COMENIUS UNIVERSITY, BRATISLAVA
FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

Empirical Analysis of Monetary Policy

DISSERTATION THESIS

676d7228-2315-4114-83b0-250b31ad849f

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COMENIUS UNIVERSITY, BRATISLAVA
FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

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DISSERTATION THESIS

9.1.9 Applied Mathematics
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UNIVERZITA KOMENSKÉHO, BRATISLAVA
FAKULTA MATEMATIKY, FYZIKY A INFORMATIKY

Empirická analýza menovej politiky

DIZERTAČNÁ PRÁCA

9.1.9 Aplikovaná matematika
Katedra aplikovanej matematiky a štatistiky
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THESIS ASSIGMENT

Name and Surname: Mgr. Katarína Danišková
Study programme: Applied Mathematics (Single degree study, Ph.D. III. deg., full time form)
Field of Study: 9.1.9. applied mathematics
Type of Thesis: Dissertation thesis
Language of Thesis: English
Secondary language: Slovak

Title: Empirical Analysis of Monetary Policy

Tutor: doc. Ing. Jarko Fidrmuc, Dr.
Departments: FMFI.KAMŠ - Department of Applied Mathematics and Statistics

Electronic version available:
bez obmedzenia

Assigned: 21.10.2010

Approved: 22.10.2010

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Univerzita Komenského v Bratislave
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ZADANIE ZÁVEREČNEJ PRÁCE

Meno a priezvisko študenta: Mgr. Katarína Danišková
Študijný program: aplikovaná matematika (Jednoodborové štúdium, doktorandské III. st., denná forma)
Študijný odbor: 9.1.9. aplikovaná matematika
Typ záverečnej práce: dizertačná
Jazyk záverečnej práce: anglický
Sekundárny jazyk: slovenský

Názov: Empirical Analysis of Monetary Policy

Školiteľ: doc. Ing. Jarko Fidrmuc, Dr.
Katedra: FMFI.KAMŠ - Katedra aplikovanej matematiky a štatistiky

Spôsob sprístupnenia elektronickej verzie práce:
bez obmedzenia

Dátum zadania: 21.10.2010

Dátum schválenia: 22.10.2010

prof. RNDr. Marek Fila, DrSc.
garant študijného programu

....

študent školiteľ práce

I declare this dissertation thesis was written on my own, with the only help provided by my supervisor and the referred-to literature.

Bratislava, 2012 ....

Mgr. Katarína Danišková

Acknowledgment

I would like to express my deep sense of gratitude to doc. Ing. Jarko Fidrmuc, Dr. for his invaluable help and guidance during the elaboration of this thesis. I am grateful to him for having given me the support and confidence.

I would like to express my thanks to colleague Ivana Bátorová for her help, support and friendship.

And also I would like to express special thanks to my family, especially my husband for their support during my study.

Abstract

DANIŠKOVÁ, Katarína: Empirical Analysis of Monetary Policy [dissertation thesis]. Department of Applied Mathematics and Statistics. Faculty of Mathematics, Physics and Informatics. Comenius University of Bratislava. Degree of academic qualification: Philosophiae Doctor (PhD.). Bratislava: FMFI UK, 2012. 102 pages.

The New Keynesian Phillips curve has become an important part of modern monetary policy models. It describes the relationship between inflation and real marginal cost, which is derived from micro-founded models with rational expectations and sticky prices. Moreover, differentiated subjects on the market may adapt their expectations based on the future and past development. These enhancements answer the previous critique of the Phillips curve. We estimate several specifications of the New Keynesian Phillips curve for the Czech Republic between 1996 and 2009. We show that the GMM suffers under the problem of weak instruments leading to biased estimates. In turn, the FIML is robust and yields significant estimates of structural parameters implying a strong forward-looking behaviour. We also review about 200 studies and analyse the weight of the forward-looking behaviour in the hybrid New Keynesian Phillips curve by means of meta-analysis. Results confirm that selected data and method characteristics have significant impact on the reported inflation expectations term. Moreover, meta-analysis suggests a significant publication bias including publications in top journals, while no such bias is found for the most cited studies and the most cited authors.

Keywords: New Keynesian Phillips curve • inflation • gmm • fiml • meta-analysis • publication bias

Abstrakt

DANIŠKOVÁ, Katarína: Empirická analýza menovej politiky [dizertačná práca]. Katedra Aplikovanej Matematiky a Štatistiky. Fakulta Matematiky, Fyziky a Informatiky. Univerzita Komenského, Bratislava. Stupeň akademickej kvalifikácie: Philosophiae Doctor (PhD.). Bratislava: FMFI UK, 2012. 102 strán.

Nová Keynesiánska Phillipsova krivka sa stala neoddeliteľnou súčasťou modelov modernej monetárnej politiky. Popisuje vzťah medzi infláciou a reálnymi hraničnými nákladmi a je odvodená na báze mikroekonomických modelov s racionálnymi očakávaniami, nepružnými cenami a diferencovanými účastníkmi na trhu. Trhové subjekty majú možnosť stanoviť svoje inflačné očakávania na báze budúceho alebo minulého vývoja. Odvodenie Novej Keynesiánskej Phillipsovej krivky odpovedá na predchádzajúcu kritiku Phillipsovej krivky. V našej práci sa zaoberáme odhadom Novej Keynesiánskej Phillipsovej krivky pre Českú republiku v rokoch 1996 až 2009. Podarilo sa nám potvrdiť, že metóda odhadu GMM nie je v tomto prípade spoľahlivou metódou kvôli problémom so slabými inštrumentami. Naopak, metóda FIML je robustná a vedie k signifikatným odhadom štrukturálnych parametrov. Zároveň potvrdzuje silný vplyv očakávanej inflácie na súčasnú infláciu. Ďalej skúmame takmer 200 štúdií zaoberajúcich sa Novou Keynesiánskou Phillipsovou krivkou a analyzujeme váhu očakávanej inflácie pomocou metódy meta-analýzy. Výsledky potvrdzujú, že vybrané údaje a charakteristiky majú signifikantný vplyv na publikované výsledky. Okrem toho, meta-analýza naznačuje existenciu publikačnej odchýlky v prácach publikovaných v časopisoch, kým podobná odchýlka nie je pozorovateľná v prípade najcitovanejších štúdií a autorov.

Kľúčové slová: Nová Keynesiánska Phillipsova krivka • inflácia • gmm • fiml • meta-analýza • publikačná odchýlka

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Introduction

> *"Inflation is always and everywhere a monetary phenomenon."*
>
> – Milton Friedman

Inflation is one of the key indicators of monetary policy, and its dynamics and the nature of short-run inflation have been very debated issues over the decades. Phillips (1958) initiated the discussion that has not been finished yet. The Phillips curve has become one of the central models in macroeconomics since it was published by A. W. Phillips in his paper *"The Relationship Between Unemployment and the Rate of Price Change of Money Wage Rates in the United Kingdom, 1862–19"*. He observed and documented an inverse statistical relationship between the wage inflation and the rate of unemployment over the business cycle. According to his paper, when unemployment was high, nominal wages increased slowly and when unemployment was low, nominal wages rose rapidly except for the period of volatile inflation between two world wars. Low rates of unemployment pressured the labour market to offer higher wages while higher rates of unemployment allowed employers to lower wages.

In further research, Paul Samuelson and Robert Solow demonstrated the equivalent relation between price inflation and unemployment since wages were closely connected to prices settled by companies (Samuelson and Solow, 1960).

The Phillips curve has become a key part of the standard Keynesian model and central to macroeconomic thinking and policy. Ignoring episodes as the Great Depression, it brought an idea that countries could choose between different combinations of unemployment and inflation. The concept is based on an argument that the price level stability (zero inflation) could be obtained by allowing higher unemployment or otherwise low unemployment could be substituted by tolerating high inflation. Thus, demand management policies could be applied to stimulate economy, raise output at the expense of higher inflation. Moving along the Phillips curve would lead to the lower rates of unemployment.

An alternative understanding of the Phillips curve appears in Friedman (1968). Milton Friedman[1] criticizes the absence of rational expectations and points out that keeping output above its "potential" level (e.g. under demand management policy) would lead to the moment, when well-informed, rational employers and workers paying attention only to real wages, would require higher growth of nominal wages. The consequence of this would be the growth of unemployment rate. His analysis and also the work of Edmund Phelps[2] (Phelps, 1967) provide a distinction between the short-term and the long-term Phillips curve, which is based on the hypothesis of the “natural level” of unemployment later exerted as NAIRU (non-accelerating inflation rate of unemployment).

For better explanation we can imagine that unemployment is at the natural level and the real wage is constant. Workers expect a given rate of price inflation and bargain the same growth of nominal wages to prevent the erosion of their purchasing power. As soon as the government uses expanding monetary policy to lower unemployment below its natural level, increase in demand encourages companies to rise prices more then workers anticipate. Under higher revenues companies hire more employees at the same wage and possibly rise wages in nominal terms. Thus, the unemployment rate falls. For a short time employees have the money illusion, that their purchasing power has risen. In reality, contrary is the case, because the price inflation is higher than the wage inflation. Right after they realize it, they offer less labour, which puts a pressure on employers to rise nominal wages. The real wage is restored at the previous level

[1]In 1976 Milton Friedman received the Nobel price for his achievements in the fields of consumption analysis, monetary history and theory and for his demonstration of the complexity of stabilization policy.

[2]In 2006 Edmund Phelps received Nobel price for his analysis of intertemporal trade-offs in macroeconomic policy, i.e. deepening the understanding of the relation between short-run and long-run effects of economic policy and his contributions to a decisive impact on economic research as well as policy.

and the rate of unemployment returns to the natural level. But the price and the wage inflation stay at the new growth rate. In the long run, the only effect of such stimulus of the government will be higher inflation for the same level of unemployment. Once, workers' expectations of the price inflation have had time to adjust, the natural level of unemployment is compatible with any rate of inflation. And the more quickly workers' expectations of the price inflation adapt to changes in the actual rate of inflation, the less successful the government will be in reducing unemployment through monetary and fiscal policy.

The claim of Milton Friedman and weakness of the Phillips curve was substantiated in 1970s, when the period of high inflation and high unemployment rate occurred. This phenomenon is generally reported as stagflation which combines stagnation and inflation and this contradicts the trade-off supposed by the Phillips curve.

Robert Lucas[3] criticizes the absence of microeconomic foundations in macroeconomic policy-making (known as *Lucas critique*):

> "Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models." (Lucas, 1976, p. 41)

and together with Thomas Sargent (Lucas and Sargent, 1979) reproach the ignorance of expectations on behaviour. The way how to proceed, they argue, is to assume that people form expectations as rationally as they can, based on the information they have.

The principal response of Keynesian economists to these theoretical critics was an attempt to build models that incorporate rational expectations and are based on microeconomic foundations. They analysed the whole basis of Keynesian economics, relied more on microeconomic foundations and incorporate them into macroeconomic models. This combination of rational expectations and micro-foundations is known as Neo-Keynesian macroeconomics which relies crucially on the term sticky prices or the so-called price rigidities. Without price rigidities, it is difficult to explain that there can be a time during which factors of production, such as labor, are under-utilized and con-

[3]In 1995 Robert Lucas received the Nobel price for having developed and applied the hypothesis of rational expectations, and thereby having transformed macroeconomic analysis and deepened our understanding of economic policy.

sequently output is under its potential level. Sticky prices allow money stock increase to cause a short-run increase in real spending and thus support real output. Eventually, fiscal and monetary policy has no effect if prices are fully flexible.

These theoretical advances have produced alternative views of the inflation process with crucially different implications for optimal monetary policy. The new inflation literature is built on the work of Fischer (1977), Taylor (1980) and Calvo (1983) and emphasizes the forward-looking behaviour of subjects on the market and sticky prices framework. One of the key New Keynesian models based on these assumptions is generally known as the New Keynesian Phillips curve (NKPC). The term was originally used by Roberts (1995) and empirically supported by Sbordone (2002a, 2002b), Galí and Gertler (1999) and Galí et. al (2001). Galí and Gertler (1999) also pioneered the estimation of the hybrid NKPC to capture the inflation persistence. Findings of Galí et al. encourage the use of this dynamic general equilibrium models in monetary policy analysis as they suggest that the observed dynamics of inflation can be understood with models derived from microeconomic foundations (Neiss et al., 2002).

The New Keynesian Phillips curve has two distinct features that characterize the relationship between inflation and economic activity. First, it is forward-looking character of inflation that is a consequence of the fact that firms set prices on the basis of their expectations about the future evolution of demand and cost factors. The second feature involves the link between inflation and real activity. The hybrid case of the New Keynesian Phillips curve allows a subset of firms to use the backward-looking rule of thumb to set prices and introduces the lagged inflation term to the former equation. Coefficients of this model are functions of three structural parameters: probability of price adjustment, the share of forward-looking firms on the market and subjective discount factor.

In our dissertation thesis we analyse monetary policy applying the New Keynesian Phillips curve. We present the derivation of the selected important NKPC models including several open economy versions of the NKPC. Moreover, we summarize possible approximations of the real marginal cost via output gap, real unit labour costs, unemployment, etc. These topics are discussed in chapter 2.

In the next chapter 3 we introduce a part of the great amount of the literature that has appeared in the last years and has discussed the topic of the NKPC.

A comparison of the two widely applied estimation techniques, Generalized Method of Moments (GMM) and Full Information Maximum Likelihood (FIML) represents one of the main goals of the thesis. Although, the GMM is popular method for estimation of the NKPC, many papers critical to this approach appeared in last years (Lindé, 2005, Mavroeidis, 2005 and 2006, Stock et al., 2002, Menyhért, 2008, Rudd and Whelan, 2005). Besides other issues, they also focus on the small sample bias, weak instruments and the inclusion of omitted variables in the instrument set. These results recommend the FIML over the GMM also in misspecified models.

We estimate New Keynesian Phillips curve for the Czech Republic and compare estimation methods. While GMM is not able to eliminate bias, FIML confirms its superior properties and allows us to estimate significant structural coefficients. Moreover, we compare obtained results with the results for advanced economies and analyse the convergence of the Czech Republic to EU through their inflation dynamics.

All these issues are discussed in chapter 4 which is based on the study Danišková and Fidrmuc (2011) published in Czech Economic Review 5(2).

In the next chapter we review the available literature on the hybrid NKPC. Henzel and Wollmershaeuser (2008) offer interesting comparison of the papers dealing with the NKPC from various points of view, e.g. selected estimation method, the usage of survey data instead of rational expectations, etc. However, in our opinion the quantitative approach is absent in the literature. Therefore we employ meta-analysis (Stanley and Jarrell, 1989) which minimizes potential subjective contribution of authors and does not follow the majority compromise in the presented issue. Moreover, meta-analysis enables to detect whether publication selection (Stanley, 2005) in this type of literature exists and to estimate genuine effect adjusted from the identified publication bias. Another important aspect of meta-analysis lies in possibility to identify important characteristics of studies and authors that significantly influence estimated effect (Havránek and Iršová, 2011, Rose and Stanley, 2005, Doucouliagos, 2005, Feld and Heckemeyer, 2011, Stanley, Doucouliagos and Jarrell, 2008).

We analyse the forward-looking coefficient in the NKPC from almost 200 studies and identify significant publication selection in the most influential journals. Lower but still significant bias is present in all journals as well. Consequently, genuine effect cleaned from the bias is lower by one third than sample average. We also collect characteristics of the studies and authors, and analyse their impact on the published estimates. The structure of the NKPC, underlying data, selected estimation method, authors' and study's properties have significant impact on the weight of the inflation expectations term.

Meta-analysis methodology and results are available in chapter 5 which is based on the working paper *Meta-analysis of the New Keynesian Phillips curve* submitted to Journal of Macroeconomics (Fidrmuc and Danišková, 2012).

We conclude in the last chapter of the dissertation thesis.

2

New Keynesian Phillips curve

2.1 Pure forward-looking case

The New Keynesian Phillips curve is one of the key New Keynesian models. It is derived from Calvo time-dependent sticky-pricing model (Calvo, 1983). Even though there are more realistic formulations as Taylor (1980) and Fischer (1977), Calvo pricing is more comfortable, simple and gives very similar results in comparison to more complicated models.

The key difference of NKPC from traditional Phillips curve lies in the explicit derivation from the optimizing behaviour of price setters. This approach produces several advantages. First, NKPC is an exempt from Lucas critique, second, it depends on structural parameters as price update periodicity and discount factor of future payments and finally the correct driving variable of inflation dynamics is the real marginal cost.

We present the derivation of the New Keynesian Phillips curve following Galí and Gertler (1999).

2.1.1 Calvo pricing

Galí and Gertler (1999) consider a continuous environment of monopolistically competitive firms.[1] These firms are basically identical with the exception of differentiated products and pricing history. Also each faces a conventional constant price elasticity of demand curve for its own product. Their pricing decision is based on a monopolistic competitor's loss minimization problem according to the constraint of time dependent price adjustment.

Let $(1-\theta)$ be a random fraction of firms that are going to adjust their price in any given period.[2] It can also be interpreted as fixed probability that the firm will adjust its price in a given period, i.e. θ is defined as the measure of price-stickiness. If $\theta = 0$, it means no price rigidities, every firm updates its price every period.

Consequently, the average time during which the price remains unchanged is equal to

$$(1-\theta)\sum_{k=0}^{\infty} k\theta^{k-1} = \frac{1}{1-\theta} \tag{2.1}$$

where k is the period of price update.[3] In other words, the average time is equal to the weighted average of these periods, where weights are probabilities that prices will be fixed for $(k-1)$ periods and changed in the period k.

Then every firm i on the market sets its price P_{it} at the time t and the new aggregate price level P_t settled at time t can be computed as follows

$$P_t = \left(\int_0^1 P_{it}^{1-\eta} di\right)^{\frac{1}{1-\eta}},$$

where η is the price elasticity. Since firms are identical ex ante, let Z_t^* be the optimal reset price defined by the $(1-\theta)$ fraction of firms that change their price in the period t. The price settled by the θ-fraction of firms that do not change the price is equal to the price from preceding period. Consequently the previous expression might be rewritten as

$$P_t = \left((1-\theta)(Z_t^*)^{1-\eta} + \theta P_{t-1}^{1-\eta}\right)^{\frac{1}{1-\eta}}. \tag{2.2}$$

[1]Monopolistically competitive markets are characterized by many producers and many consumers in a given market; consumers have clearly defined preferences and sellers attempt to differentiate their products from those of their competitors, the goods and services are heterogeneous; there are few barriers to entry and exit; producers have a degree of control over price on the market.

[2]Parameter θ is from the interval $[0, 1]$.

[3]If $\theta = 0.75$ in a quarterly model then the average time prices are fixed is four quarters, i.e. one year.

A log-linearisation of (2.2) around a zero inflation steady-state yields[4]

$$p_t = (1-\theta)z_t^* + \theta p_{t-1}, \tag{2.3}$$

where p_t and z_t^* are percent deviations from their zero-inflation steady states.[5]

Thus, the aggregate price level on the market is a convex combination of the last year's price level and the optimal reset price with respect to θ. So far, we do not know the value of the optimal reset price z_t^*. Its derivation is presented in the next section (Whelan, 2005).

2.1.2 Optimal reset price

Firms try to minimize the value of their future losses expressed by loss functions and in such way find the optimal value of the reset price. The loss functions are identical and they have the following form

$$L(z_t) = \sum_{k=0}^{\infty} (\theta\beta)^k \, \mathbf{E}_t (z_t - p_{t+k}^*)^2,$$

where $\beta \in (0,1)$ is a subjective discount factor, z_t is the reset price, p_t^* is the optimal price that firm would set at the time t if there were no price rigidities and $\mathbf{E}_t$ is the expectations operator conditional on information available in period t. Difference between the reset price and the optimal price is weighted by $(\theta\beta)^k$ because future effects of inappropriate price have lower power since the reset price will not persist for a long time. Infinite future is regarded as soon as we do not know the length of the period during the price remains unchanged.

The derivation of the loss function leads to the first order condition for the optimal reset price z_t^*:

$$2\sum_{k=0}^{\infty} (\theta\beta)^k \, \mathbf{E}_t (z_t^* - p_{t+k}^*) = 0.$$

If z_t^* is separated out from p_t^*, it implies

$$z_t^* \sum_{k=0}^{\infty} (\theta\beta)^k = \sum_{k=0}^{\infty} (\theta\beta)^k \, \mathbf{E}_t \, p_{t+k}^*,$$

[4]The derivation is presented in appendix A.

[5]Lower case letters' variables stand for a log deviation from the zero inflation steady state.

where

$$\sum_{k=0}^{\infty}(\theta\beta)^k = \frac{1}{1-\theta\beta}.$$

Thus, firms determine their optimal reset price as

$$z_t^* = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k\,\mathbf{E}_t\{p_{t+k}^*\},$$

where we consider the optimal price p_t^* to be the fixed markup μ over deviation of the nominal marginal cost mc_t from the steady state

$$p_t^* = \mu + mc_t.$$

Finally we get

$$z_t^* = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k\,\mathbf{E}_t\{\mu + mc_{t+k}\}. \tag{2.4}$$

Hence, the optimal reset price is defined as the weighted average of the mark-up over the future marginal cost. If $\theta = 0$, what means no price rigidities, then $z_t^* = \mu + mc_t$. In this case, firms do not need to take into account future, because they are able to change their price every period. Future becomes relevant only when there is a price rigidity ($\theta > 0$).

