the NKPCs using CPI data that by nature incorporates influence of external environment. Therefore, the effects of foreign price changes might be captures in the hybrid NKPC that proves to fit data relatively well.

Perhaps greater success would have the estimation of the open-economy hybrid NKPC, that is presented for instance by Rumler (2005). This may be the subject of our future research.

Conclusions

In this analysis, we presented the historical developments that led to an inception of the so-called New Keynesian Phillips Curve. We discussed its theoretical background based on incorporation of nominal rigidities into DSGE models that emerged from the RBC theory.

Researchers developed several specifications of the NKPC. The original NKPC – that is built on the Calvo’s (1983) pricing model – assumes that firms decide regarding their price-developments upon only discounted future path of marginal costs, or – in some specifications – upon the sum of discounted output gaps. Inflation process is therefore purely forward-looking. The original NKPC soon started to be challenged by researchers that reported mainly its poor fit with data. The response came from Galí and Gertler (1999) in the form of the hybrid NKPC that combined the forward-looking component with a backward-looking behaviour, as a fraction of firms follow a backward-looking rule of thumb in their price-setting decisions. Such a specification better captures possible inflation inertia, which is also of importance for monetary-policy analysis. The final specification that we discussed is the open-economy NKPC, first introduced by Galí and Monacelli (2004). It incorporates terms of trade as another driving variable and it should therefore represent a good model for a small open economy.

Researchers met with significant difficulties relating to the NKPC. Those inherent to the theoretical background of the NKPC are issues with measuring the real economic activity that should be a driver in the inflation equation. Many analyses use the labour income share or real unit labour costs as a proxy for marginal cost of firms. Also, output gap has been used as a measure of the real activity but with mixed results. Neiss and Nelson (2002) argue that output gap based upon DSGE modelling might prove more relevant in the estimation process.

In our analysis, we studied all three specifications of the NKPC, and we utilised the all three common measures of the real economic activity – the labour income share, the real unit labour costs, and output gap (however, based on HP filter).

We adopted the most common estimation method in NKPC modelling – the Generalised Method of Moments, as the presence of expectations operator (i.e. the fact that inflation equations contain expected inflation, which is not observable) prevents from using more straightforward methods. We described the basic features of the GMM, a critique that GMM faced, and also a consequent defence of this method.

Inflation took form of the CPI in our analysis. Data were obtained from the Czech Statistical Office, and Bloomberg. All the series were seasonally adjusted and stationarised. In a discussion of the open-economy NKPC, we also used year-on-year data.

The pure forward-looking NKPC did not post convinced results. The estimates were rather volatile, depending on the chosen set of instruments, and in some cases inconsistent with their expected values. The disappointing results corresponded with brief findings of Vašíček (2009).

Much more cheerful were the estimates of the hybrid NKPC. Namely, the labour income share and real unit labour costs driven equations with instrument sets containing only the driving variables with up to four lags offered interesting findings. The estimated parameter β was in line with the expectations (we estimated β separately using real interest rates). The coefficient θ showed that the average fixing period of prices lasts some two to three quarters, which is roughly in line with surveys quoted by Galí and Gertler (1999) (these were however done in the US). Most importantly, the coefficient ω is significantly higher compared to the findings of Galí and Gertler (1999) or Nason and Smith (2008). This suggests higher backwardness of inflation process in the Czech Republic. Indeed, the 'primitive' parameter γ_b that measures the backward-looking component in the hybrid NKPC, reached significantly higher level vis-a-vis the results of the other authors. Vašíček (2009) reports findings similar to ours in year-on-year Czech data. This high degree of backwardness puts further weight on a rejection of the pure-forward looking NKPC as an appropriate representative of the inflation process in the Czech Republic. Also, it implies higher inflation persistence in the Czech Republic (ceteris paribus) with implications in likely lower effectiveness of monetary policy-imposed shocks.

The last section of our result is focused on the open-economy NKPC. Unfortunately, none of the specifications tested resulted in satisfactory estimates and identification of the respective equations. However, findings of Mihailov, Rumler and Scharler (2008) were somewhat similar to ours, as a significant part of their open-economy NKPCs did not performed well, either. Of further interest might be the hybrid open-economy NKPC that was not covered in this analysis.

In sum, the answer to the question constituting the title of our analysis is that the hybrid New Keynesian Phillips Curve (with either the labour income share or the real unit labour cost as driving variables) can be considered as an appropriate model describing inflation in the Czech Republic.

Overall, it can be difficult to evaluate the NKPC in terms of its descriptive and forecasting abilities due to a simple, yet important phenomenon. Perhaps with the exception of the deflationary period in 1998 (that was vastly affected by a change in monetary-policy regime and the effects of 1997 crisis) and a one-off spike 2007, inflation did not see any major significant swings, or huge volatility. Nason and Smith (2008) elaborate on this in their analysis of US data, which showed a substantial moderation since 1980's. Summarising the intrinsic challenge within the NKPC analyses, they state: *"Perhaps competent central bankers can take some credit for creating a low, stable inflation rate that has not displayed persistent swings or cycles, but that outcome inherently makes it difficult to isolate an inflation forecast that differs from current or lagged inflation."* (pp. 375)

List of Tables

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