Equation (2.4) may be considered as the solution of the first-order stochastic difference equation

$$y_t = ax_t + b\,\mathbf{E}_t\,y_{t+1}, \tag{2.5}$$

that is obtained by stepwise substitution of $\mathbf{E}_t\,y_{t+k}$ for $k > 0$:

$$y_t = a\sum_{k=0}^{\infty}b^k\,\mathbf{E}_t\,x_{t+k}. \tag{2.6}$$

If we substitute a, b, y_t and x_t for $a = 1-\theta\beta$, $b = \theta\beta$, $y_t = z_t^*$ and $x_t = \mu + mc_t$ in (2.6), then naturally, the optimal reset price z_t^* must obey this first-order stochastic difference equation (2.5) rewritten as

$$z_t^* = \theta\beta\,\mathbf{E}_t\,z_{t+1}^* + (1-\theta\beta)(\mu + mc_t). \tag{2.7}$$

Further, from (2.3) the term z_t^* can be expressed as

$$z_t^* = \frac{1}{1-\theta}(p_t - \theta p_{t-1}). \tag{2.8}$$

By substituting (2.8) into (2.7) we obtain

$$\frac{1}{1-\theta}(p_t - \theta p_{t-1}) = \frac{\theta\beta}{1-\theta}(\mathbf{E}_t\, p_{t+1} - \theta p_t) + (1-\theta\beta)(\mu + mc_t)$$

what can be treated in the following way:

$$\begin{aligned}
\frac{1}{1-\theta}(p_t - p_{t-1} + p_{t-1} - \theta p_{t-1}) &= \frac{\theta\beta}{1-\theta}(\mathbf{E}_t\, p_{t+1} - p_t + p_t - \theta p_t) + (1-\theta\beta)(\mu + mc_t)\\
\frac{1}{1-\theta}(p_t - p_{t-1}) + p_{t-1} &= \frac{\theta\beta}{1-\theta}(\mathbf{E}_t\, p_{t+1} - p_t) + \theta\beta p_t + (1-\theta\beta)(\mu + mc_t)\\
\frac{1}{1-\theta}(p_t - p_{t-1}) + p_{t-1} - p_t &= \frac{\theta\beta}{1-\theta}(\mathbf{E}_t\, p_{t+1} - p_t) + \theta\beta p_t - p_t + (1-\theta\beta)(\mu + mc_t)\\
\frac{1}{1-\theta}(p_t - p_{t-1}) - (p_t - p_{t-1}) &= \frac{\theta\beta}{1-\theta}(\mathbf{E}_t\, p_{t+1} - p_t) - (1-\theta\beta)p_t + (1-\theta\beta)(\mu + mc_t)\\
\frac{\theta}{1-\theta}(p_t - p_{t-1}) &= \frac{\theta\beta}{1-\theta}(\mathbf{E}_t\, p_{t+1} - p_t) + (1-\theta\beta)(\mu + mc_t - p_t).
\end{aligned}$$

Multiplying by $\frac{1-\theta}{\theta}$ and replacing term $(p_t - p_{t-1})$ by inflation π_t we get

$$\pi_t = \beta\, \mathbf{E}_t\, \pi_{t+1} + \lambda(\mu + mc_t - p_t), \tag{2.9}$$

where

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

According to (2.9) the current inflation π_t is the function of expected inflation $\mathbf{E}_t\, \pi_{t+1}$ and the gap between the optimal price level $\mu + mc_t$ and the current price level p_t. We consider the term $\mu + mc_t - p_t$ to be equal to the real marginal cost mc_t^r.

Thus, the *New Keynesian Phillips curve* takes reduced form

$$\pi_t = \beta\, \mathbf{E}_t\, \pi_{t+1} + \lambda mc_t^r + \varepsilon_t \tag{2.10}$$

with $\lambda = \frac{(1-\theta)(1-\theta\beta)}{\theta}$ and i.i.d. disturbance term ε_t accounting for unobserved innovation process.

It can be noticed that coefficient λ depends negatively on θ and β. Thus, the higher θ is, the less sensitive inflation is to the value of the real marginal cost. And if $\theta = 1$ what means absolute price rigidities then $\lambda = 0$ and

$$\pi_t = \beta\, \mathbf{E}_t\, \pi_{t+1}.$$

Hence, current inflation is determined only by the expected inflation for the next period multiplied by subjective discount factor.

Above derived forward-looking model assumes expectations to be rational based on available information. Using survey data for expected inflation term breaks this assumptions since it incorporates possible subjectivity and non-rationality. Model assuming survey data instead of rational expectations is derived by Adam and Padula (2003). One of key differences is that firm's forecasts are produced by finite number of professional forecasters. The subjective forecast estimated by forecaster i based on information available at t is denoted by F_t^i. The resulting NKPC is similar to the previous model:

$$\pi_t = \beta \bar{F}_t \pi_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta} mc_t^r + \epsilon_t, \tag{2.11}$$

where

$$\bar{F}_t = \frac{1}{I} \sum_{i=1}^{I} F_t^i.$$

The model holds in case professional forecasters can not expect that current forecasts of future variables will be revised in the next periods. Such condition is specified as

$$F_t^i [F_{t+1}^h mc_{t+s} - F_t^h mc_{t+s}] = 0 \quad \forall s > 0; i, h = 1, \ldots, I.$$

2.2 Hybrid New Keynesian Phillips curve

Fuhrer (1997) suggests that the pure forward-looking specification of NKPC is empirically unsuccessful in explaining inflation behaviour. Critique of the NKPC is summarized in Mankiw (2001) as well. Its failure comes from the inability to catch inflation persistence, the implication that disinflation can be achieved without any cost[6] and incapability of generating empirically plausible impulse response functions to monetary policy shocks. Fuhrer (1997) proposes to improve the forward-looking model upon the backward-looking price specification to capture inflation persistence. In this section we introduce the backward-looking behaviour to the New Keynesian Phillips curve following Galí and Gertler (1999).

A high degree of persistence is an inherited feature of inflation. It is based not only on the rational expectations but also on the persistence of the agents' behaviour on the

[6]The second property is obvious from the NKPC rewritten by substituting expected inflation term to $\pi_t = \lambda \sum_{i=1}^{\infty} \beta^i \, \mathbf{E}_t \, mc_{t+i}^r$ and if credible monetary authority is able to accomplish steady and balanced path of the future real activity.

market. Agents often use past information in addition to the expectation formation. For this reason instead of one type of the firm in Section 2.1, we consider two types of firms co-existing with different strategies of the price policy. While the first type behaves analogous to *Calvo pricing*, the second type uses the backward-looking *rule of thumb* for its price setting. At the same time we still assume $(1-\theta)$ to be a random fraction of firms that are going to adjust their price in any given period.

Thus, according to the previous section, the aggregate price level is equal to

$$p_t = \theta p_{t-1} + (1-\theta) z_t^*, \tag{2.12}$$

where z_t^* is the optimal reset price settled for period t.

Since we have two types of firms, let $(1-\omega)$ be the fraction of firms which we consider as forward-looking and p_t^f denotes the price determined by the forward-looking firm at the time t.[7] Then ω is the fraction of backward-looking firms and p_t^b is the price set by the backward-looking firm at the time t. Consequently the optimal reset price is the convex combination of the forward-looking and backward-looking behaviour:[8]

$$z_t^* = (1-\omega) p_t^f + \omega p_t^b. \tag{2.13}$$

We also assume that $(1-\omega)$ of the forward-looking and ω of the backward-looking subjects on the market form $(1-\theta)$ part of the market (regardless of the value as well as the distribution of the whole market).

As we mentioned above, the forward-looking fraction of firms behaves exactly as in the baseline Calvo model. Therefore, p_t^f may be written in the following way

$$p_t^f = (1-\theta\beta) \sum_{k=0}^{\infty} (\theta\beta)^k \, \mathbf{E}_t \{\mu + mc_{t+k}\}. \tag{2.14}$$

The Equation (2.14) is the solution of first-order stochastic difference equation (2.5) with $a = 1-\theta\beta$, $b = \theta\beta$, $y_t = p_t^f$ and $x_t = \mu + mc_t$:

$$p_t^f = \theta\beta \, \mathbf{E}_t \, p_{t+1}^f + (1-\theta\beta)(\mu + mc_t). \tag{2.15}$$

Further, concerning the backward looking behaviour, p_t^b is set by the *rule of thumb* as a sum of the optimal reset price from the previous period and a correction of lagged

[7] Coefficient ω is from the interval $[0, 1]$.

[8] It can be noticed that the derivation of this equation is based on the same principles as the derivation of the Equation (2.3).

inflation (used to forecast current inflation):

$$p_t^b = z_{t-1}^* + \pi_{t-1}. \tag{2.16}$$

A rule of thumb has three important features according to Galí and Gertler (1999):

- in a steady state equilibrium the rule is consistent with optimal behaviour, i.e. $p_t^b = z_{t-1}^*$.
- the price settled by this rule depends only on a past information (information dated $t-1$ or earlier).
- this rule indirectly includes the future information, since the optimal reset price from the previous period z_{t-1}^* is partly given also by forward-looking firms that set their prices as infinite sums of a markup over the expected nominal marginal cost. However, this feature is valid only in the case of small fraction of backward-looking firms.

Combining previous equations we are able to derive the hybrid case of NKPC:[9]

$$\pi_t = \gamma_f \, \mathbf{E}_t \, \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda mc_t^r + \varepsilon_t, \tag{2.17}$$

where coefficients are functions of structural parameters

$$\begin{aligned} \gamma_f &\equiv \theta\beta\phi^{-1} \\ \gamma_b &\equiv \omega\phi^{-1} \\ \lambda &\equiv (1-\beta\theta)(1-\omega)(1-\theta)\phi^{-1} \end{aligned}$$

with $\phi \equiv \theta + \omega[1-\theta(1-\beta)]$.

All the coefficients of the hybrid NKPC are functions of three model parameters: $(1-\theta)$, $(1-\omega)$ and β. As well as in the previous section, higher measure of price stickiness θ reduces the sensitivity of inflation to the real marginal cost. The hybrid NKPC has also other interesting features:

- if there is no price rigidity on the market ($\theta = 0$), then $\pi_t - \pi_{t-1} = \frac{1-\omega}{\omega} mc_t^r$. Thus, the growth of the inflation rate depends on the change of real marginal cost's percent deviation from the steady state multiplied by the ratio of the forward-looking and the backward-looking fraction of the firms.

[9]Entire procedure is presented in appendix B.

- if all firms are forward-looking ($\omega = 0$), the hybrid NKPC converges to the NKPC introduced in the previous section.
- subjective discount factor $\beta = 1$ corresponds to the $\gamma_f + \gamma_b = 1$.

The last feature is obvious from expression

$$\gamma_f + \gamma_b = 1 - \frac{\theta(1-\beta)(1-\omega)}{\theta + \omega[1-\theta(1-\beta)]}$$

derived by few elementary substitutions. What is also interesting, the expression implies that values of structural parameters from defined intervals are available only in case $\gamma_f + \gamma_b \leq 1$.

2.3 Real marginal cost

The NKPC can not be directly estimated due to the missing data on the real marginal cost. National accounts data do not contain the information about the cost of additional unit of output. In the literature, there are generally described two approaches where the real marginal cost is replaced by an appropriate proxy variable.

2.3.1 Approximation by the output gap

The real marginal cost is generally known to be procyclical variable. Once when output is higher than its potential level, there is more competition for available factors of intermediate consumption and consequently the real marginal cost increases.[10] Written in the algebraic language

$$mc_t^r = \kappa x_t,$$

where output elasticity κ is a positive constant and x_t is the output gap defined as the difference between the log of real output y_t and the log of the natural or potential level of output y_t^*:

$$x_t = y_t - y_t^*.$$

[10] Galí and Gertler (1999) emphasize that relation between the real marginal cost and the output gap is proportional as soon as the standard sticky price framework without variable capital is taken into account. Otherwise this relation remains very close to proportional.

Then the NKPC can be rewritten as

$$\pi_t = \gamma_f \, \mathbf{E}_t \, \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda \kappa x_t + \varepsilon_t.$$

Disadvantage of this approach lies in the possible systematic bias due to the error arisen during the computation of the potential level of output. Moreover, the presence of nominal rigidities, supply shocks are likely to move detrended output and the true output gap in the opposite directions.

Widely used measures of potential output level are (1) quadratically detrended real GDP and (2) detrended real GDP using HP filter with smoothing parameter 1600 for quarterly data. Zhang (2009) presents other possible measures of output gap but with no significant impact on overall results in comparison to above mentioned measures.

2.3.2 Approximation by real unit labour costs

In the second approach we assume the Cobb-Douglas production technology with output specified as

$$Y_t = A_t K_t^{\alpha_k} N_t^{\alpha_n}, \tag{2.18}$$

where A_t is the technology, K_t is the amount of capital, N_t amount of labour force and α_k and α_n denote shares of production factors on total output.

The real marginal cost is defined by the ratio of the wage rate to the marginal product of labour:

$$MC_t^r = \frac{W_t}{P_t} \frac{1}{\frac{\partial Y_t}{\partial N_t}}.$$

Taking first derivation of (2.18) with respect to N_t, we obtain

$$MC_t^r = \frac{1}{\alpha_n} \frac{W_t N_t}{P_t Y_t} = \frac{S_t}{\alpha_n},$$

where S_t is the labour income share or equivalently real unit labour costs (RULC).

Consequently, lower case letters stand for a percent deviation from the steady state that takes the following form

$$mc_t^r = log(MC_t^r) - E[log(MC_t^r)] = log\left(\frac{S_t}{\alpha_n}\right) - E\left[log\left(\frac{S_t}{\alpha_n}\right)\right] = s_t.$$

Now we are able to rewrite NKPC as follows

$$\pi_t = \gamma_f \, \mathbf{E}_t \, \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda s_t + \varepsilon_t.$$

Real unit labour costs are inertial because of wage rigidities. Such property allow them to capture part of the inflation persistence.

Mazumder (2008) criticizes derivation presented above giving two claims: (1) calculated RULC seems to be countercyclical and (2) allows freely adjustment of the labour input at a fixed real wage rate. Therefore he derives new measure of labour share by splitting labour into employment N_t and worked hours H_t with assumption of employment to be quasi-fixed. Then RULC can be calculated as

$$s_t = \frac{1}{1-\alpha}\left(\frac{N_t H_t}{Y_t}\right)\omega_t[1 + p_t(\nu(H_t) + H_t\nu'(H_t))],$$

where ω_t stands for straight-time real wage rate, p_t is the overtime premium paid on top of the w_t for overtime hours per worker and $\nu(H_t)$ is the ratio of overtime hours to average hours per worker, which is dependent on the average number of hours worked. Such measure is procyclical for U.S. data as the theory suggests.

Besides approaches described above, traditional way of using unemployment variable in the Phillips curve is still applied. Examples of estimations of the NKPC with unemployment may be found in Blanchard and Galí (2007) and Russel (2011). On the other hand, if the NKPC should be accommodated for open economies, real marginal cost is usually updated to incorporate variable describing relationship between domestic country and rest of the world. This topic is closely described in the next section.

2.4 Examples of open economy NKPC

New Keynesian Phillips curve does not contain any indicators of foreign policies and development which may be important for inflation dynamics. Therefore many authors introduce open economy NKPCs with additional variables related to the import prices, foreign inflation, terms of trade, etc. We present some examples of the open economy NKPC and their derivation in this section.

With respect to Kara and Nelson (2005) and McCallum and Nelson (1999) hybrid case of NKPC can be extended to open economy model by two different assumptions: (1) imported goods are specified as final consumption goods or (2) as intermediate production goods.

The first case allows consumers to choose between domestic and imported goods, i.e. the overall inflation rate is a convex combination of domestic inflation rate π_t^d

and imported goods inflation rate π_t^m defined in foreign currency and adjusted by the depreciation rate of the domestic currency Δe_t[11]

$$\pi_t = (1-s)\pi_t^d + s(\pi_t^m + \Delta e_t)$$

with full pass-through on the prices of imported goods assumed.

Real exchange rate is defined as $q_t = p_t^m + e_t - p_t^d$ where p_t^d stands for the domestic price level, p_t^m for the imported goods price level and e_t for the exchange rate between domestic and foreign currency. Rearrangement of both equations gives

$$\pi_t^d = \pi_t - s\Delta q_t. \tag{2.19}$$

Combination of (2.19) with closed economy NKPC (2.17) rewritten as

$$\pi_t^d = \gamma_f \mathbf{E}_t \pi_{t+1}^d + \gamma_b \pi_{t-1}^d + \lambda mc_t^r$$

and applying restriction $\gamma_f + \gamma_b = 1$ yields to the first type of open economy NKPC

$$\pi_t = \gamma_f \mathbf{E}_t \pi_{t+1} + \gamma_b \pi_{t-1} - s\gamma_f(\mathbf{E}_t \Delta q_{t-1} - \Delta q_t) + s\gamma_b(\Delta q_t - \Delta q_{t-1}) + \lambda mc_t^r. \tag{2.20}$$

Comparing to the closed economy NKPC, current inflation rate also depends negatively on the expected future and positively on the current change of real depreciation rate.

The second open economy NKPC considers imported goods as intermediate production goods. This has an impact on the definition of real marginal cost. If we assume Cobb-Douglas production function

$$y_t = \alpha(z_t + l_t) + (1-\alpha)y_t^m,$$

where y_t stands for gross output, z_t for labour technology shock and y_t^m for index of imported differentiated intermediate goods then newly derived real marginal cost is defined as

$$mc_t^r = \alpha(w_t - z_t) + (1-\alpha)q_t$$

with real wage w_t, real costs of the unit of imported good q_t and the assumption that the price of one unit of the imported intermediate good is $p_t^m + e_t$. Substituting new mc_t^r into closed economy NKPC (2.17) leads to

$$\pi_t = \gamma_f \mathbf{E}_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda\alpha(w_t - z_t) + \lambda(1-\alpha)q_t. \tag{2.21}$$

[11] Again all lower case letters stands for natural log deviations from steady state. Moreover, notation in this chapter follows notation of original papers.

Similar approach is used by Genberg and Pauwels (2005) who apply this model to describe inflation dynamic in Hong Kong.

The approach of Galí and Monacelli (2005) derives the open economy NKPC by introducing new external macroeconomic variable, the change in terms of trade. Mihailov et al. (2011) extend this model to

$$\pi_t = \beta\,\mathbf{E}_t\,\pi_{t+1} + \kappa_\alpha x_t + \alpha(\Delta s_t - \beta\,\mathbf{E}_t\,\Delta s_{t+1}),$$

where s_t is the natural log of the terms of trade.[12] Detailed derivation may be found in Galí and Monacelli (2005) and Mihailov et al. (2011). However, results of Mihailov et al. (2011) do not find much empirical support for the model.

Literature on open economy NKPC was also influenced by Batini et al. (2005) who concentrate on United Kingdom. Their version adjusts NKPC to

$$\begin{aligned}\pi_t = \alpha_0 + \phi\,\mathbf{E}_{t-1}\,\pi_{t+1} + \alpha_1\,\mathbf{E}_{t-1}\,z_{pt} + \alpha_{11}\,\mathbf{E}_{t-1}(y_t - y_t^*) + \alpha_{12}\,\mathbf{E}_{t-1}(p_t^w - p_t^*)\\ + \alpha_1\,\mathbf{E}_{t-1}\,s_{Lt} + \alpha_{13}\,\mathbf{E}_{t-1}(p_{mt} - p_t) + \alpha_2\phi\,\mathbf{E}_{t-1}\,\Delta n_{t+1} + \alpha_2\,\mathbf{E}_{t-1}\,\Delta n_t + v_t,\end{aligned} \tag{2.22}$$

where z_{pt} stands for changes as variation in the rigour of anti-trust regulation or the extent of trade barriers, $(y_t - y_t^*)$ is the deviation of output from its trend and p_t^w is the world price of domestic GDP in domestic currency terms. Moreover, open economy NKPC also contains s_{Lt} which stands for share of labour, p_{mt} is price of imported materials and finally Δn_t is change in employment. Batini et al. (2005) provide empirical evidence that equation (2.22) is important in explaining inflation dynamics in United Kingdom.

Berk and Swank (2007) are motivated by study of price level convergence in US and EMU. Their open economy NKPC can be considered as simplified representation of the more general specification (2.22) developed by Batini et al. (2005) and it is specified as

$$\pi_t = \theta_1\pi_{t-1} + (1-\theta_1)\,\mathbf{E}_{t-1}\,\pi_{t+1} + \theta_2\,\mathbf{E}_{t-1}\,\pi_{t+1}(x_t - \bar{x}_t) - \theta_3\,\mathbf{E}_{t-1}(e_t - \bar{e}_t) + \bar{d}_t + \varepsilon_t, \tag{2.23}$$

where $0 \le \theta_1 \le 1$ measures inflation persistence, θ_2 and θ_3 are both positive and $\bar{d}_t$ reflects a linear combination of the steady state levels of the (expected) inflation rates in the equation. Deviation of real marginal cost from its steady state is expressed by $(x_t - \bar{x}_t)$ and deviation of real exchange rate by $(e_t - \bar{e}_t)$.

[12] Terms of trade is calculated as the ratio of the import deflator to the export deflator.

Vašíček (2009a) aggregates various approaches and develops the open economy NKPC by simply introducing all possible determinants of inflation dynamics, both domestic and foreign. Such construction yields to

$$\pi_t = \alpha + \beta_1 \pi_{t-1} + \beta_2 \, \mathbf{E}_t \, \pi_{t+1} + \gamma y_{t-1} + \delta \pi_t^{for} + \eta s_{t-1} + \mu i_{t-4} + u_t. \qquad (2.24)$$

Variable y_{t-1} is defined as lagged output gap, π_t^{for} stands for foreign inflation rate and s_{t-1} is lagged exchange rate. Domestic interest rate i_{t-4} enters with four lags since the horizon of the monetary transmission is around one year. Vašíček (2009a) uses this model to examine inflation process in the twelve new member states. Similar model is applied in Vašíček (2009b).

3

Literature review

In the last decade, the NKPC has become an inherent part of monetary policy models. Its major advantage over the traditional Phillips Curve is its structural interpretation, which can be used in policy analysis. The recent literature is built on the work of Calvo (1983) and it is based on the concept of sticky prices and price setting decision of the forward-looking and/or backward-looking subjects on the market. Since new settled prices depend also on some measures of real activity, aggregating leads to the relation which is in the spirit of traditional Phillips Curve. In the following paragraphs we conclude recent major results affecting the NKPC.

3.1 Standard approach

Galí and Gertler (1999) create an important benchmark for most of future discussions and pioneered an approach of estimation of the hybrid NKPC. They extend the baseline model of the NKPC by introduction of the backward-looking behaviour. According to their approach, the inflation expectations term is found to be an important determinant of inflation dynamics with coefficient around 0.7 while the backward-looking term is statistically significant with limited quantitative importance. Moreover, real unit labour costs are preferred to catch up inflation persistence with coefficient being around 0.03 while the output gap measure of real marginal cost failed with negative slope coefficient and/or being insignificant:

> "Our analysis of data suggests that movements in our measure of the real marginal cost tend to lag movements in output, in direct contrast to the identifying assumptions that imply a co-incident movement." (Galí and Gertler, 1999, p. 8.)

In the subsequent research, Galí et al. (2001) present the NKPC for the euro area between 1970 and 1998. They relax the assumption that firms face identical constant marginal costs and they compare the characteristics of European inflation dynamics with those observed in the USA. The hybrid NKPC seems to possibly fit the euro area data better than the earlier estimations for the USA. Moreover, the forward-looking component was found to be higher for the euro area than for the USA. Similarly as for the US data, sluggish movement in the marginal cost appears to be an important factor accounting for observed high degree of inflation persistence.

These papers caused an intense discussion in recent years. The question is whether the NKPC is the appropriate measure of inflation dynamics. Raised issues may be divided into the five areas: (1) the assumption of rational expectations versus usage of expected inflation survey data, (2) the real marginal cost approximation with output gap, real unit labour costs, etc., (3) the relevance of lagged inflation term or the issue of the pure forward-looking model, (4) the selection of appropriate estimation method and dealing with the error term serial correlation, structural changes in data, weak instruments and weak identification, etc., and (5) the enhancement of the NKPC for small open economies. We go through some of these issues in detail.

3.2 Rational expectations versus survey data

Galí and Gertler (1999) assume rational expectations implying that the expected inflation term $E_t(\pi_{t+1})$ can be substituted with realized future inflation and forecasting error term.[1] Thus, equation (2.17) can be transformed to

$$\pi_t = \gamma_f \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda mc_t^r + e_t \tag{3.1}$$

[1]The relationship between expected inflation and future inflation may be expressed as $\pi_{t+1} = E_t \pi_{t+1} + \nu_t$, where ν_t stands for a forecasting error with zero mean, which is not predictable using information available at time t.

with $e_t = \varepsilon_t - \gamma_f \nu_t$. However, future inflation is endogenous because the error term also includes the forecasting error, ν_t[2]. Therefore, equation (3.1) can not be estimated by simple OLS.

The rational expectations assumption and endogeneity problems are avoided if inflation forecasts are used directly. Adam and Padula (2003) use data from the Survey of Professional Forecasters. Similarly, Paloviita (2006) uses the OECD forecasts and Henzel and Wollmershaeuser (2008) employ data from ifo World Economic Survey. While Adam and Padula (2003) assume a finite number of professional forecasters that form expectations for a set of firms, Henzel and Wollmershaeuser (2008) take individual firms as individual forecasters. The latter approach allows to introduce the backward-looking subjects in the NKPC while in case of Adam and Padula (2006) it is the problem to find rationale for incorporation of the lagged inflation term. Generally, Adam and Padula (2003) emphasize additional advantages of using survey data in correctly captured agent's expectations and the lack of restrictive assumptions about the precise form of non-rationality.

A departure from the rational expectations assumption leads to a surprising result on the output gap position in the pure forward-looking NKPC formulation. While Galí and Gertler (1999) conclude that the output gap fails to be a relevant proxy, the analysis with survey data shows that the output gap is correctly signed and significant. Adam and Padula (2003) explain it by the difference of $corr(\pi_t, x_t)$ and $corr(\mathbf{E}_t\, \pi_{t+1}, x_t)$[3]. If the correlation of actual inflation with lagged output gap is higher than correlation with contemporaneous output gap, than λ results as negative. This is mostly the case of rational data incorporation. On the other side, correlation of subjective expectations and output gap is much lower than the same for rational expectations. That may lead to the correctly signed coefficient. Another paper dealing with survey measure of inflation expectations is Jean-Baptiste (2011). Again, it concludes that output gap proxy of real marginal cost satisfies theoretical assumptions in case of survey-based inflation forecasts and assumption of rational expectations does not work well in this case.

Adam and Padula (2003) address also the role of lagged inflation. As was already

[2]Generally, correlation between independent variables and error term may occur when (1) the dependent variable causes at least one of the independent variables ("reverse" causation), (2) relevant explanatory variables are omitted from the model or (3) the independent variables are subject to measurement error.

[3]Output gap regression coefficient is equal to $\frac{1}{A}(corr(\pi_t, x_t) - corr(\mathbf{E}_t\, \pi_{t+1}, x_t)B)$; $A > 0$ and $B = corr(\pi_t, \mathbf{E}_t\, \pi_{t+1}) \approx 0.8$ for the US data.

mentioned, the usage of survey data with their assumption of professional forecasters causes the uselessness of lagged inflation term. It is quite intuitive that subjective inflation forecast already incorporate lagged inflation. Therefore mentioned authors investigate regression of lagged inflation on subjective inflation forecast and incorporate regression error term (orthogonalized part of lagged inflation) into NKPC instead of lagged inflation term. Overall, its results are encouraging regarding significance and coefficient's signs. Therefore they suggest to use so called indexation model developed by Christiano, Eichenbaum and Evans (2005). Comparing to Galí and Gertler (1999), all prices change in every period, i.e. there is no price rigidity. Random fraction of price setters reset the price in line with profit maximization decision, the rest update last period price by "indexing" to the last period inflation rate. Consequently, this yields

$$\pi_t = \frac{\beta}{1+\beta}\mathbf{E}_t\,\pi_{t+1} + \frac{1}{1+\beta}\pi_{t-1} + \xi mc_t^r + \varepsilon_t,$$

where β is the discount rate.

Regarding the size of the forward and backward-looking terms in survey based NKPC, Henzel and Wollmershaeuser (2008) compare their results with other similar publications and show that the forward-looking coefficient γ_f seems to be lower in an analysis based on the rational expectations assumption.[4] They explain this puzzle by non-rationalities in survey data. Overall, the backward-looking share is more relevant according to their estimations. These findings are confirmed by Zhang et al. (2009) who use several measures of the output gap and inflation.

Alternatively, Fuhrer (2006) studies the importance of the lagged inflation term in the NKPC under the assumption of rational expectations. He shows that inflation persistence follows from the persistence of real marginal cost. By contrast, Roberts (1997) provides empirical evidence on flexible prices. Hondroyiannis et al. (2009) apply the time-varying coefficient (TVC)[5] method proposed by Chang et al. (2000). The TVC approach suggests that the high weight of lagged inflation in estimates of the NKPC might be due to the specification bias and spurious correlation.

[4]Averages of the forward-looking coefficients reported by Henzel and Wollmershaeuser (2008) are different. While rational expectations average is 0.59, survey data generate an average of 0.4 for US.

[5]The TVC allows to separate the bias-free component of each coefficient from the other components so that specification bias can be corrected.

3.3 Estimation method

Most of authors estimating the NKPC with rational expectations prefer the instrumental variables (IV) methods in order to avoid biased estimates. The instruments should include all exogenous variables available at time t, which are correlated with the endogenous explanatory variables. However, the disadvantage of IV methods is that their results can be sensitive to specification changes, to the proxy for real marginal cost and selected instrument set.

Mavroeidis (2005, 2006) raises issue related to the power of instruments in case of IV estimation methods. Simulation results imply that weak instruments lead to an overestimation of the forward-looking coefficient at all sample sizes and without any tendency to converge to the true value of the coefficient. Stock et al. (2002) provide a deeper discussion of the weak identification problem and the selection of an appropriate test procedure. Menyhért (2008) examines the problem of weak instruments related to the two stage least squares proposed by Lendvai (2005), and suggests the countinuous-updating GMM estimator and the full information maximum likelihood estimator (FIML) as preferred estimation methods. He concludes that the FIML has superior properties in small samples and avoids structural identification analysis that is necessary for GMM. Kleibergen and Mavroeidis (2009) proposed the robust version of GMM estimator which covers weak instrument robust statistics for testing hypotheses on the parameter vector.

Zhang et al. (2009) discuss a possibility of serial correlation in the NKPC as the result of omitted variable. In such case, the usage of inflation lags as instrumental variables would lead to biased and inconsistent estimation results. They hope *"to mitigate the evident serial correlation that is potentially induced by insufficient inflation dynamics"*[6] by introducing additional lags into the price setting of the backward-looking agents.[7] Thus, equation (2.16) may be rewritten as

$$p_t^b = z_{t-1}^* + \rho(L)\pi_{t-1},$$

where $\rho(L) = \rho_1 + \rho_2 L + \rho_3 L^2 + \cdots + \rho_q L^{q-1}$ is a polynomial in the lag operator with $\rho(1) = 1$. Zhang et al. (2009) set optimal lag q based on AIC and serial correlation tests.

[6] Zhang et al. (2009), p. 14.

[7] Additional inflation lags in the NKPC model was already suggested by Galí and Gertler (1999) but without exact derivation.

According to them, newly derived NKPC using survey data and containing additional lags of inflation is generally free from serial correlation.

Rudd and Whelan (2005) present one of the most critical papers about the NKPC. They criticize several issues. Firstly, the pure forward-looking NKPC is inappropriate for monetary analysis because this specification lacks inflation inertia, hence it supports a free trade-off between output and inflation. Secondly, unit labour costs are shown not to be a valid proxy for the real marginal cost because they do not sufficiently follow the cyclical movements of real marginal cost. Most importantly, the GMM is not appropriate for the estimation of the hybrid NKPC because it is subject of an omitted variables problem, while potential omitted variables are included in the instrument set (and correlated with π_{t+1}). Consequently, the influence of omitted variables is captured by a proxy for $E_t\pi_{t+1}$ which leads to an overestimation of γ_f. Similarly, Rudd and Whelan (2005) argue that the lagged inflation role may be captured by the forward-looking term if inflation lags are included in the instrument set. Moreover, the upward bias of the forward-looking estimates may be large when estimating the structural form of the NKPC, rather than the corresponding closed form solution of the model.

Further, Lindé (2005) adds that the GMM estimates may be severely biased in small samples and dependent on changes in monetary policy. Based on Monte Carlo simulations, he concludes that reliable estimates of the NKPC cannot be obtained by single equation methods. Therefore, he favours the FIML that performs well also under model miss-specification and non-normally distributed measurement errors.

Galí et al. (2005) review most of these critical points and conclude that the main conclusions in Galí and Gertler (1999) and Galí et al. (2001) remain intact also under alternative methods of estimation. They conclude that their estimates are robust to a variety of different econometric procedures, including the GMM estimation of the closed form as suggested by Rudd and Whelan (2005) and nonlinear instrumental variables in the spirit of Lindé (2005). They also review publications with similar results using alternative econometric approaches including Sbordone (2005) who presents the two-step minimum distance estimation procedure. Finally, Rudd and Whelan (2007) are not able to reject the hypothesis that inflation and real marginal cost are completely unrelated when using data of Galí and Gertler (1999), only with revised labour share data used as proxy for real marginal cost. This finding suggests that the results in Galí and Gertler (1999) are not robust to revisions of data. Martins and Gabriel (2009) use alternative approach to question these results and conclude that the backward-looking component of inflation is more important than the forward-looking part and the marginal cost variable is not significant.

Jondeau and LeBihan (2006) compare GMM and ML specifications of the NKPC with output gap and RULC. The GMM leads to an overestimation of the forward looking coefficient in both specifications for all selected countries except Italy. Furthermore, Monte Carlo simulations presented by Fuhrer et al. (1995) show that GMM estimates are often statistically insignificant and unstable. A moderate degree of instrument relevance can lead to biased estimates in small samples. Therefore, they support the superior properties of the FIML estimator which is robust, also in miss-specified models and small samples.

At last, NKPC is widely applied in DSGE models used for policy evaluation. This topic is discussed by Smets and Wouters (2003) or Beyer et al. (2008) who focus on the importance of the forward-looking components in the equations of a standard New-Keynesian model.

3.4 NKPC for open and emerging economies

Behind standard analysis for developed countries, numerous authors estimated the NKPC for emerging markets, developing and transition economies. Vašíček (2009a, 2009b) presents NKPC estimates for twelve new EU member states (NMS). His approach is based on the open economy NKPC which covers more broader factors than a typical analysis for closed developed economies. He recommends to focus on the post-reform period with low, one-digit inflation levels. The inflation dynamic of the NMS is found to be highly persistent with the significant forward-looking component. Inflation persistence is also studied by Franta et al. (2007). Their results suggest that inflation persistence in the new member states is comparable to the inflation persistence of earlier member states.

Hondroyiannis et al. (2008) study the effects of monetary policy and economic system changes on inflation dynamic. They show that once NKPC coefficients are allowed to vary, the forward-looking component becomes dominant and leaves the backward-looking behaviour insignificant. Such claim is supported by Zhang et al. (2008, 2009) that also documents structural instability of the NKPC across regimes with substantially different inflation levels.

Stavrev (2009) distinguishes between external and internal forces driving inflation. The inflation is decomposed into a component common to all NMS and country-specific component using generalized dynamic factor model. Results show that over 40% of common inflation variability is explained by external factors, such as price level convergence, energy prices and EU integration (the convergence of nominal interest rates). Determinants of country-specific factor (financial conditions pass-through from foreign prices, real interest rates, nominal effective exchange rate, EU inflation, and demand-supply situation in each country proxied by output gap) also play an important role (they explain over 50% of country specific inflation variability).

Estimations of open economy NKPC derived by Mihailov et al. (2011) present terms of trade to be a moderately better CPI inflation driver comparing to the commonly used output gap for the most sample countries.

Other authors interested in inflation dynamics of emerging countries are Ramos-Francia and Torres (2005) who are concerned in the study of inflation dynamics in Mexico. Their results support the hybrid version of the New Keynesian Phillips curve and lagged inflation to play a key role as an inflation determinant. Patra and Kapur (2010) underline a model estimated for India. Inflation posses persistance and validates the vertical nature of the long-run Phillips curve. Turkish inflation is studied by Saz (2011) who brings novelty in the measure of marginal cost. The forward-looking coefficient is estimated at approximately the same value as the backward-looking one.

Parsely and Popper (2009) use a large data set for Korea and employ GMM in model estimation. Zamulin and Golovan (2007) estimate the NKPC with a trade-off between inflation and exchange rate for Russia. Similarly, Boroditskaya and Whittaker (2007) compare the GMM and the FIML by the estimation of the Russian NKPC. Inflation dynamics in South Africa is examined by Plessis and Burger (2006). Finally there are numerous authors interested in China. Mehrotra et al. (2010) use data for Chinese regions. Funke (2005) explores the relationship between inflation expectations and inflation dynamics in China. Scheibe and Vines (2005) estimate the NKPC in China with a rather low coefficient of the forward-looking behavior at 0.2.

4

Inflation convergence in the Czech Republic *

"Among the central issues in macroeconomics is the nature of short run inflation dynamics. This matter is also one of the most fiercely debated, with few definitive answers available after decades of investigation. At stake, among other things, is the nature of business cycles and what should be the appropriate conduct of monetary policy."

– GALÍ AND GERTLER (1999)

4.1 Introduction

Inflation and inflation dynamic are important indicators of economic development. In particular, the Euro area membership depends crucially on a sustainable stabilization of inflation. Therefore, inflation stabilization was often addressed in the literature, but

*This chapter is based on results from the paper *Inflation Convergence and the New Keynesian Phillips Curve in the Czech Republic* elaborated in cooperation with Jarko Fidrmuc and published in Czech Economic Review (Danišková and Fidrmuc, 2011).

papers have concentrated on the Balassa-Samuelson effect (e.g. Backé et al., 2003, MacDonald and Wójcik, 2008).

Recent theoretical advances have produced alternative views of the inflation process with fundamentally different implications for an optimal monetary policy. One of the key New Keynesian concepts is the New Keynesian Phillips curve. There is a large number of papers on this issue and most of them are looking at developed countries, including especially the USA and the Euro area countries. We try to contribute to the studies on Eastern European countries with an estimation of the hybrid New Keynesian Phillips curve for the Czech Republic during the progressed reform period from 1996 to 2009. Besides that, we compare the Generalized Method of Moments (GMM) and the Full Information Maximum Likelihood (FIML) for the estimation of the NKPC.

In theory, the GMM estimator should be strongly consistent and asymptotically normal. However, Monte Carlo simulations show that GMM estimates are often biased in small samples (Fuhrer et al., 1995, Lindé, 2005). This leads to coefficients which are statistically insignificant. Moreover, as we already discussed in the literature review, the GMM estimator suffers from weak instruments what causes overestimation of the forward-looking coefficient (Mavroeidis, 2005, 2006, Stock and Yogo, 2002, Menyhért, 2008, Jondeau and LeBihan, 2006). Our results support these findings also in case of the Czech Republic. We estimate several specifications of the NKPC using either the output gap or real unit labour costs as a proxy for real marginal cost. The reduced-form estimates yield typically high coefficients of the forward-looking behaviour, while real activity is often negative or insignificant in most cases.

Further, we apply FIML and compare results to those obtained from GMM. They confirm superior properties of FIML which are granted also in misspecified models. Since FIML is invariant to normalizations, we present significant structural estimates as well. The interpretation of results as a frequency of price changes and a share of forward-looking subjects is largely similar to values reported for developed economies. Similarly to Borys et al. (2009), our results confirm that the Czech Republic has already successfully converged to developed market economies.

The chapter is organized as follows. Section 4.2 describes our data set. Section 4.3 presents the results related to the Generalized Method of Moments while section 4.4 focuses on the Full Information Maximum Likelihood. We conclude in section 4.5.

4.2 Data description

We focus on the Czech Republic because disinflation was achieved faster in the Czech Republic than in the remaining Central and Eastern European countries (Fidrmuc, 2009). Therefore, we can use longer time series which were less influenced by monetary regime changes than in other countries (Fidrmuc and Senaj, 2006, Kočenda, 2005, Kočenda and Valachy, 2005, Fidrmuc and Horváth, 2008).

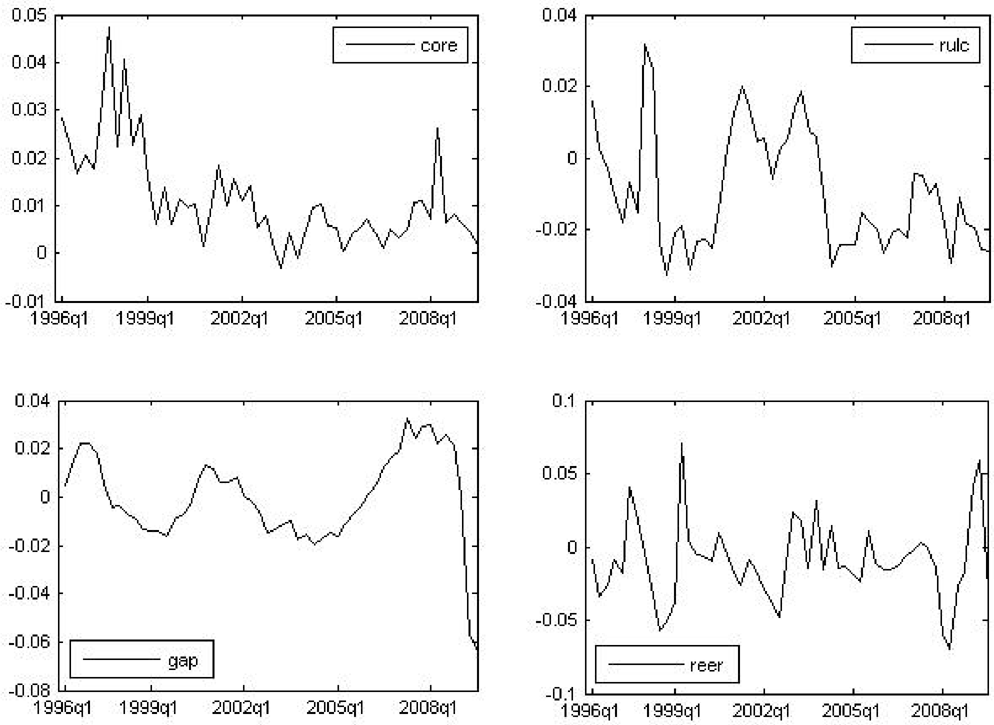

Figure 4.1: Selected time series for the Czech Republic, 1996-2009

Although the Czech Republic is considered to be a small open economy we estimate the hybrid specification of NKPC without open economy extensions discussed in section 2.4. An open economy NKPC generally leads to the mixed results which are not significantly different from standard NKPC what is supported by Mihailov et al. (2011). They do not find overwhelming support for the open economy NKPC derived in Galí and Monacelli (2005) for countries as Austria, Canada, Switzerland, etc. Since we intend to compare different estimation methods we assume NKPC specified by equation (2.17).

We study the period from 1996q1 to 2009q2. The variables are taken from the OECD (Main Economic Indicators) and Eurostat. They include real GDP, real unit labour costs (RULC), consumer prices (CPI), core inflation (defined as consumer prices excluding food and energy), the real effective exchange rate and the short-term interest rate. The variables are displayed in Figure 4.1. GDP, RULC and price variables are in logs and seasonally adjusted. For estimations we use first differences.

We estimate the NKPC applying the iterative GMM with the starting estimates coming from the two stage least squares. Since the GMM assumes stationary time series, the variables are tested for stationarity with DF-GLS and KPSS unit root tests. The detailed results are summarized in Table 4.1 and stationarity may be assumed in all cases with the exception of core inflation. But core inflation is also stationary if unit root tests are performed for a sub-sample period starting in 2000q1.

Table 4.1: Unit root tests for selected time series, 1996-2009

	ADF-GLS H^0: unit root		KPSS H^0: stationarity	
Time series	$stat^c$	$stat^t$	$stat^c$	$stat^t$
core	-1.1174	-2.3979	0.6043**	0.1609*
$core^{\text{from 2000}}$	**-2.7972*** **	-2.8363	**0.1227**	**0.1064**
rulc	**-2.4930** **	**-3.0431***	**0.1491**	**0.0783**
gap	**-2.4928** **	-2.4144	**0.0808**	**0.0827**
reer	**-5.2095*** **	**-6.0749*** **	**0.0564**	**0.0563**

c - test equation includes constant.
t - test equation includes constant and trend.
* - significance at 10%, ** - significance at 5%, *** - significance at 1%.
Bold numbers indicate stationarity.

4.3 Generalized Method of Moments

We estimate several specifications with the output gap and RULC as a proxy for real marginal cost. We use the following orthogonality conditions to form the baseline for the GMM estimation

$$\mathbf{E}_t\{(\pi_t - \gamma_f \,\mathbf{E}_t\, \pi_{t+1} - \gamma_b \pi_{t-1} - \lambda mc_t^r)\mathbf{z}_{t-1}\} = 0,$$

where mc_t^r stands either for the output gap or RULC as a proxy variable for real marginal cost and $\mathbf{z}_t$ is a vector of instrumental variables. We assume that expectations are rational[1]

$$\pi_{t+1} = \mathbf{E}_t\, \pi_{t+1} + \nu_t,$$

with the disturbance term ν_t to be i.i.d. Galí and Gertler (1999) interpret the error term as a "cost-push" shock, while Neiss et al. (2002) refer to this component as a "price-level shock."[2] The analyzed period is characterized by a comparably stable inflationary process which was less influenced by the reform shocks (e.g. price liberalizations) than the earlier periods. We use quarterly data over the period from 1996q1 to 2009q2. Table 4.2 presents the GMM and OLS estimates.[3] We compare four different instrument sets. The first basic set includes three lags of inflation and the proxy for real marginal cost. Then we add three lags of the alternative proxy variable (set 2), the real effective exchange rate (set 3) and the interest rate (set 4). Similar instrument sets were used by Menyhért (2008) for Hungary. The sum of the forward and backward-looking behaviour is restricted to unity. Unrestricted estimates show that the sum would be less than unity in specifications with a larger number of instruments.

The results for the gap specification imply a high weight of forward-looking behaviour. The corresponding coefficients are between 0.613 and 0.756, while the coefficients for backward-looking behaviour are between 0.244 and 0.387. The coefficient of the output gap is, as in the previous literature, negative and insignificant. The specifications with the real unit labour costs proxy put lower weight on future inflation. Both forward and backward-looking parameters are significant while the coefficient for the real marginal cost proxy is again negative (and insignificant) except for two cases. These figures are slightly above values from earlier studies. Vašíček (2009b) for example estimated the reduced-form NKPC for the Czech Republic and obtained γ_f equal to 0.56 for the gap specification and 0.43 for the RULC specification.

The GMM results are surprisingly similar to the OLS estimates[4]. Actually, the GMM

[1] In general, regular quarterly forecasts are not available as an alternative to rational expectations. Moreover, inflation forecasts showed a significant forecast error during the analyzed period (see Antal et al., 2008).

[2] This means that the shock permanently raises the price level, but (provided that monetary policy is non-accomodative) it increases inflation only temporarily.

[3] We set the kernel as Barlett with a fixed Newey-West bandwidth selection. The prewhitening was not applied (prewhitening in our case does not have significant impact on the coefficients and their signs).

[4] OLS estimates are restricted to $\gamma_f + \gamma_b = 1$, the unrestricted estimates are significantly less than one.

Table 4.2: GMM estimates for the Czech Republic

	λ	γ_f	γ_b	J-stat	Part. R^2	Adj. P. R^2	F-stat	S-Y 10%/30%
GAP 1	-0.016	0.613***	0.387*	3.602	0.406	0.344	7.223	11.12/5.15
	(0.032)	(0.204)	(0.204)	(0.463)				
GAP 2	-0.035	0.756***	0.244***	3.929	0.440	0.340	5.249	11.46/4.92
	(0.023)	(0.126)	(0.126)	(0.788)				
GAP 3	-0.026	0.715***	0.285***	5.646	0.633	0.537	5.698	11.52/4.75
	(0.017)	(0.073)	(0.073)	(0.844)				
GAP 4	-0.017	0.664***	0.336***	6.404	0.826	0.764	4.305	11.49/4.63
	(0.015)	(0.065)	(0.065)	(0.930)				
GAP OLS	-0.024	0.516***	0.484***					
	(0.057)	(0.132)	(0.132)					
RULC 1	-0.004	0.638***	0.362***	3.283	0.438	0.379	6.541	11.12/5.15
	(0.025)	(0.122)	(0.122)	(0.512)				
RULC 2	0.002	0.549***	0.451***	4.996	0.531	0.448	5.249	11.46/4.92
	(0.021)	(0.106)	(0.106)	(0.660)				
RULC 3	-0.008	0.652***	0.348***	6.196	0.680	0.596	5.698	11.52/4.75
	(0.018)	(0.084)	(0.084)	(0.799)				
RULC 4	0.001	0.500***	0.500***	6.770	0.848	0.793	4.305	11.49/4.63
	(0.017)	(0.066)	(0.066)	(0.914)				
RULC OLS	-0.054	0.518***	0.482***					
	(0.038)	(0.103)	(0.103)					

Estimated period: 1996q1 - 2009q2.
Standard errors are reported in parentheses below the coefficient's estimates.
p-values are reported in parentheses below J-statistics.
S-Y 10%/30% are Stock-Yogo critical values for Weak IV test statistics for maximal percentage bias.
* - significance at 10%, ** - significance at 5%, *** - significance at 1%.
Instrumental Variables: GAP 1 - core(1, 2, 3), gap(1,2,3); GAP 2 - core(1,2,3), gap(1,2,3), rulc(1,2,3);
GAP 3 - core(1,2,3), gap(1,2,3), rulc(1,2,3), reer(1,2,3); GAP 4 - core(1,2,3), gap(1,2,3), rulc(1,2,3), reer(1,2,3), ir(1,2,3).
Instrumental Variables: RULC 1 - core(1, 2, 3), rulc(1,2,3); RULC 2 - core(1,2,3), rulc(1,2,3), gap(1,2,3);
RULC 3 - core(1,2,3), rulc(1,2,3), gap(1,2,3), reer(1,2,3); RULC 4 - core(1,2,3), gap(1,2,3), rulc(1,2,3), reer(1,2,3), ir(1,2,3).

results for the forward-looking coefficient are higher than the OLS coefficient. This is especially true if we include a parsimonious set of instruments. However, using the GMM with weak instruments often leads to an overestimation of the forward-looking coefficient and misleading sampling errors biased towards the probability limit of the OLS estimator, which may be the case also in our results. The weak instrument problem can arise if future inflation is not sufficiently correlated with the selected instruments.

To test the quality of instruments we employ the Stock and Yogo (2002) test based on the concentration parameter. For instrument set (including a constant) $\mathbf{Z}$ and normally distributed error terms, ε_t and ν_t, the concentration parameter μ^2 is defined as

$$\mu^2 = \boldsymbol{\delta}'\mathbf{Z}'\mathbf{Z}\boldsymbol{\delta}/\sigma_\nu^2,$$

where $\boldsymbol{\delta}$ is the vector of coefficients estimated in

$$\pi_{t+1} = \mathbf{z}_t'\boldsymbol{\delta} + \nu_t.$$

With $\mu^2 \to \infty$, the GMM sampling distribution converges to the normal distribution with zero mean. However, for small values of μ^2, the distribution is nonstandard. To decide whether the instruments are weak we test $H_0 : \boldsymbol{\delta}_{nc} = \mathbf{0}$[5]. High F-statistics indicate high relevance of instrument set and higher μ^2. Their values range between 4.3 and 7.2 (see Table 4.2) in all specifications and they are decreasing with the number of instruments in the instrument set. There are various interpretations of these F-statistics. Stock and Yogo (2002) report critical values for a GMM bias. If F-statistics are higher than the reported critical value for 10% or 30% significance levels, the maximum bias of the GMM will be less than 10% or 30% of the OLS bias. Thus, in our estimations the GMM exceeds 10% in three cases and even 30% in one case for both proxy specifications. The conclusion is that the GMM is only partially able to improve the OLS estimates.

Another approach to detect instrument relevance is the examination of partial R^2 suggested by Shea (1997). Low values of this indicator discredit selected instruments to predict the endogenous variable. In our case, partial R^2 values increase with the number of instruments, as can be expected. Moreover, R^2 depends positively on the number of observations. Therefore we compute also adjusted partial R^2 that takes into account the number of instruments and observations. Both these values suggest the largest instrument set. Comparing with the F-statistics, hence, partial R^2 leads to the opposite results and it does not take into account the growing GMM bias.

Finally, J-statistics show Hansen's (1982) J-statistics of overidentifying restrictions. These test statistics are equal to the value of the GMM objective function multiplied by the number of observations. Reported p-values are all above the 10% significance level and suggest the validity of overidentifying restrictions. However, the disadvantage of

[5]The subscript nc stands for "no constant" because the constant term is not included in the null hypothesis.

J-statistics is that the asymptotic distribution provides only a poor approximation for the finite-sample distribution of estimators.

Overall, the results are not very encouraging since the GMM contains more than 10%, and in one case more than 30%, of the OLS bias. Also estimated coefficients vary with the employed instrument set. The bias of GMM estimates is found by Lindé (2005) and Rudd and Whelan (2005) but they differ in its direction. While Lindé (2005) shows that forward-looking behaviour is downward biased, Rudd and Whelan (2005) favour the backward-looking specification of NKPC. Menyhért (2008) also analysed the two stage least squares and the continuous-updating GMM estimator and concluded that these methods are likely to produce biased estimates. Therefore, Lindé (2005) and Menyhért (2008) recommend using the full information maximum likelihood estimator.

4.4 Full Information Maximum Likelihood

The FIML estimator belongs to the class of full information methods. Specification requires a multiple-equation model formed by a complete system of simultaneous equations which are formulated for each endogenous variable.[6] The advantage of FIML is that it is consistent also for models where the error term does not follow a normal distribution. Moreover, the FIML exploits the full information available in the complete system of simultaneous equations.[7] Our approach follows Menyhért (2008) and Fuhrer et al. (1995). It is formed by the NKPC equation (2.17) and a vector autoregressive model (VAR) containing the endogenous variables collected in a K-dimensional vector $\mathbf{z}_t$ specified as

$$\mathbf{z}_t = \mathbf{c} + \mathbf{M}(L)\mathbf{z}_{t-1} + \mathbf{m}(L)\pi_{t-1} + \boldsymbol{\xi}_t,$$

where $\mathbf{M}(L) = \mathbf{M}_0 + \mathbf{M}_1 L + \mathbf{M}_2 L^2 + \cdots + \mathbf{M}_I L^I$, $\mathbf{m}(L) = \mathbf{m}_0 + \mathbf{m}_1 L + \mathbf{m}_2 L^2 + \cdots + \mathbf{m}_I L^I$, I equals the number of lags and L is the lag operator. $\mathbf{M}_i$ and $\mathbf{m}_i$ are $K \times K$ matrices of coefficients and $\boldsymbol{\xi}_t$ is a vector of residuals. Our set of endogenous variables includes RULC, output gap and the real exchange rate. For each specification we also consider three different lag lengths. The results for gap specification are reported in Table 4.3.[8]

[6] Details on FIML can be found in Hayashi (2000).

[7] This can be turned into a disadvantage in case part of the system is misspecified. In that case, selecting limited-information maximum likelihood is preferable.

[8] We are grateful Jeffrey C. Fuhrer from the Federal Reserve Bank of Boston for providing us the Matlab code for FIML estimations.

Table 4.3: FIML estimates of the NKPC with output gap proxy

GAP	Reduced-form estimates			Structural estimates					
	λ	γ_f	γ_b	θ	ω	β	λ	γ_f	γ_b
V1L1	0.004	0.615***	0.391***	0.876***	0.556***	1.000***	0.005	0.612	0.388
	(0.007)	(0.054)	(0.055)	(0.218)	(0.118)	(0.101)			
V1L2	0.018	0.602***	0.398***	0.827***	0.406***	0.999***	0.014	0.671	0.329
	(0.011)	(0.085)	(0.072)	(0.063)	(0.024)	(0.013)			
V1L3	0.005	0.605***	0.395***	0.860***	0.564***	0.996***	0.006	0.602	0.397
	(0.009)	(0.065)	(0.065)	(0.107)	(0.122)	(0.011)			
V2L1	0.005	0.603***	0.404***	0.875***	0.545***	0.999***	0.0002	0.641	0.359
	(0.017)	(0.089)	(0.105)	(0.184)	(0.117)	(0.079)			
V2L2	0.015	0.605***	0.397*	0.802***	0.516***	0.997***	0.015	0.607	0.392
	(0.024)	(0.189)	(0.210)	(0.056)	(0.094)	(0.017)			
V2L3	0.003	0.604***	0.396***	0.898***	0.592***	0.999***	0.003	0.602	0.397
	(0.003)	(0.048)	(0.048)	(0.072)	(0.099)	(0.002)			
V3L1	0.006	0.617***	0.389***	0.862***	0.524***	0.999***	0.007	0.621	0.378
	(0.006)	(0.042)	(0.044)	(0.112)	(0.105)	(0.094)			
V3L2	0.016	0.598***	0.405***	0.708***	0.514***	0.982***	0.036	0.572	0.423
	(0.010)	(0.062)	(0.061)	(0.030)	(0.085)	(0.024)			
V3L3	-0.001	0.580***	0.419***	0.754***	0.597***	0.990***	0.003	0.612	0.388
	(0.002)	(0.035)	(0.035)	(0.000)	(0.101)	(0.002)			

Estimated period: 1996q1 - 2009q2.
Standard errors are reported in parentheses below the coefficient's estimates.
VKLI stands for VAR(K) and LAG(I); I=1,2,3; K=1,2,3 contains the output gap and is extended with rulc and reer.
* - significance at 10%, ** - significance at 5%, *** - significance at 1%.

The first three rows contain the estimations of VAR with initially only the output gap of different lag lengths. In further specifications the VAR model is extended by RULC and the real effective exchange rate. The central part of the table presents the estimates of structural parameters θ, ω, β.[9] Finally, the right part of the table shows the reduced-form parameters calculated from estimated structural parameters. The estimates of the forward and backward-looking behaviour are close to unity in all cases, therefore no restrictions are applied. The forward-looking behaviour receives less weight than in the GMM estimates. The estimated coefficients range between 0.580 and 0.617 and

[9]Due to the FIML's invariance to normalization we can explore both structural and reduced-form estimates.

Table 4.4: FIML estimates of the NKPC with RULC proxy

RULC	Reduced-form estimates			Structural estimates					
	λ	γ_f	γ_b	θ	ω	β	λ	γ_f	γ_b
V1L1	0.015*	0.598***	0.403***	0.793***	0.537***	0.996***	0.015	0.594	0.404
	(0.008)	(0.035)	(0.036)	(0.105)	(0.147)	(0.010)			
V1L2	-0.000	0.616***	0.384***	0.779*	0.528**	0.993***	0.018	0.593	0.405
	(0.003)	(0.095)	(0.092)	(0.418)	(0.264)	(0.101)			
V1L3	-0.006	0.610***	0.384***	0.807***	0.584***	0.999***	0.011	0.580	0.420
	(0.035)	(0.054)	(0.048)	(0.104)	(0.113)	(0.006)			
V2L1	0.019	0.606***	0.405***	0.789***	0.513***	0.998***	0.017	0.605	0.395
	(0.016)	(0.115)	(0.036)	(0.070)	(0.094)	(0.011)			
V2L2	-0.000	0.615***	0.384***	0.775***	0.513***	0.996***	0.020	0.600	0.399
	(0.006)	(0.071)	(0.067)	(0.151)	(0.102)	(0.016)			
V2L3	-0.013	0.606***	0.381***	0.910***	0.590***	0.998***	0.002	0.605	0.394
	(0.044)	(0.056)	(0.052)	(0.107)	(0.082)	(0.004)			
V3L1	-0.000	0.613***	0.386***	0.785***	0.518***	0.997***	0.017	0.601	0.398
	(0.000)	(0.043)	(0.043)	(0.111)	(0.109)	(0.089)			
V3L2	-0.000	0.616***	0.384***	0.681***	0.458***	0.997***	0.048	0.597	0.402
	(0.003)	(0.045)	(0.045)	(0.070)	(0.096)	(0.001)			
V3L3	0.004*	0.617***	0.383***	0.807***	0.584***	0.999***	0.011	0.579	0.420
	(0.002)	(0.010)	(0.008)	(0.104)	(0.113)	(0.006)			

Estimated period: 1996q1 - 2009q2.
Standard errors are reported in parentheses below the coefficient's estimates
VKLI stands for VAR(K) and LAG(I); I= $1, 2, 3$; K= $1, 2, 3$ contains rulc and is extended with output gap and reer.
* - significance at 10%, ** - significance at 5%, *** - significance at 1%.

they are highly significant. The output gap coefficient is in nearly all cases positive but insignificant. A more encouraging result can be found for the estimated structural coefficients, which are highly significant. The discount factor, β, is close to one as predicted by the reduced form estimates. The share of subjects with constant prices is estimated at 0.708 to 0.898. The average duration of constant prices is calculated as $1/(1-\theta)$ and varies from 3.4 quarters to 9.8 quarters. Approximately a half of the firms are backward-looking. The implied reduced-form parameters for inflation parameters are similar to estimated parameters and the coefficient for real marginal cost, λ, is close to 0.010 on average.

The results for the RULC specification can be found in Table 4.4. The share of forward and backward-looking firms is similar to the output gap version. While the forward-looking component is between 0.598 and 0.617, the backward-looking component ranges from 0.381 to 0.405. Contrary to the gap specifications, λ is marginally significant and correctly signed in two models, V1L1 and V3L3, with values of 0.015 and 0.004. The structural estimates are again highly significant with average duration of constant prices from 3 to 11 quarters. For comparison, Galí and Gertler (1999) report θ above 0.8 for the USA and 0.9 for the euro area, which implies price durations from 5 to 10 quarters. Menyhért (2008)[10] reports only 3 to 4 quarters for Hungary. Using micro-data, Coricelli and Horváth (2010) estimate an average duration of price spells between 3.7 and 4.2 months in Slovakia.

The average implied value for λ from the structural estimates is 0.018, which is close to the V1L1 specification. Comparing our results to the results obtained by Menyhért (2008) for Hungary, the structural parameters are quite similar with slightly lower θ and higher ω. However, his reduced-form estimates lead significant estimates for λ in nearly all cases.

Overall, our results show that forward-looking behaviour is close to 0.6 in both specifications. More importantly, stronger forward-looking behaviour can also act as a shock stabilizer (Menyhért, 2008). An interesting outcome follows from the structural estimates which provide significant structural parameters of the NKPC. They imply that slightly more than half of the firms is backward-looking, which is shown by a relatively high coefficient ω. We have to keep in mind that a high value of γ_f and a high share of backward-looking firms, ω, are not in contradiction because the backward-looking subjects also use information from forward-looking firms.

Finally, the estimated results are also similar to those obtained by other authors for the early member states of the European Union. Jondeau and LeBihan (2006) estimated the forward-looking coefficients in a RULC specification at 0.6 for the EU, 0.54 for France, USA and Italy, 0.56 for Germany and 0.71 for the UK.

[10]Menyhért (2008) and Galí and Gertler (1999) estimate structural NKPC only for a specification with the real unit labour costs as a proxy variable.

4.5 Summary

Price liberalization was a substantial part of economic reforms in Central and Eastern European countries. Market prices allowed an efficient allocation of resources in transition economies, but they also resulted in high inflation persistence and a loss of international competitiveness in some countries. Macroeconomic policies often focused on disinflation, but also on the reduction of unemployment. These two aims of economic policy were often seen as contradictory, although this view was contradicted by modern macroeconomic theory.

So far, there have not been many deeper analyses on the relationship between inflation dynamics and aggregate output. Short time series, structural breaks, and external inflationary factors make the analysis of inflation dynamics in Eastern Europe especially difficult. Therefore, we concentrate on the Czech Republic between 1996 and 2009. The Czech Republic completed major macroeconomic reforms before other Eastern European countries. The Czech economy was not subject to a deep currency crisis and reform reversals, which were observed in some neighbouring countries.

We compare two methods for the estimation of the NKPC. First, we use the GMM which dominates the previous literature. However, these results have been strongly criticized by several authors. Therefore, we apply also the FIML, which was proposed more recently. Our results support the critical conclusions formulated by Fuhrer et al. (1995), Menyhért (2008) and others. Their and our results show that the GMM results are likely to be biased. Furthermore, we demonstrate that the results may depend strongly on the selected instruments and a proxy for real marginal cost. If real unit labour costs are applied as a proxy, as recommended in the literature, the size of the bias depends on the choice of instrumental variables. If the output gap is used as a proxy, we can see that the bias is generally rather high.

Our preferred results are comparable to those reported for other countries of the EU. In particular, real activity is correctly signed in some specifications, but the coefficients are generally low or even insignificant. This implies that the New Keynesian Phillips Curve is flat in the Czech Republic in comparison to other countries. In turn, we find a relatively high share of the forward-looking behaviour of about 60%. Thus, we can conclude that the monetary features of Czech Republic has converged to those characterized for the advanced economies.

It is rather difficult to derive implications from the Czech Republic to other transition economies in Eastern Europe. The initial conditions including the tradition of conservative monetary policy were better in the Czech Republic than in the neighbouring countries, and much better than those of the more distant East European countries. Nevertheless, we can see that these economies are converging to developed economies if their institutional settings are reformed.

5

Meta-analysis of the New Keynesian Phillips curve *

"Have you ever wondered why there is so much variation among the reported empirical results of economic research? Why do researches come to such different findings when they are purportedly investigating the same phenomenon?"

– STANLEY AND JARRELL (1989)

5.1 Introduction

There is hardly a more controversial issue in economics than the relationship between real activity and monetary policy, which is traditionally described as the Phillips curve (Phillips, 1958, and Samuelson and Solow, 1960). While the Phillips curve was sometimes used as an example of spurious correlation, its empirical performance also motivated intensive economic research into true causalities underlying the simple relationship between output growth and inflation. The Nobel Prize has never been awarded

*This chapter is based on results from the working paper *Meta-Analysis of the New Keynesian Phillips Curve* elaborated in cooperation with Jarko Fidrmuc (Fidrmuc and Danišková, 2012).

to William Phillips although his paper is claimed to be the most cited macroeconomic title of the past century (Sleeman, 2011). Moreover, Samuelson's and Solow's contribution to the implementation of the Phillips curve as a tool of macroeconomic analysis were actually not mentioned at the occasions of their Nobel Prize awards (1970 and 1987 respectively). In contrast to that, several Nobel Prize laureates were honored for their contributions to the critical discussion of the issue. Robert E. Lucas Jr. received his Nobel Prize in 1995, partly because he was able to explain why the Phillips curve appeared to have so much empirical support. About one decade later, the issue again received the greatest honour in economics. In 2006, Edmund S. Phelps was prized for his analysis of the determination of wages and prices, which addressed problems of information in the economy. Work on monetary policy and inflation persistence also made up a substantial part of the novel contributions by Finn E. Kydland and Edward C. Prescott, who jointly received the Nobel Prize in 2004.

As we have already mentioned, the intensive discussion of the Phillips curve has become a foundation stone of the New Keynesian economics with the New Keynesian Phillips curve as the key element thereof. The empirical literature on the hybrid version of NKPC is well founded, with approximately 200 papers published in the past 12 years. However, these studies do not have the same conclusions and often goes to opposite direction. To examine this issue we apply meta-analysis (Stanley and Jarrell, 1989, Stanley, 2005) and investigate the true relationship between contemporaneous inflation and inflation expectations. We base our analysis on a collection of all studies estimating the hybrid version of the NKPC. We address the issue of whether the differences between studies can be attributed to different characteristics of data sets and methods, or whether they can correspond to underlying structural differences of included economies. Moreover, we analyse possible asymmetry in the literature and relate it to the publication selection.

This chapter is based on the working paper *Meta-Analysis of the New Keynesian Phillips Curve* presented on

- 5$^{\text{th}}$ annual MAER-Net colloquium at Wolfson College, University of Cambridge, United Kingdom
- conference *Fiscal Stabilization and Monetary Union* at Mendel University, Brno, Czech Republic
- seminar meeting at National Bank of Slovakia

- EAPG Workshop 2011, Belušské Slatiny, Slovak Republic.

The chapter is structured as follows. The next section introduces the basic concept and utilisation of meta-analysis in economy. Subsequently we briefly present estimation methods applied in meta-analysis in section 5.3. Section 5.4 reviews estimates of inflation expectations term from nearly 200 papers which were collected for our meta-analysis. Further, we focus on the possible existence of publication bias in empirical literature on the NKPC. This issue is examined in section 5.5. Finally, sections 5.6 and 5.7 present meta variables that may influence expected inflation term and provide meta-regression results. The last section concludes our findings.

5.2 Meta-analysis applications in economy

Meta-analysis is the regression analysis of regression analyses. More precisely, it is a set of quantitative techniques for evaluating and combining empirical results from different studies (Rose and Stanley, 2005). Estimates of an investigated coefficient are considered as individual observations. This data set can be used for joint test whether published coefficients are jointly different from zero. Moreover, meta-analysis enables to filter out publication selection and include additional variables describing original studies in order to detect their influence on resulting estimate (meta-regression analysis, MRA).

Meta-analysis minimizes potential subjective contributions of authors which appear to be damaging in the case of literature surveys and do not help to find a general consensus on the presented issue. However, a possible shortcoming of the meta-analysis is the presence of a systematic bias across the literature. If certain views become widespread across the literature, the meta-analysis will not succeed in handling this pattern and identifying a true effect.

Meta-analysis has already been applied in many different areas including social sciences, health sciences, marketing, education, etc. The attitude to the meta-analysis is different in these fields since they all use different models and estimation techniques, and features of primary studies are also unique for every area. Stanley and Jarrell (1989) paved the way for the meta-analysis to economics and meta-analysis is becoming more and more popular in this field with number of papers growing every year. To list several examples of analysed topics we mention Rose and Stanley (2005) who focus on the effect of common currencies on the international trade. They examine thirty-four studies and conclude robust positive effect on trade although publication selection exists in this type of literature. After filtering it out, the estimated effect is reduced but the main conclusions remain intact. Moreover, Rose and Stanley (2005) identify several characteristics that help to explain part of variation in reported results, e.g. EMU which impact on international trade is smaller than in postwar currency unions. This paper is a breaking point as meta analysis is used by a distinguished member of the scientific community, which is also broadly recognized as can be seen on the number of quotations.

Djankov and Murrell (2002) examine enterprise restructuring in transition adopting meta-analysis. They collect more than hundred empirical studies and conclude that positive economic effects of enterprise are implied by privatization, especially to outsiders, comparing to state ownership which is less effective. Product market competition is another positive determinant of successful enterprise restructuring with higher productivity than monopolies. Finally, hardened budget constraints has a beneficial effect on enterprise restructuring as well.

Havránek and Iršová (2011) investigate issue of vertical spillovers from foreign direct investments (FDI) and detect publication bias in backward spillovers coming from top ranked journals. It means that positive and significant estimates are more preferable in publication process and are more likely to be published. Important determinants of spillovers are uncovered with multivariate meta-regression and suggest that nationality of foreign investors, distance, technology gap, degree of foreign ownership, etc. play considerable role. Insignificant impact is detected in protection of intellectual property. FDI and taxation is analysed in the study of Feld and Heckemeyer (2011). The paper extends meta-analyses on this topic by inclusion of additional publications, meta regressors and by the application of different techniques. Again, authors find robust evidence of publication bias which strongly influence semi-elasticity of FDI. Genuine effect filtered from this bias is reduced by ten or even fifty percent depending on the selected estimation method. Moreover, differences in effect estimation across studies are caused by selection of data level (aggregate versus micro data), econometric treatment of unobserved variables, integrating bilateral tax regulations, etc.

Minimum wage impact on employment is elaborated by Doucouliagos and Stanley (2009) with no evidence of negative association. Even further, their meta-analysis with 1474 elasticities finds small positive employment elasticity when correction for publication bias is performed. Abreu et al. (2005) developed meta-analysis on beta convergence. Doucouliagos (2005) analyses the literature on the relationship of economic growth and economic freedom. He concludes that it is strongly influenced by publication bias and recommends to focus on disaggregated measures of economic freedom which are less affected. Meta-analysis of gender wage gap is investigated by Weichselbaumer and Winter-Ebmer (2005). Stanley, Doucouliagos and Jarrell (2008) study the socio-economics of economic research and include additional variables into meta-regression analysis. These socio-economic variables represent forces that affect publication selection and meta-analysis is applied on the test of unemployment hysteresis.

Despite its increasing use in economics, meta-analysis did not focus on the New Keynesian Phillips curve yet. The single exception is Carré (2008), who concentrates on the importance of the backward-looking component in inflation targeting. The database developed by Carré (2008) contains 79 papers and 891 estimates, which is significantly less than ours. Moreover, Carré (2008) does not discuss the publication bias and characteristics of the examined effect, which are important according to our results.

5.3 Meta-analysis models

Meta-analysis by its goals, definition and database structure demands advanced estimation techniques. Cluster sampling (for example according countries, authors and studies) is frequent in meta-analysis and introduces within-cluster correlation in a data set since variables within cluster may be correlated due to common observable or unobservable characteristics. The estimates from one study are mostly based on the same database, similar models and estimation methods, which may cause their dependency. Hence, the presence of the within-study correlation demands estimation techniques generally applied in panel data analysis.

In this section we would like to briefly describe techniques we plan to employ in our meta-analysis. If the within-cluster unobservables are uncorrelated with regressors then only the variances of the regression parameters need to be adjusted and simple OLS with clustered standard errors may be applied. If instead the within-cluster unobservables are correlated with regressors then the regression parameters are inconsistent and suitable alternative estimators are needed. Therefore we consider fixed-effects models and appropriate estimators. Finally we mention random-effects and mixed-effects models. The following subsections are based on the Cameron and Trivedi (2005), Gutierrez (2006) and Schmidheiny (2011).

5.3.1 Linear regression with clustered standard errors

Consider linear model with clusters indexed by $s = 1, 2, \dots, S$ and observations $i = 1, 2, \dots, N_s$ with $\sum_{s=1}^{S} N_s = N$ written as

$$y_{is} = \mathbf{x}'_{is}\boldsymbol{\beta} + \varepsilon_{is}, \tag{5.1}$$

where y_{is} is dependent variable, $\mathbf{x}_{is}$ stands for $K < N$ independent variables including constant and ε_{is} is the error term. Every cluster may be expressed by separate equation

$$\mathbf{y}_s = \mathbf{X}_s\boldsymbol{\beta} + \boldsymbol{\varepsilon}_s,$$

where $\mathbf{y}_s$ is a $N_s \times 1$ vector, $\mathbf{X}_s$ is a $N_s \times K$ matrix and $\boldsymbol{\varepsilon}_s$ is a $N_s \times 1$ vector. Further stacking over clusters leads to the general linear model

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon},$$

which can be easily estimated by OLS and if certain conditions are satisfied OLS is considered to be BLUE[1]. In case of clusters in a data, the homoskedasticity assumption may not hold any more and disturbances are correlated within groups or so-called clusters. Coefficients $\boldsymbol{\beta}$ can be still estimated by OLS

$$\hat{\boldsymbol{\beta}}_{OLS} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{y} = \left(\sum_{s=1}^{S} \mathbf{X}'_s\mathbf{X}_s\right)^{-1} \sum_{s=1}^{S} \mathbf{X}'_s\mathbf{y}_s = \left(\sum_{s=1}^{S}\sum_{i=1}^{N_s} \mathbf{x}_{is}\mathbf{x}'_{is}\right)^{-1} \sum_{s=1}^{S}\sum_{i=1}^{N_s} \mathbf{x}_{is}y_{is}$$

but OLS estimator is not efficient in this case and tests based on standard errors are not valid.

Let's assume that $\mathbf{E}(\varepsilon_{is} \mid \mathbf{X}_s) = 0$ and $\mathbf{E}(\boldsymbol{\varepsilon}_s\boldsymbol{\varepsilon}'_s \mid \mathbf{X}_s) = \sigma^2\boldsymbol{\Omega}_s \succ 0$ where $\sigma^2\boldsymbol{\Omega}_s$ is finite. If $(\mathbf{X}_s, \mathbf{y}_s)_{s=1}^{S}$ are i.i.d. then the variance-covariance matrix of error term is specified as

$$\mathbf{E}(\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}' \mid \mathbf{X}) = \sigma^2\boldsymbol{\Omega} = \begin{pmatrix} \sigma^2\boldsymbol{\Omega}_1 & 0 & \dots & 0 \\ 0 & \sigma^2\boldsymbol{\Omega}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma^2\boldsymbol{\Omega}_S \end{pmatrix}.$$

[1]BLUE stands for best linear unbiased estimator.

Consequently the covariance matrix of $\hat{\boldsymbol{\beta}}_{OLS}$ is equal to

$$\mathrm{V}(\hat{\boldsymbol{\beta}}_{OLS} \mid \mathbf{X}) = \sigma^2(\mathbf{X}'\mathbf{X})^{-1}[\mathbf{X}'\boldsymbol{\Omega}\mathbf{X}](\mathbf{X}'\mathbf{X})^{-1}$$

and cluster-robust covariance matrix is estimated as follows

$$\hat{\mathrm{V}}(\hat{\boldsymbol{\beta}}_{OLS} \mid \mathbf{X}) = (\mathbf{X}'\mathbf{X})^{-1}\left[\sum_{s=1}^{S}\mathbf{X}_s'\mathbf{e}_s\mathbf{e}_s'\mathbf{X}_s\right](\mathbf{X}'\mathbf{X})^{-1}$$

with $\mathbf{e}_s = \mathbf{y}_s - \mathbf{X}_s\hat{\boldsymbol{\beta}}_{OLS}$. It does not impose any restrictions on the form of both heteroskedasticity and correlation within clusters but we assume independence of the error terms across clusters. The cluster-robust covariance matrix is consistent when the number of clusters $S \to \infty$. In practice it means 50 or more clusters of small and similar size.

We use Stata 11 command `regress` with `cluster` option in order to estimate equations by OLS with cluster-robust covariance matrix.

But as we mentioned above, OLS with clustered standard errors is consistent method in case within-cluster unobservable effects are not correlated with regressors. Otherwise fixed-effects regression estimator, which is discussed in the next section, should be applied.

5.3.2 Fixed-effects models

Let's return to the equation (5.1) and specify the error term as the cluster-specific effect u_s and the new error term ϵ_{is}

$$\varepsilon_{is} = u_s + \epsilon_{is}.$$

This yields to the equation

$$y_{is} = \mathbf{x}_{is}'\boldsymbol{\beta} + u_s + \epsilon_{is}, \tag{5.2}$$

where $s = 1, 2, \ldots, S$ and $i = 1, 2, \ldots, N_s$ with $\sum_{s=1}^{S} N_s = N$.

If the term u_s is considered to be random with some distribution, model is called random-effects model or mixed-effects model (these models are described in the next subsections). On the other hand, in the fixed-effects model term u_s stands for random unobservables possibly correlated with regressors. Moreover, regressors $\mathbf{x}_{is}$ do not include constant term in the latter case and cluster effect u_s enters the conditional mean function through the intercept term.

Let's consider $\epsilon_{is} \sim (u, \sigma^2_{is})$. This permits heteroskedasticity of unknown form but assumes that inclusion of the fixed effects u_s is sufficient to control for any error correlation within a cluster. The main complication and challenge in the estimation of the fixed-effects model is the presence of many small clusters what generates too many intercepts u_s. In such case OLS estimator can no longer be applied due to large number of parameters $(S + K - 1) \rightarrow \infty$ which are to be estimated and inconsistency unless $N_s \rightarrow \infty$.

In case of small number of large clusters effects u_s can be estimated directly by OLS via introduction of dummy variables into the model. The underlying equation is

$$y_i = \sum_{s=1}^{S} u_s d_{si} + \mathbf{x}_i' \boldsymbol{\beta} + \epsilon_i \quad i = 1, \ldots, N,$$

where dummy variables d_{si} are equal to 1 if observation belongs to cluster s and otherwise they are zero. Moreover, one can employ the usual heteroscedasticity-consistent estimators to deal with heteroskedastic errors.

If clusters are small relative to their number elimination of cluster effect u_s needs to be performed by a differencing transformation. Within-cluster estimator excludes fixed effects u_s by transformation which subtracts equation of clusters means $\bar{y}_s = \bar{\mathbf{x}}_s' \boldsymbol{\beta} + u_s + \bar{\epsilon}_s$ from equation (5.2). Means $\bar{y}_s$ and $\bar{\mathbf{x}}_s$ are defined as $\bar{y}_s = N_s^{-1} \sum_i y_{is}$ and $\bar{\mathbf{x}}_s = N_s^{-1} \sum_i \mathbf{x}_{is}$.

Applying OLS on the resulting equation

$$y_{is} - \bar{y}_s = (\mathbf{x}_{is} - \bar{\mathbf{x}}_s)' \boldsymbol{\beta} + \epsilon_{is} - \bar{\epsilon}_s$$

leads to the consistent estimation of $\boldsymbol{\beta}$. Finally effects u_s can be estimated by direct calculation from equation of cluster means

$$\hat{u}_s = \bar{y}_s - \bar{\mathbf{x}}_s' \hat{\boldsymbol{\beta}}.$$

Below we apply Stata 11 command `xtreg` with `fe` option which represents fixed-effects within regression estimator.

5.3.3 Random-effects models

Specification of the random-effect model is similar to the fixed-effect model but an assumption of u_s to be drawn from a specific distribution, usually $u_s \sim N(0, \sigma_u^2)$. Advantage of this approach lies in the lower number of parameters to be estimated. Disadvantage or complication is that error term $u_s + \epsilon_{is}$ is correlated for observations within cluster. In such case OLS estimation is consistent but inefficient and GLS should be applied what yields

$$\hat{\boldsymbol{\beta}}_{GLS} = \left(\sum_{s=1}^{S} \mathbf{X}_s' \boldsymbol{\Sigma}_s^{-1} \mathbf{X}_s \right)^{-1} \sum_{s=1}^{S} \mathbf{X}_s' \boldsymbol{\Sigma}_s^{-1} \mathbf{y}_s,$$

where $\boldsymbol{\Sigma}_s = \mathrm{V}(u_s)$ and

$$\mathrm{V}(\hat{\boldsymbol{\beta}}_{GLS}) = \left(\sum_{s=1}^{S} \mathbf{X}_s' \boldsymbol{\Sigma}_s^{-1} \mathbf{X}_s \right)^{-1}.$$

The advantage of GLS estimator is that it can be implemented by OLS estimation of the transformed regression. If we assume $\epsilon_{is} \sim (0, \sigma_\epsilon^2)$ then $\mathrm{V}(u_s + \epsilon_{is}) = \sigma_u^2 + \sigma_\epsilon^2$ and $\mathrm{Cov}[u_s + \epsilon_{is}, u_s + \epsilon_{js}] = \sigma_u^2$ for $i \neq j$. Intra-class correlation coefficient ρ is defined as

$$\rho = \mathrm{Cor}(u_s + \epsilon_{is}, u_s + \epsilon_{js}) = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_\epsilon^2} \quad \text{if} \quad i \neq j.$$

Hence transformed random-effect model

$$y_{is} - \theta_s \bar{y}_s = (\mathbf{x}_{is} - \theta_s \bar{\mathbf{x}}_s)' \boldsymbol{\beta} + \epsilon_{is} - \theta_s \bar{\epsilon}_s$$

with

$$\theta_s = 1 - \frac{\sqrt{1-\rho}}{\sqrt{1+\rho(N_s - 1)}} = 1 - \frac{\sigma_\epsilon}{\sqrt{\sigma_\epsilon^2 + N_s \sigma_u^2}}$$

can be estimated by OLS, but consistent estimate $\hat{\theta}_s$ is necessary. More details can be find in Cameron and Trivedi (2005) and Wooldridge (2002). We apply Stata 11 command `xtreg` with `re` option to estimate random-effects model.

5.3.4 Mixed-effects models

Random-effects models as well as fixed-effects models are widely used in studies focused on meta-regression analysis. The reason lies in the possibility to treat different groups jointly and separately at once. Groups in meta-regression analysis are often defined as different studies or countries. Both of them have in common that one group contains usually more parameters' estimates which can be of different properties among these groups. Mixed-effect regression[2] aggregates fixed-effect and random-effect in the one model.

The general representation of mixed-effect model is

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \boldsymbol{\epsilon},$$

where $\mathbf{y}$ is the $N \times 1$ vector of dependent variable, $\mathbf{X}$ is the $N \times K$ fixed-effects design matrix of independent variables, $\boldsymbol{\beta}$ is the $K \times 1$ vector of fixed effects, $\mathbf{Z}$ is the $N \times Q$ random effects design matrix, $\mathbf{u}$ is the $Q \times 1$ vector of random effects and $\boldsymbol{\epsilon}$ is the $N \times 1$ vector of errors. Random effects and vector of errors are both normally distributed with zero mean and covariances

$$\begin{bmatrix} \boldsymbol{u} \\ \boldsymbol{\epsilon} \end{bmatrix} \sim N\left(\mathbf{0}, \begin{bmatrix} \boldsymbol{G} & \mathbf{0} \\ \mathbf{0} & \sigma_\epsilon^2 \boldsymbol{I}_N \end{bmatrix}\right).$$

The model described above is too general for our needs therefore we divide it into S independent clusters

$$\mathbf{y}_s = \mathbf{X}_s\boldsymbol{\beta} + \mathbf{Z}_s\mathbf{u}_s + \boldsymbol{\epsilon}_s,$$

where index $s = 1, \ldots, S$ represents one cluster (study, country, ...). Original $\mathbf{y}$ consists of vectors $\mathbf{y} = [\mathbf{y}_1, \mathbf{y}_2, \ldots, \mathbf{y}_S]'$ which do not have to be of equal size. Vector of errors $\boldsymbol{\epsilon}$ and random effects $\mathbf{u}$ are defined in the similar way. Matrices $\boldsymbol{X}$ and $\mathbf{Z}$ are specified as

$$\mathbf{X} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_S \end{bmatrix}; \quad \mathbf{Z} = \begin{bmatrix} \mathbf{Z}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{Z}_2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{Z}_S \end{bmatrix}.$$

Finally we assume that vectors $\mathbf{u}_s$ are identically distributed with parameters $\mathbf{u}_s \sim N(\mathbf{0}, \boldsymbol{\Sigma}_{\boldsymbol{u}})$ and variance matrix $\mathbf{G}$ is defined as $\mathbf{G} = \mathbf{I}_m \otimes \boldsymbol{\Sigma}_{\boldsymbol{u}}$.

Mixed model is fitted by estimating vector of fixed-effects parameters $\boldsymbol{\beta}$, variance of error terms σ_ϵ^2 and variance components in $\mathbf{G}$. Random effects are not directly estimated but they can be "predicted" as it is described in Gutierrez (2006).

Described model can be estimated with command `xtmixed` in the programm Stata using the estimation method REML (restricted maximum likelihood or residual maximum likelihood).

[2]Description of the mixed-effect model is based on the Gutierrez (2006).

5.4 Meta-analysis of NKPC

The literature on the hybrid version of the NKPC is very rich, with numerous papers published since 1999 when Galí and Gertler introduced their first paper on the hybrid New Keynesian Phillips curve. We focus on the coefficient of expected inflation solely coming from hybrid NKPC. We do not include estimates from the pure forward-looking NKPC for two reasons. Firstly, literature has not agreed on the preferred specification. Some authors claim that purely forward-looking specification is appropriate, others tend to favour the opposite backward-looking specification. In order not to suffer from omitted variable bias, we consider only the hybrid specification which includes both the lagged and future inflation. Secondly, the coefficients related to the expected inflation in the hybrid and forward-looking specifications have different theoretical interpretations. While the former is the function of underlying structural parameters with expected value between 0 and 1, the latter is equal to the discount factor with expected value close to 1. Therefore, the coefficients for the different specifications of the NKPC are not directly comparable.

Our meta-analysis includes 197 available studies, consisting of 87 working papers, 92 papers published in journals or as book chapters, 6 dissertation theses and 3 master theses. The share of published papers is 47%. The search for papers was performed in the Repec database and Google Scholar. Studies in the Repec database were identified according to the keywords *"keynesian phillips curve"*. The search led to 476 results which were individually examined. The search applied in Google Scholar contained the keywords *hybrid estimation forward backward reduced "keynesian phillips curve"* with 897 results found. The relevant studies were included in the underlying database which was completed in July 2011.

The estimates are included in the database only if they originate from the hybrid version of the NKPC (closed or open economy version). We do not apply any restrictions to the proxy variable of the real marginal cost and we allow for additional inflation lags and leads. We also consider only the newest version of the study, e.g. if a dissertation thesis is published in a journal, we consider its published version instead of the original dissertation thesis. Moreover, many authors report re-estimated coefficients of Galí and Gertler (1999) for comparison with their results. We do not include the replicated coefficients in the database. Finally, we drop studies with missing information on standard errors, t-statistics or p-values.

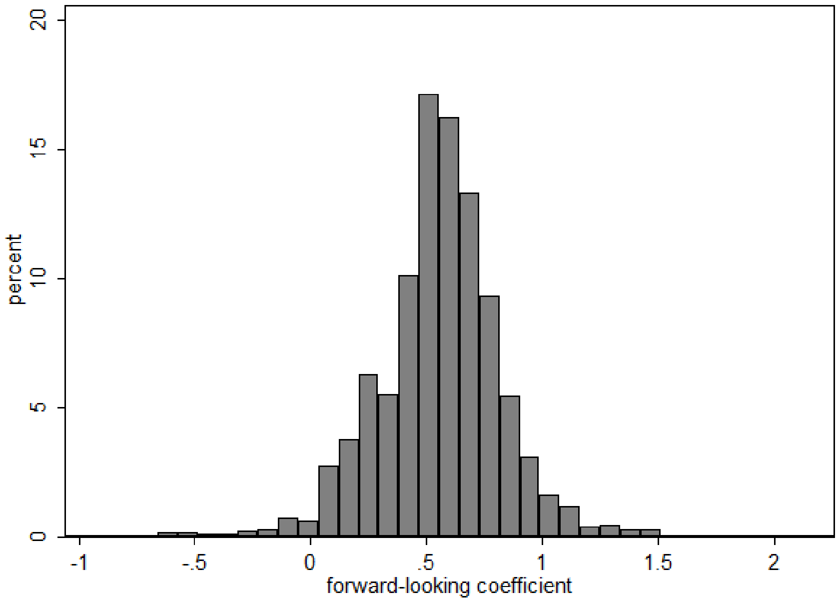

Figure 5.1: Distribution of estimates

Nevertheless, our data set covers 51 countries and three country aggregates (OECD, EU/EMU and new member states - NMS). For the majority of these we have more than five estimated values of the forward coefficient, γ_f. The largest number of estimates, which is equal to 613, is reported for the USA, while the EU follows with 165 estimates. The mean of the estimates of γ_f for different countries lies between 0.3 and 0.7 with exceptions such as Japan, Sweden, Finland, etc. The median is close to the mean in most cases which suggest that estimates are symmetrically distributed. A detailed description across countries is given in Table 5.3[3].

Overall, the number of estimates available in each study ranges from 1 up to 75. The mean number of observations is 21 and the median is 15. Since the range of the estimates of the forward coefficient is quite wide we collect one preferred estimate per study in order to perform a robustness analysis of our results. In sensitivity analysis we analyse the preferred estimates according to authors' notes. If authors consider more estimates to be preferable, we compute their average. However, several studies,

[3]Two countries (Pakistan and New Zealand) are not included because of only one estimate being available for each.

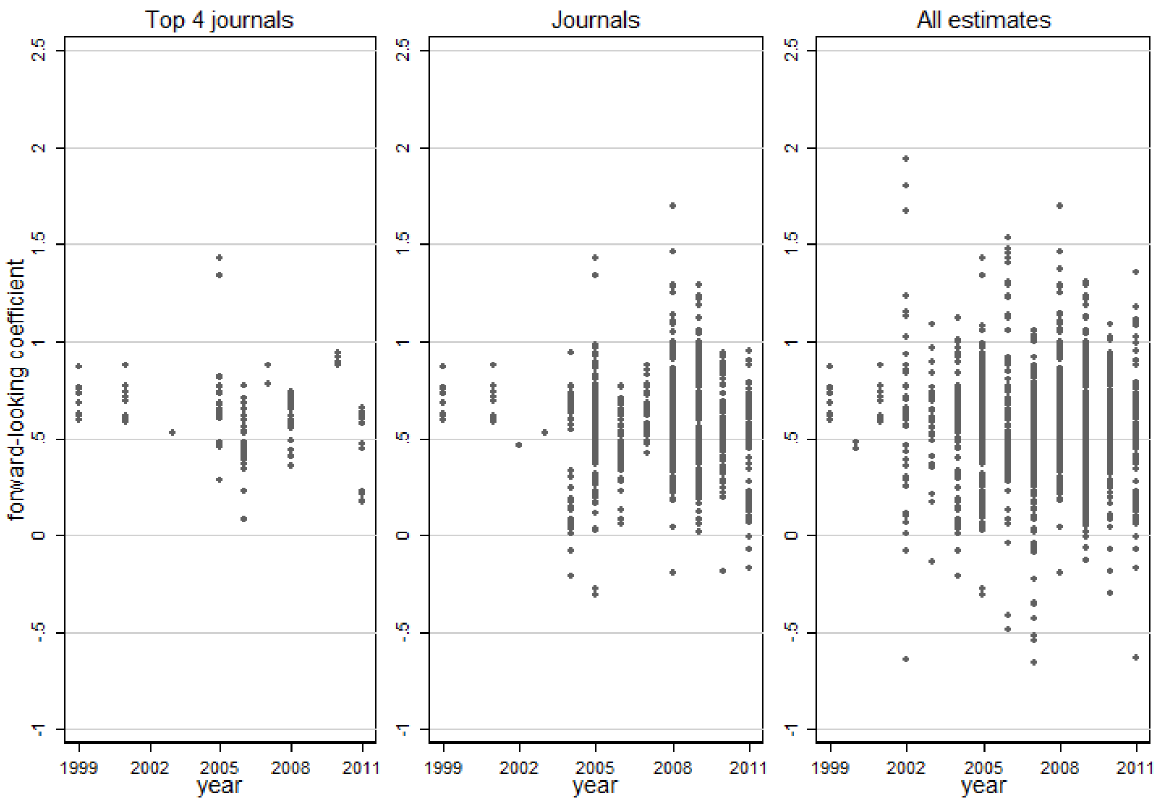

Figure 5.2: Evolution of estimates

especially those presenting critical arguments on the estimation of the NKPC, present no result as preferable.

The theoretical parameter γ_f is defined as the expected inflation term and its estimates should satisfy condition $0 \leqq \gamma_f \leqq 1$. Border values are also possible because some authors claim that only expected inflation causes current inflation, while other authors see the past inflation as the sole determinant of inflation dynamics. However, some of the estimated values exceed the border values of the theoretical interval. The lowest available estimate is -2.699, for the United Kingdom while the highest value of 3.590 is reported for the USA. Furthermore, 6.2% of estimates are lower than zero or higher than one. Quartiles of estimates are quite close to each other. First quartile (25^{th} percentile) is equal to 0.420 while the other two are 0.562 and 0.707.

The development of estimates of the forward-looking parameter by years is displayed in Figure 5.2. The first two blocks of figures present the estimates published by journals. Since different journals are of different quality we also consider category including only publications in the top journals. In particular, we identify the top journals with rating A and A+ according to the standard rankings (Combes and Linnemer, 2003).[4] The top 4 journals include Journal of Monetary Economics, European Economic Review, International Economic Review and Journal of International Economics. The top 7 journals, which are evaluated later, extend previous journals by Journal of Money, Credit and Banking, Journal of Applied Econometrics and Economics Letters.

Weights displayed in the first block are, with two exceptions, between 0 and 1 and 74% of them between 0.5 and 1, thus satisfying the theoretical expectations. The second block contains estimates presented by all journals. Their variance is higher, nevertheless, 96% of estimates again satisfy the assumption regarding the forward-looking coefficient. Moreover, more than half of the estimates is between 0.5 and 1. Finally, the last figure with all estimates in the third block displays the highest variance and deviation from the theoretical benchmarks.

The previous picture suggests the presence of some kind of selection performed by either authors or journals since almost all published estimates satisfy theoretical condition $0 \leqq \gamma_f \leqq 1$, and especially in top journals. The authors may intentionally select the results in line with general expectations and other results remain unpublished or unseen in drawers. Moreover, referees or journals may act similarly since unexpected parameter values may suggest inconsistent inflation development in the long run. Correspondingly, the results different from the general expectations are rather rare in the first two categories. Moreover, the estimates published by top journals are often close to theoretical values $1/2$ and $2/3$. Therefore, we address the issue of publication selection more deeply by the Funnel plot and the Funnel Asymmetry Test.

5.5 Publication bias

The publication bias expresses preference for statistically strong, significant and theoretically sound results. However, publication bias or publication selection (also referred as "file-drawer problem") is often used also for other types of selection bias causing that

[4]We use the updated version of journal ranking according the Handelsblatt.

the results are asymmetrically distributed around the true effect. This misinterpretation may occur if researchers test only the asymmetry of available parameters and do not analyze the sources of their asymmetry. By contrast, the publication selection is determined only by the decisions made by the editors, reviewers and researches who tend to prefer results of a specific range (Stanley, 2005, 2008). Their bias in a particular direction might be detected in the funnel plot which would reveal it unless veiled by the asymmetry from other sources. The funnel plot is a scatter diagram displaying the precision (e.g. inverse standard errors, square root of sample size, etc.) against an examined effect. If publication bias is insignificant, the funnel plot should look like an inverted funnel and the estimates should vary symmetrically around the true effect. The estimates which are close to the true effect should be characterized by the highest precision. Similarly, the less precise estimates should be located in the lower part of the chart. On the other hand, if publication selection prefers significant results then the funnel plot would be hollow and unduly wide. In such a case, a better tool for investigating this pattern would be the Galbraith plot.

However, we have to keep in mind that the funnel plot is a subjective tool for the detection of publication bias. Stanley (2005) sees its limitation in subjective interpretation of the beholder. Moreover, he also stresses its wrong implicit assumption that a common true effect exists for all studies (it does not take into account different data sets, time periods or countries) or if not, its variation is assumed to be symmetric. Finally, Stanley (2005) mentions modelling issues including omitted variables, estimation techniques, functional forms, etc. which cause misspecification bias often wrongly attributed to the publication bias. Thus, the asymmetry presented in the funnel plot may not be the result of publication selection but rather the result of heterogeneity coming from different data sets and applied methods.

Bearing in mind these limitations, we examine the funnel plots which are displayed in Figure 5.3 with precision equal to the inverse standard error. The upper two blocks present the estimates for studies published in top ranked journals, while the lower blocks display the estimates from all journals and books on the left hand side, and all estimates on the right hand side. The funnel plots exclude outliers in order to support the readability of the charts.

A visual examination of the funnel plots is often not conclusive in the detection of asymmetry. Nevertheless, Figure 5.3 provides the first evidence of a publication selection for the journals. The lower part of the figures misses insignificant estimates

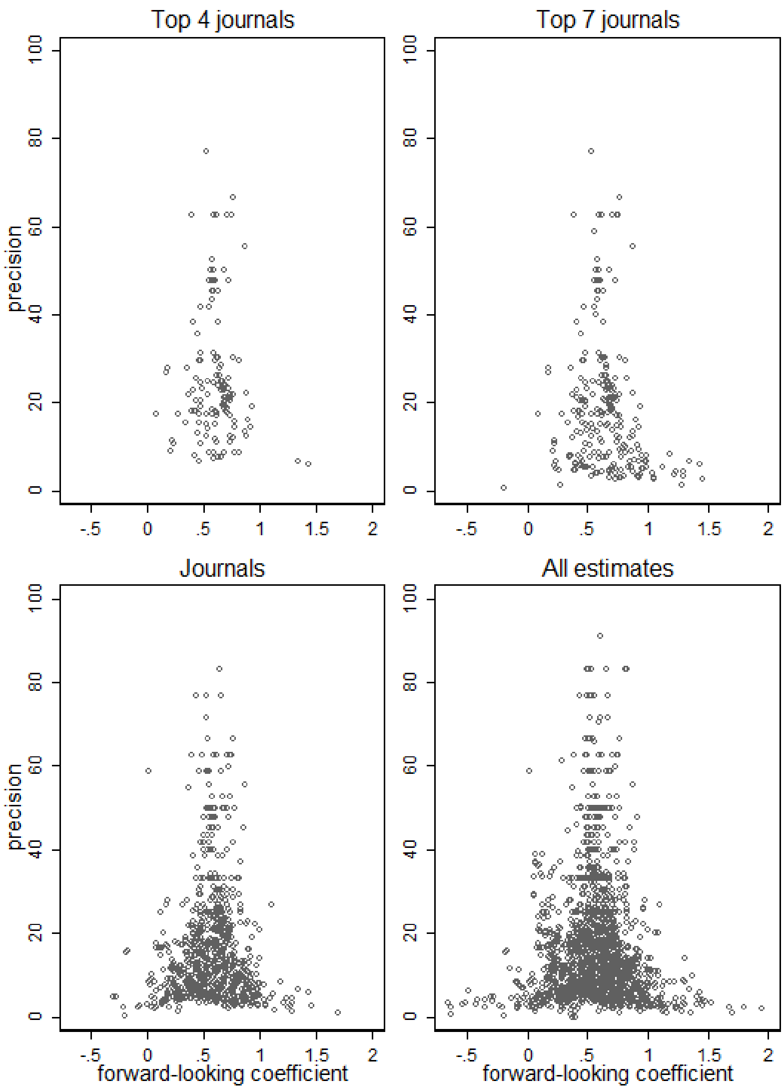

Figure 5.3: Funnel plots

especially for the top ranked journals. Furthermore, most observations are on the right hand side of the funnel plots which shows a preference for higher values of estimates. Regarding the lower blocks, they have the shape close to an inverted funnel having slightly more weight on their right hand side as well. Finally it seems that the true effect is somewhere around 0.5 in all samples.

To test the symmetry we employ the Funnel Asymmetry Test (FAT). This test is based on the simple meta-regression of available effects and the corresponding standard errors (Card and Krueger, 1995; Ashenfelter et al., 1999)

$$\hat{\gamma}_i = \alpha se_i + \gamma + \varepsilon_i, \tag{5.3}$$

where $\hat{\gamma}_i$ denotes the reported estimates of the forward-looking coefficient that vary around "true" effect γ and αse_i stands for the so called publication bias. If the estimates are distributed symmetrically around the true effect γ then coefficient α should not be significantly different from zero. Otherwise if there is a tendency to report certain parameter values or significant results, α would be non-zero and significant and publication bias would be proportional to standard error. In other words if a person engaged in the publication process acts in line with the publication selection (e.g. reports estimates high enough to achieve their significance) reported effects are correlated with their standard errors.

It is clear that equation (5.3) is heteroskedastic. Therefore it is recommended to employ inverse standard errors as weights. This means that equation (5.3) is divided by se_i what leads to (Stanley, 2005)

$$t_i^f = \hat{\gamma}_i / se_i = \alpha + \gamma / se_i + \nu_i. \tag{5.4}$$

This equation puts the t-statistic of effect significance on the left hand side and inverse standard error on its right hand side. Following Egger (1997) the conventional t-test of hypothesis $\alpha = 0$ is a basis for the FAT and its rejection implies the presence of publication bias or more precisely said, presence of asymmetry.

Table 5.1 presents the results of the FAT for selected samples. Moreover, we apply two estimation approaches, the mixed-effects model and OLS with clustered standard errors. According to Feld and Heckemeyer (2011) it is important to cautiously select the proper estimation method. The model choice can be based on the Q-test for unobserved heterogeneity. In our case, I^2 calculated from Q-statistics supports mixed-effects model since the amount of between study variability is large.

The first two columns of the table contain the FAT based on published estimates in journals and books. As we can see, the coefficient α is in both cases highly significant and the presence of strong positive asymmetry is confirmed by both estimation methods. Afterwards the estimates in the row PET show that the genuine effect cleaned

Table 5.1: Funnel Asymmetry and Precision Effect Test

	Journals		Top journals		Top cited studies		Top cited authors		All estimates		United States	
	ME	OLSCL	ME	OLSCL	ME	OLSCL	ME	OLSCL	ME	OLSCL	ME	OLSCL
A. Funnel Assymetry Test and Precision Effect Test												
PET (γ)	0.461***	0.476***	0.400***	0.400***	0.635***	0.676***	0.639***	0.662***	0.370***	0.375**	0.707***	0.698**
	(0.003)	(0.041)	(0.008)	(0.002)	(0.023)	(0.037)	(0.021)	(0.043)	(0.007)	(0.145)	(0.007)	(0.071)
FAT (α)	2.668***	1.552**	5.336***	5.399***	0.086	-0.710	-0.734	-0.201	3.847***	3.583	-2.492***	-1.730
	(0.668)	(0.767)	(1.221)	(1.039)	(0.796)	(0.598)	(0.729)	(1.020)	(1.165)	(3.002)	(0.490)	(1.196)
obs	899	899	143	143	80	80	102	102	1899	1899	613	613
studies	93	93	14	14	12	12	15	15	197	197	87	87
τ	0.112		0.117		0.101		0.114		0.305		0.161	
I^2	98.3%		99.4%		88.5%		87.3%		99.9%		97.1%	
R^2		0.96		0.95		0.94		0.94		0.64		0.94
B. Arithmetic and weighted means												
Mean R/F	0.462 / 0.482		0.403 / 0.414		0.642 / 0.656		0.626 / 0.656		0.373 / 0.383		0.699 / 0.674	
Mean	0.558		0.602		0.570		0.652		0.559		0.602	
C. Precision-effect estimate with standard error												
PEESE	0.462***	0.482***	0.406***	0.411***	0.641***	0.657***	0.626***	0.657***	0.373***	0.382***	0.699***	0.674**
	(0.004)	(0.039)	(0.008)	(0.007)	(0.018)	(0.025)	(0.017)	(0.030)	(0.006)	(0.119)	(0.008)	(0.062)

Note: Standard errors are in parentheses.
* - significance at 10%, ** - significance at 5%, *** - significance at 1%.
ME - mixed-effects model, OLSCL - ordinary least squares with clustered s.e.
R/F stands for random/fixed weights.
Top journals: 4 top rated journals (Journal of Monetary Economics, European Economic Review, International Economic Review and Journal of International Economics).
Top cited authors: the most cited author has more than 1000 citations in Repec; Top cited studies: paper has more than 100 citations in Google Scholar.
Correlations between these categories: top journal vs. top authors = 0.30; top journal vs. top studies = 0.34; top authors vs. top studies = 0.37.

from bias has the value 0.461 which is 17% lower than the sample average.

The next columns present the test results for the top journals. The magnitude of asymmetry increases in comparison to the all journals. Such results suggest even stronger publication selection and tend to prove the above mentioned claims. Moreover, we mentioned that effects from top journals were almost all from the expected interval with average value 0.602. This is in line with theoretical expectations that set the forward-looking behaviour around 2/3 which apparently affected reported inflation expectations term. PET suggests genuine effect to be 0.4 which is even lower than the effect of all journals.

Alternatively, we test the presence of asymmetry among the most cited studies and the most cited authors. If no asymmetry is detected in these categories, the evidence of asymmetry in journals attributed to the publication bias will be even stronger. According to the selected criterion for the number of citations we identified 12 studies with 80 estimates for the most cited studies and 15 studies with 102 estimates for the most cited authors.

The results of the FAT provided in Table 5.1 does not identify any significant publication bias for most cited studies and authors. On the other hand the true effect is significant and achieves a level around 0.64 in both cases what is higher than effects in categories of journals. However, this result may be significantly influenced by the US since it reports stronger inflation expectations and slightly more than half of the top cited estimates are related to the US (51% in case of top cited authors and 66% in case of top cited studies). We explore this issue deeper and estimate equation (5.4) for two sub-samples, one includes only the US estimates and the second one all other estimates. The results of both top cited specifications remain untouched. The coefficient of publication bias is insignificant in all cases and genuine effect for non-US estimates is little lower with value around 0.55.

Hence, we showed that citations are symmetrically distributed around the expected effect which is in line with the theory. Since the most cited authors and studies do not display any selection bias, it seems that the asymmetry found for journals and top journals may be attributed to the publication bias. If the asymmetry of journals was not caused by the publication process, we should find it for the other categories as well. Thus, we may conclude that the publication process selects the theoretically expected and significant results.

In the last two columns of Table 5.1, we compare the results for all countries and the US. We chose the US since this is the country for which the highest number of estimates is published. Again the weighted average is close to the expected result of 2/3. However, the PET detects an even higher effect with a negative bias which points to a different tendency than the other categories. Regarding all estimates, significant estimated effect decreases to 0.37 which is almost half of the sample average. In both cases the publication selection is only confirmed for the preferred estimation approach (ME).

If asymmetry is present in the literature of the NKPC, then the obtained estimated effect can be biased. Publication bias can heavily inflate estimated effect in the case that the genuine effect exists, i.e. it is different from zero. Therefore Stanley and Doucouliagos (2007) recommend replacing equation (5.3) with

$$\hat{\gamma}_i = se_i \lambda(c) + \gamma + \varepsilon_i, \tag{5.5}$$

where $\lambda(c)$ is the inverse Mill's ratio, which captures distortions in the mean of observed effect. Since it is not possible to identify its values for every observation due to unavailability of unreported results, the term is approximated. One possible approximation is applied in equation (5.3) where we use a constant to proxy the inverse Mill's ratio. However, because of the non-linearity of inverse Mill's ratio, quadratic approximation is preferable (Stanley and Doucouliagos, (2007), Feld and Heckemeyer (2011)):

$$\hat{\gamma}_i = \alpha se_i^2 + \gamma + \varepsilon_i. \tag{5.6}$$

As before, the heteroscedasticity necessitates dividing the whole equation (5.6) by se_i which implies

$$t_i^f = \hat{\gamma}_i / se_i = \alpha se_i + \gamma / se_i + \nu_i. \tag{5.7}$$

The main difference between equation (5.3) and (5.7) is in the independent variable se_i. Estimated effect corrected by the described concept is called PEESE (precision-effect estimate with standard error). Monte-Carlo simulations performed by Stanley and Doucouliagos (2007) show that PEESE reduces the potential bias of the publication selection.

Since we showed clear evidence of the existence of genuine effect in this type of literature we estimate PEESE and report it in Table 5.1. If we compare rows PEESE and PET, the highest correction is in case of US estimates where effect is corrected by 3.4%.

Regarding all other cases, the estimated effects are very close and recommend linear relationship between the reported effects and their standard errors.

To show that our results are robust we include estimations with changed threshold values for categories top journals, and top cited studies and authors in Table 5.5. Updated samples produce similar results and prove that previous findings are robust. Moreover, we perform FAT, PET and PEESE for the sub-samples including only preferred estimates: preferred estimates from journals and all preferred estimates. Again, results are comparable, and estimated effect for all preferred estimates is even lower than the effect for all estimates.

5.6 Meta-regression analysis

Another goal of meta-analysis is to answer the question about differences in estimates of the same parameter. What causes estimates of γ_f to come from such a wide range and authors to come to totally opposite conclusions? After all, they do investigate similar issues, trying to employ the most appropriate tools. Using the corresponding parameter estimates for γ_f from nearly 200 studies investigating the hybrid NKPC for different countries and periods, we estimate multi-variable regression models which aim to explain the differences of the estimated coefficients.

The meta-regression equation is given by

$$\hat{\gamma}_i = \gamma + \sum_{k=1}^{K} \beta_k D_{ik} + \varepsilon_i, \tag{5.8}$$

where $\hat{\gamma}_i$ is the estimated share of inflation expectations term, and ε_i is the error term. Variables D_k represent a set of K variables, which include both continuous and dummy variables and summarize information related to data definition, data structure, estimation method, publication, and included control variables, among others. The intercept, γ, shows a value of the forward-looking weight, which corresponds to the benchmark characteristics.

In principle, the equation (5.8) could be estimated by ordinary least squares (OLS) methods. However, the OLS estimation does not take into account the likely heteroskedasticity of residuals. A potential way to overcome such a caveat is to use the weighted least squares (WLS) estimation, which uses the precision of each parameter estimate (measured by the inverse of their standard errors) as a weight in the regression. Thus we get

$$\frac{\hat{\gamma}_i}{se_i} = t_i^{\gamma} = \gamma \frac{1}{se_i} + \sum_{k=1}^{K} \beta_k D_{ik} \frac{1}{se_i} + \nu_i, \tag{5.9}$$

where the dependent variable is t-statistics for $\hat{\gamma}_i$. Through this transformation, the former intercept is estimated by the coefficient for $1/se$.

As it is likely that coefficients presented in a particular study are closely related, the approach of the random-effects and fixed-effects linear models for the estimation of weighted meta-regression is preferable. The inclusion of unobserved effects u_s for individual studies or along other dimension of the data sample (authors, countries, etc.) controls for an error correlation within a cluster. The general estimation equation using study dimension s can be stated as

$$t_i^{\gamma} = \gamma \frac{1}{se_i} + \sum_{k=1}^{K} \beta_k D_{ik} \frac{1}{se_i} + u_s + \epsilon_i. \tag{5.10}$$

In our analysis we compare a mixed linear model to alternative estimation approaches including the fixed-effects model and the OLS with clustered standard errors. Selected specifications are also extended by standard fixed effects for countries or regions.

As control variables in our meta-regressions we include information on the sample used and the characteristics of the study (for exact definitions of the control variables, see Table 5.4). The year of publication (*yeardm*) shows whether there is a trend in overall analysis of the NKPC. This could correspond to actual structural changes (e.g. increasing liberalization in analysed countries), which should be associated with *yeardm*. Subsequently, we differentiate between studies published by recognized journals (*jr*) which also aggregates studies published in books, working papers (*wp*) and other unpublished studies (*othstudy*) such as dissertation and master theses. Similarly to Havránek and Iršová (2010) we also include the citation number of the study according to Google scholar (*citg*), the citation index of the best author (*acitr*) according to the Repec working paper archive, and the recursive impact factor (*recfac*) of the journal or working paper series, also according to the Repec. Finally, the emerging economies are denoted as (*em*).

The next group of variables includes a dummy for authors from emerging economies (*aem*) and those from developed ones (*awest*). We also considered whether authors are affiliated with an academic institution (*aaca*) or a central bank (*acb*).

Furthermore, we include several variables describing the properties of data sets analysed by reviewed studies. This includes information on whether estimates are based on monthly, quarterly or annual data. In addition to that we also collected the first and the last year of the sample, and the number of years in observations (*obs*). Inflation is most commonly defined as GDP deflator (*gdp*), but many studies use alternative definitions like CPI (*cpi*), the core inflation (*core*) or other inflation measure (*othinf*).

Equation characteristics cover definition of inflation expectations. Reviewed studies can use either realized inflation values under the assumption of rational expectations (*rat*), or survey data (*sur*). In addition to that, all estimations also include a proxy for marginal cost, which can be defined as real unit labour costs (*rulc*), output gap (*gap*) or unemployment (*unempl*). Further variables describe whether estimates were gained using a closed (*closed*) or open (*open*) economy version of the NKPC, number of inflation lags (*inflags*) and leads (*inflead*), and restriction of the sum of coefficients (*beta*). Usage of changes in inflation rates instead of inflation rates themselves is expressed by variable *infdev*.

Finally, the empirical literature also discussed intensively the appropriate methods of estimation as the OLS did not deal with endogeneity issues. Originally, the GMM or the two stage least squares dominated the literature, but most recent papers rather prefer maximum likelihood estimation or the Bayesian methods and experimentation with other methods mentioned in Table 5.4.

Due to the perfect multicollinearity, we have to exclude some characteristics. Then estimated effect is related to selected benchmark characteristics and estimated coefficients are interpreted as the differences from a benchmark. Hence, our estimated effect corresponds to the effect coming from the closed economy NKPC without restriction on the sum of expected and past inflation terms. Inflation is measured as the GDP deflator, its expectations are rational and equation is estimated with the GMM on quarterly data starting in 1979 and ending in 2003. The unemployment is considered as a proxy for real marginal cost and the final study is published in a journal. All authors of the study are from developed countries and at least one of them works in an academic institution.

Finally, the robustness tests of the results are performed by excluding correlated or insignificant variables and outliers. Tests of robustness do not include the estimation based on the preferred estimates because many studies do not identify a single preferred estimate and such estimates may not have unique characteristics described above. Therefore, if we take into account the recommended average of all preferred estimates, then we are not able attach unique characteristics to this preferred average.

5.7 Results of meta-regression analysis

Almost all meta-studies enhance classical meta-analysis by including possible relevant explanatory variables as it is expressed by equation (5.8). Feld and Heckemeyer (2011) propose a method for the selection of appropriate meta-analysis techniques. One of the main issues is the selection of the correct estimation method, which is determined by various test steps. Firstly, we check whether unobserved heterogeneity remains even after the inclusion of meta-regressors. To test sample homogeneity we use the Q-test which clearly rejects sample homogeneity. Then we perform the Breusch-Pagan LM test ($\chi^2(67) = 7010.12$, p-value$=0.000$) which indicates a presence of unobserved cluster effects. We consider study-clusters to account for the dependency within the studies. Furthermore, we test the robustness of our results with country-clusters.

As we detect the between-study heterogeneity, following study Feld and Heckemeyer (2011), we use the Hausman test to determine whether these effects are not correlated with independent variables ($\chi^2(65) = 82.59$, p-value$= 0.0695$). Our result is not clear about the inconsistency of the random-effects regression. Since the Hausman test is not robust under heteroskedasticity, Wooldridge (2002) proposes an alternative test, which is based on the test of over-identifying restrictions. Result of the test ($\chi^2(67) = 359.70$ p-value$=0.000$) claims that the fixed-effects cluster-econometric model is appropriate for the final analysis. Nonetheless we report also the mixed-effects meta-regression results and the OLS with clustered standard errors in order to compare the robustness of our obtained results. The Wald test for the significance of the slope coefficients rejects the null hypothesis in all cases.

Table 5.2 reports estimated meta-regressions. Estimated specifications also includes coefficients of dummy variables for countries and regions which are not reported here. The first three columns of Table 5.2 include all explanatory variables, while the next three columns exclude insignificant and highly correlated characteristics. We focus on these parsimonious specifications.

The results largely confirm our expectations. Regarding study characteristics, it seems that all of them have a significant impact on the published forward-looking coefficients. The inclusion of the demeaned year of publication appears to have significant positive impact although with different coefficients. This suggests that a trend can be identified either in publications or in analysed economies. The estimated shares of the inflation expectations term are more than 10 percentage points lower for working papers (including unpublished manuscripts) than for journal publications. Google citations appear with a positive and significant coefficient which supports earlier claims that the most cited papers report higher results.

Regarding the author's characteristics, *acaa* has negative impact on the effect which means that if at least one of the co-authors holds position in an academic institution, published estimates are lower. Among the equation characteristics, the following variables are found to determine the results. The sum restriction ($\gamma_f + \gamma_b = 1$) denoted by *beta* tends to increase the associated estimates. If a study uses real unit labour costs and output gap as a proxy variable for the real marginal cost or includes additional lags into the NKPC, the results are lower. Other proxy variables are significantly different with negative sign as well.

The open economy NKPC lowers the weights of inflation expectations. This can correspond to a lower impact of inflation expectations in an open economy. Quite surprisingly, our estimates suggest that the assumption of rational expectations performs similarly as the use of survey data.

The next set of explanatory variables describes the data characteristics. The way inflation is measured is important since CPI and core inflation give significantly different results comparing to the baseline GDP deflator. It seems that GDP deflator overestimates the impact of inflation expectations. The choice of data frequency turns out to be unimportant in parsimonious specifications since monthly and annual frequency of the data are not significantly different from quarterly frequency. Finally, the range of data set expressed by the first and last year[5] of the sample says that database starting before 1979 and ending after 2003 leads to the higher estimates.

The general expectations related to the estimation methods are largely confirmed. The claims of Jondeau and LeBihan (2006), who compare the GMM and the ML specifications, are in line with our meta analysis. They report that the GMM leads to an overestimation of the forward-looking behaviour. This is clearly confirmed by results of

[5]Note that *lastdm* is not correlated with year of the study, because studies also contain estimates for different historical sub-samples.

Table 5.2: Multivariate meta-regresion

	ME	FE	REGCL	ME	FE	REGCL	ME^{out}	FE^{out}	$REGCL^{out}$
yeardm	0.029***	0.047***	0.021*	0.030***	0.037***	0.019*	0.011***	0.011*	-0.001
	(0.004)	(0.006)	(0.011)	(0.003)	(0.004)	(0.010)	(0.004)	(0.006)	(0.007)
wp	-0.144***	-0.219***	-0.127***	-0.136***	-0.189***	-0.097**	-0.071***	-0.109***	-0.013
	(0.024)	(0.030)	(0.047)	(0.021)	(0.025)	(0.042)	(0.015)	(0.018)	(0.028)
othstud	-0.137***	-0.186***	-0.118**	-0.102***	-0.113***	-0.088**	0.065***	0.051***	0.050*
	(0.024)	(0.031)	(0.056)	(0.018)	(0.021)	(0.041)	(0.017)	(0.020)	(0.027)
citg	0.062***	0.119***	0.066**	0.085***	0.116***	0.059***	0.026***	0.023**	0.009
	(0.014)	(0.019)	(0.029)	(0.009)	(0.012)	(0.020)	(0.008)	(0.010)	(0.011)
em	-0.146***	-0.170***	-0.101						
	(0.035)	(0.043)	(0.063)						
recfac	0.074**	0.000	-0.036						
	(0.037)	(0.053)	(0.058)						
acitr	-0.007	-0.008	0.002						
	(0.004)	(0.006)	(0.009)						
aem	0.036	0.179***	0.001						
	(0.028)	(0.038)	(0.043)						
aaca	-0.110***	-0.099***	-0.059*	-0.103***	-0.114***	-0.059**	-0.079***	-0.105***	-0.013
	(0.019)	(0.023)	(0.032)	(0.016)	(0.021)	(0.028)	(0.013)	(0.015)	(0.021)
beta	0.159***	0.156***	0.164***	0.155***	0.148***	0.158***	-0.006	-0.010	0.006
	(0.009)	(0.009)	(0.027)	(0.008)	(0.009)	(0.025)	(0.008)	(0.008)	(0.021)
gap	-0.055**	-0.035	-0.071	-0.088***	-0.085***	-0.098	-0.111***	-0.132***	-0.079**
	(0.026)	(0.030)	(0.054)	(0.025)	(0.029)	(0.061)	(0.017)	(0.019)	(0.038)
rulc	-0.142***	-0.130***	-0.146**	-0.177***	-0.184***	-0.176***	-0.050***	-0.081***	0.005
	(0.026)	(0.030)	(0.057)	(0.024)	(0.029)	(0.065)	(0.017)	(0.019)	(0.041)
othproxy	-0.149***	-0.163***	-0.072	-0.164***	-0.207***	-0.086	-0.050**	-0.086***	0.014
	(0.042)	(0.047)	(0.091)	(0.041)	(0.047)	(0.090)	(0.024)	(0.027)	(0.067)
sur	0.039	0.080**	-0.006	0.014	0.025	0.001	0.000	0.013	-0.028
	(0.028)	(0.032)	(0.052)	(0.025)	(0.028)	(0.044)	(0.015)	(0.016)	(0.035)

Continued on next page. . .

Table 5.2 – Continued

	ME	FE	REGCL	ME	FE	REGCL	ME^{out}	FE^{out}	REGCL^{out}
othexp	-0.017	0.010	-0.120						
	(0.090)	(0.096)	(0.075)						
inflag	-0.158***	-0.150***	-0.160***	-0.128***	-0.129***	-0.128***	-0.054***	-0.055***	-0.079*
	(0.029)	(0.032)	(0.052)	(0.026)	(0.028)	(0.041)	(0.016)	(0.017)	(0.046)
inflead	0.042	0.007	0.079						
	(0.064)	(0.066)	(0.088)						
infdev	-0.110***	-0.103	-0.104*	-0.084**	-0.088	-0.092*	0.001	0.007	-0.055
	(0.039)	(0.068)	(0.053)	(0.037)	(0.069)	(0.048)	(0.030)	(0.037)	(0.068)
open	-0.083***	-0.113***	-0.076**	-0.060***	-0.065***	-0.054*	-0.031**	-0.014	-0.092***
	(0.018)	(0.020)	(0.036)	(0.017)	(0.018)	(0.032)	(0.014)	(0.016)	(0.032)
firstdm	-0.004***	-0.004***	-0.005***	-0.005***	-0.004***	-0.006***	-0.002***	-0.002***	-0.000
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
lastdm	0.013***	0.011***	0.011**	0.012***	0.013***	0.010**	0.002**	0.002**	0.003
	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)	(0.004)	(0.001)	(0.001)	(0.002)
month	-0.067*	-0.108**	-0.086	-0.048	-0.069	-0.077	-0.076***	-0.108***	-0.111**
	(0.037)	(0.052)	(0.054)	(0.036)	(0.052)	(0.054)	(0.024)	(0.029)	(0.056)
annual	-0.035	-0.051	-0.082						
	(0.054)	(0.100)	(0.069)						
obs	-0.002	-0.006*	0.001						
	(0.002)	(0.004)	(0.002)						
cpi	-0.135***	-0.110***	-0.146***	-0.134***	-0.124***	-0.147***	-0.085***	-0.099***	-0.055*
	(0.012)	(0.013)	(0.031)	(0.012)	(0.013)	(0.028)	(0.011)	(0.011)	(0.028)
core	-0.065***	-0.051***	-0.094**	-0.098***	-0.090***	-0.116***	0.107***	0.115***	0.053
	(0.017)	(0.019)	(0.044)	(0.016)	(0.017)	(0.040)	(0.030)	(0.033)	(0.060)
othinf	0.001	0.016	-0.018						
	(0.021)	(0.023)	(0.039)						
tsls	0.080**	0.043	0.107	0.095**	0.063	0.078	0.036	0.013	0.080
	(0.041)	(0.050)	(0.080)	(0.040)	(0.049)	(0.070)	(0.023)	(0.025)	(0.054)

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Table 5.2 – Continued

	ME	FE	REGCL	ME	FE	REGCL	ME^{out}	FE^{out}	$REGCL^{out}$
like	-0.072***	-0.104***	-0.085*	-0.050***	-0.046**	-0.060	-0.053***	-0.063***	-0.059**
	(0.021)	(0.025)	(0.046)	(0.019)	(0.022)	(0.040)	(0.013)	(0.015)	(0.027)
ols	0.051*	0.020	0.092*	0.074***	0.059**	0.091	0.031**	0.020	0.062
	(0.029)	(0.031)	(0.053)	(0.027)	(0.029)	(0.055)	(0.015)	(0.016)	(0.040)
bayes	-0.142	-0.683**	-0.109	-0.085	-0.424	-0.044	0.106	-0.065	0.185***
	(0.109)	(0.311)	(0.122)	(0.101)	(0.309)	(0.083)	(0.070)	(0.159)	(0.066)
eel	0.069	0.032	0.090*	0.081	0.048	0.125**	0.001	-0.002	-0.012
	(0.083)	(0.089)	(0.051)	(0.083)	(0.091)	(0.052)	(0.044)	(0.046)	(0.023)
gse	0.206***	0.183***	0.243***	0.246***	0.242***	0.259***	-0.009	-0.020	-0.019
	(0.031)	(0.036)	(0.040)	(0.026)	(0.028)	(0.035)	(0.021)	(0.024)	(0.038)
tvc	0.059	-0.028	0.232*	0.061	-0.014	0.248*	0.009	-0.015	0.191*
	(0.152)	(0.161)	(0.130)	(0.153)	(0.164)	(0.135)	(0.081)	(0.083)	(0.103)
gel	0.047	0.041	0.068						
	(0.064)	(0.068)	(0.050)						
othmeth	0.006	0.011	-0.000						
	(0.014)	(0.014)	(0.014)						
model	0.036	0.166***	0.033						
	(0.023)	(0.032)	(0.048)						
constant	0.119	-0.021	-0.007	0.221	0.042	-0.066	0.447*	0.513***	0.175
	(0.331)	(0.221)	(0.316)	(0.314)	(0.203)	(0.324)	(0.238)	(0.126)	(0.241)
obs	1,899	1,899	1,899	1,899	1,899	1,899	1,853	1,853	1,853
R^2 adj.		0.991	0.990		0.991	0.989		0.874	0.895
n groups	197	197	197	197	197	197	194	194	194
groups	studies	studies	studies	studies	studies	studies	studies	studies	studies

Standard errors are reported in parenthesis. Upper index out stands for regression “without outliers”.
ME - mixed-effects model, FE - fixed-effects model, OLSCL - ordinary least squares with clustered s.e.
* - significance at 10%, ** - 5%, *** - 1%.

meta-regression where maximum likelihood represented by variable *like* is significantly negative. It is also expected that the results for the TSLS are more or less comparable with the GMM results, which is considered as the base category. Regarding other estimation methods (OLS, EEL, GSE and TVC) we can see a positive bias even compared to the GMM.

In our robustness analysis, we exclude outliers from all specifications following the approach proposed by Hadi (1994) with p-value$= 0.001$. For comparison we present these results in columns whose headers are augmented by *out*. The results for majority of variables are robust to this sensitivity test. However, some variables (e.g. sum restriction *beta*, inflation deviations *infdev*) turned out to be insignificant and other marginal variables even switched their sign (e.g. core inflation *core*, other studies *othstudy*). The impact of RULC as a proxy of real marginal cost is lower comparing to output gap and monthly frequency is significantly different from quarterly frequency with negative sign. The estimation methods TSLS and OLS are no more significant for preferred method, which supports the critique of GMM as not dealing appropriately with the endogeneity problems.

Finally, Table 5.6 contains the specifications clustered by countries with and without outliers. Despite of this, the results are largely comparable to the previous estimates with two exceptions. First, two specifications find survey measures of inflation expectations significantly different from rational expectations. Second, all specifications report significant difference between OLS and GMM.

Moreover, we estimate the genuine effect for every country separately. We only include countries with five or more estimates. Table 5.7 reports the results, which confirm overwhelming differences between the countries. The meta effect is insignificant for eight countries including Japan, Brazil, China, Estonia, Norway, Latvia, Turkey and Romania. The weak results for Japan and China can be explained by deflation in these countries in some periods. In turn, Brazil and Eastern European countries were characterized by a successful disinflation process. Besides these countries it is Greece and Germany that show the lowest (while significant) shares of forward-looking coefficient. The individual results confirm a high share of inflation expectations term in the USA and several emerging markets. The highest values are actually reported for Lithuania and Russia.

5.8 Summary

The Phillips curve represents one of the most critically discussed issues in economics. Several Nobel Prizes were awarded for theoretical contributions to the discussion. Similarly, we identified nearly 200 empirical papers estimating the hybrid version of the new New Keynesian Phillips curve, which assumes both forward and backward-looking firms. We present a meta-analysis of the forward-looking component in order to identify reasons of different findings across the literature.

Our results confirm the presence of asymmetry in this type of literature which can be attributed to the publication bias. Top journals show even higher publication bias accepting significant estimates close to the expected value. There is an overall positive trend in the literature concerning the NKPC. Impact of authors' characteristics is not essential except for holding a position in an academic institution.

Moreover, we find that characteristics of analysed studies have a significant impact on the reported results. The meta-regressions confirm that the published results are higher than results in working papers. Besides this, estimation characteristics are especially important. The GMM, which is frequently used in the earlier literature on the topic, was actually not performing statistically differently than the simple OLS in specification clustered by studies and without outliers. This provides further empirical support for the widespread critique of the GMM method in final samples. On the other hand, likelihood estimators recommended by recent studies report lower shares of the forward-looking term as it was predicted. Survey measures of inflation expectations, which are also stressed in the recent literature, appear not to be significantly different from rational expectations.

Finally, we find significant differences between price characteristics in different countries and world regions. The role of inflation expectations is much higher for the US than it is for EU countries. The EU is also characterized by a significant heterogeneity. There is mixed evidence for emerging economies, which are often characterized by a comparably high or a comparably low weight of inflation expectations.

5.9 Appendix

Table 5.3: Meta-statistics for individual countries

Country	am	ar	at	au	be	bg	br	ca	ch	cl
n	2	5	26	7	4	2	11	41	21	23
mean	0.35	0.15	0.64	0.57	0.57	0.27	0.47	0.50	0.29	0.52
median	0.35	0.14	0.62	0.55	0.54	0.27	0.52	0.59	0.34	0.56
max	0.41	0.23	0.94	0.93	0.76	0.55	0.97	1.16	0.50	0.60
min	0.30	0.10	0.36	0.12	0.46	0.00	-0.14	-1.05	0.08	0.18
sd	0.07	0.05	0.14	0.27	0.14	0.39	0.32	0.36	0.17	0.11
skewness	0.00	1.04	0.16	-0.39	0.66	0.00	-0.36	-2.15	0.06	-2.35
kurtosis	1.00	2.80	2.25	2.23	1.84	1.00	2.50	9.73	1.22	7.30
country	cn	co	cy	cz	ee	eu	fi	fr	ge	gr
n	34	3	2	77	7	165	4	54	45	7
mean	0.24	0.53	0.60	0.57	0.39	0.51	1.24	0.64	0.60	0.50
median	0.19	0.54	0.60	0.60	0.46	0.54	1.29	0.65	0.59	0.45
max	0.52	0.55	0.61	1.12	0.73	0.95	1.94	1.13	1.22	0.84
min	0.05	0.50	0.59	0.10	0.03	-0.30	0.42	0.19	0.18	0.30
sd	0.15	0.02	0.01	0.16	0.27	0.22	0.70	0.21	0.27	0.21
skewness	0.62	-0.55	0.00	0.33	-0.42	-1.10	-0.16	0.08	0.19	0.57
kurtosis	1.97	1.50	1.00	5.52	1.83	4.51	1.38	2.80	2.00	2.00
country	hk	hu	id	il	in	ir	it	jp	kr	lt
n	43	70	48	10	8	4	78	21	9	7
mean	0.76	0.52	0.23	0.57	0.41	1.03	0.52	0.73	0.56	0.34
median	0.77	0.53	0.23	0.58	0.41	0.82	0.50	0.68	0.57	0.46
max	1.09	0.83	0.41	0.88	0.54	2.13	1.14	1.30	0.65	0.76
min	0.41	0.37	-0.01	0.32	0.35	0.36	-0.08	0.01	0.45	-0.31
sd	0.16	0.07	0.07	0.15	0.06	0.84	0.26	0.26	0.07	0.45
skewness	-0.27	0.85	-0.40	0.36	1.18	0.52	0.24	-0.20	-0.34	-0.70
kurtosis	2.38	6.50	6.31	3.14	3.63	1.66	2.86	4.78	1.85	1.78
country	lv	lx	ma	mt	mx	my	ne	no	pl	pt
n	7	5	3	2	17	3	7	8	43	7

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Table 5.3 – Continued

country	lv	lx	ma	mt	mx	my	ne	no	pl	pt
mean	0.44	0.37	0.25	0.45	0.50	0.52	0.96	0.45	0.54	0.46
median	0.55	0.44	0.24	0.45	0.57	0.52	0.63	0.67	0.56	0.47
max	0.68	1.13	0.29	0.62	0.83	0.56	2.08	0.84	1.31	0.65
min	0.12	-0.64	0.22	0.28	-0.19	0.48	0.46	-0.64	-0.66	0.31
sd	0.23	0.64	0.03	0.24	0.25	0.04	0.68	0.52	0.33	0.11
skewness	-0.42	-0.64	0.31	0.00	-1.30	0.02	0.96	-1.40	-1.22	0.36
kurtosis	1.60	2.61	1.50	1.00	4.38	1.50	2.05	3.42	7.26	2.74
country	ro	ru	si	sw	sp	tn	tu	uk	us	za
n	9	56	2	20	29	9	14	151	613	8
mean	0.41	0.42	0.31	1.06	0.56	0.57	0.62	0.61	0.60	0.84
median	0.45	0.36	0.31	1.11	0.49	0.62	0.52	0.69	0.61	0.77
max	0.71	1.06	0.45	1.53	1.18	0.74	0.95	1.08	3.59	1.40
min	-0.17	-1.01	0.16	0.50	0.01	0.28	0.36	-2.70	-0.49	0.35
sd	0.25	0.36	0.21	0.34	0.27	0.15	0.22	0.37	0.29	0.39
skewness	-1.28	-0.92	0.00	-0.36	0.60	-0.66	0.32	-5.26	2.13	0.15
kurtosis	4.33	6.02	1.00	1.88	3.16	2.21	1.43	43.42	23.67	1.78

Table 5.4: Description of regression variables

Category	Description	mean	s.e.
Study characteristics			
yeardm	year of publication subtracted by its average; rounded average of year is 2007	0.000	2.353
jr	=1 if study is published in a journal or in a book	0.473	0.499
wp	=1 if study is working paper	0.422	0.494
othstudy	=1 if study is dissertation, master thesis or unpublished	0.111	0.314
citg	number of study citations from Google scholar (divided by age, log)	0.808	1.041
recfac	recursive factor for working paper series and journals from Repec database; *http://ideas.repec.org/top/top.series.recurse.html*	0.278	0.341
em	=1 if study is focused on emerging countries	0.270	0.444
Author characteristics			
acitr	number of citations of the most cited author from Repec database (log)	3.972	2.485
awest	=1 if one or more co-authors work in developed country	0.855	0.353
aem	=1 if one or more co-authors work in developing country	0.219	0.414
acb	=1 if one or more co-authors are affiliated with a central bank	0.513	0.500
aaca	=1 if one or more co-authors are affiliated with an academic institution	0.699	0.459
Equation characteristics			
beta	=1 if the sum of forward and backward coefficient is restricted	0.330	0.470
rulc	=1 if real marginal cost is proxied by real unit labour costs	0.425	0.495
unempl	=1 if real marginal cost is proxied by unemployment	0.058	0.235
gap	=1 if real marginal cost is proxied by output gap	0.471	0.499
othproxy	=1 if real marginal cost is proxied by other variable	0.064	0.245
rat	=1 in case of assumption of rational expectations	0.735	0.442
sur	=1 in case of survey data approximation for inflation expectations	0.235	0.424
othexp	=1 in case of other types of expectations	0.034	0.181
inflag	=1 if NKPC is estimated with extra inflation lags	0.099	0.299
inflead	=1 if NKPC is estimated with extra inflation leads	0.029	0.169
infdev	=1 if inflation changes are considered instead of absolute values	0.037	0.190

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Table 5.4 – Continued

Category	Description	mean	s.e.
closed	=1 if estimate comes from closed economy NKPC	0.787	0.410
open	=1 if estimate comes from open economy NKPC	0.213	0.410
Data characteristics			
firstdm	first year of the data subtracted by its average; rounded average first year is 1979	0.000	13.755
lastdm	last year of data subtracted by its average; rounded average last year is 2003	0.000	4.757
month	=1 in case of monthly data structure	0.092	0.289
quarter	=1 in case of quarterly data structure	0.817	0.387
annual	=1 in case of annual data structure	0.091	0.287
obs	number of years in observations	28.447	51.246
cpi	=1 if inflation is measured by cpi	0.360	0.480
gdp	=1 if inflation is measured by gdp deflator	0.483	0.500
core	=1 if inflation is measured by core inflation	0.021	0.142
othinf	=1 if inflation is measured by nfb, rpi, etc.	0.140	0.348
Method characteristics			
like	=1 if estimation method is maximum likelihood	0.086	0.280
gmm	=1 if estimation method is generalized method of moments	0.677	0.468
tsls	=1 if estimation method is two stage least squares	0.101	0.301
bayes	=1 if bayes estimation method is applied	0.005	0.072
ols	=1 if estimation method is ordinary least squares	0.074	0.261
eel	=1 if estimation method is 3S-EEL estimator	0.004	0.065
gse	=1 if estimate comes from generalized spectral estimation	0.011	0.102
tvc	=1 in case of time-varying coefficient estimation technique	0.007	0.086
gel	=1 if estimation method is generalized empirical likelihood	0.006	0.079
othmeth	=1 in case of other estimation method	0.057	0.233
model	=1 if NKPC is estimated within model	0.065	0.247

Table 5.5: Robustness check of FAT and PET

	Top 7 journals		Top cited studies		Top cited authors		Journals preferred		All preferred	
	ME	OLSCL	ME	OLSCL	ME	OLSCL	ME	OLSCL	ME	OLSCL
A. Funnel Assymetry Test and Precision Effect Test										
PET (γ)	0.402***	0.404***	0.632***	0.678***	0.632***	0.659***	0.479***	0.485***	0.155***	0.155
	(0.006)	(0.006)	(0.022)	(0.036)	(0.020)	(0.044)	(0.004)	(0.006)	(0.013)	(0.118)
FAT (α)	4.467***	4.037***	-0.311	-1.066	-0.518	-0.189	2.022***	1.191***	8.821***	8.870***
	(0.866)	(0.824)	(0.704)	(0.570)	(0.647)	(0.924)	(0.511)	(0.437)	(2.247)	(2.637)
obs	262	262	97	97	124	124	160	160	343	343
studies	25	25	16	16	17	17	88	88	181	181
τ	0.120		0.106		0.112		0.131		0.330	
I^2	98.9%		88.4%		85.9%		95.5%		99.9%	
R^2		0.95		0.94		0.93		0.99		0.30
B. Arithmetic mean										
Mean	0.621		0.541		0.653		0.538		0.539	
C. Precision-effect estimate with standard error										
PEESE	0.404***	0.417***	0.626***	0.647***	0.622***	0.652***	0.481***	0.489***	0.165***	0.165
	(0.006)	(0.012)	(0.017)	(0.027)	(0.016)	(0.029)	(0.004)	(0.008)	(0.013)	(0.120)

Note: Standard errors are in parentheses.
* - significance at 10%, ** - significance at 5%, *** - significance at 1%.
ME - mixed-effects model, OLSCL - ordinary least squares with clustered s.e.
Top journals: 7 top rated journals (previous + Journal of Money, Credit and Banking, Journal of Applied Econometrics and Economics Letters.
Top cited authors: more than 800 citations in Repec; Top cited studies: more than 80 citations in Google Scholar.
Correlations between these categories: top journal vs. top authors = 0.43; top journal vs. top studies = 0.48; top authors vs. top studies = 0.51.
Preferred stands for one estimate per each study which is marked as preferred by author of the study.
In case of more such estimates, their average is considered. Studies critical to the NKPC does not have any preferred estimate.

Table 5.6: Multivariate meta-regresion - robustness

	ME	FE	OLSCL	ME^{out}	FE^{out}	OLSCL^{out}
yeardm	0.020***	0.020***	0.019*	0.002	0.003	-0.001
	(0.003)	(0.003)	(0.010)	(0.003)	(0.003)	(0.007)
wp	-0.105***	-0.108***	-0.097***	-0.024**	-0.031***	-0.013
	(0.015)	(0.015)	(0.036)	(0.011)	(0.011)	(0.029)
othstud	-0.087***	-0.088***	-0.088	0.047***	0.043***	0.050*
	(0.014)	(0.014)	(0.057)	(0.012)	(0.013)	(0.027)
citg	0.056***	0.056***	0.059**	0.014***	0.015***	0.009
	(0.006)	(0.006)	(0.023)	(0.005)	(0.005)	(0.011)
aaca	-0.063***	-0.063***	-0.059**	-0.025***	-0.025***	-0.013
	(0.012)	(0.013)	(0.026)	(0.008)	(0.009)	(0.016)
beta	0.154***	0.153***	0.158***	-0.002	-0.003	0.006
	(0.008)	(0.008)	(0.028)	(0.008)	(0.008)	(0.020)
gap	-0.073***	-0.069***	-0.098**	-0.082***	-0.083***	-0.079**
	(0.020)	(0.020)	(0.039)	(0.015)	(0.015)	(0.032)
rulc	-0.154***	-0.150***	-0.176***	-0.006	-0.012	0.005
	(0.020)	(0.020)	(0.033)	(0.015)	(0.015)	(0.033)
othproxy	-0.062*	-0.054	-0.086	0.018	0.020	0.014
	(0.035)	(0.035)	(0.052)	(0.022)	(0.022)	(0.043)
sur	-0.004	-0.004	0.001	-0.037***	-0.038***	-0.028
	(0.019)	(0.019)	(0.040)	(0.012)	(0.012)	(0.024)
inflag	-0.111***	-0.108***	-0.128***	-0.052***	-0.048***	-0.079
	(0.024)	(0.024)	(0.039)	(0.016)	(0.016)	(0.055)
infdev	-0.077**	-0.075**	-0.092**	-0.041	-0.049*	-0.055
	(0.032)	(0.033)	(0.041)	(0.026)	(0.027)	(0.062)
open	-0.032**	-0.025*	-0.054**	-0.065***	-0.055***	-0.092**
	(0.015)	(0.015)	(0.026)	(0.013)	(0.013)	(0.037)
firstdm	-0.005***	-0.005***	-0.006***	-0.001	-0.001*	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
lastdm	0.009***	0.008***	0.010*	0.003**	0.003**	0.003
	(0.001)	(0.001)	(0.006)	(0.001)	(0.001)	(0.002)
month	-0.064**	-0.064**	-0.077	-0.094***	-0.095***	-0.111
	(0.028)	(0.029)	(0.048)	(0.018)	(0.018)	(0.070)
cpi	-0.132***	-0.128***	-0.147***	-0.048***	-0.052***	-0.055
	(0.011)	(0.011)	(0.031)	(0.010)	(0.010)	(0.035)
core	-0.142***	-0.149***	-0.116***	0.075***	0.077***	0.053
	(0.015)	(0.015)	(0.041)	(0.025)	(0.026)	(0.083)
tsls	0.121***	0.121***	0.078	0.088***	0.086***	0.080*
	(0.030)	(0.030)	(0.062)	(0.018)	(0.018)	(0.047)

Continued on next page. . .

Table 5.6 – Continued

	ME	FE	OLSCL	ME^{out}	FE^{out}	$OLSCL^{out}$
like	-0.069***	-0.073***	-0.060	-0.047***	-0.046***	-0.059*
	(0.016)	(0.016)	(0.038)	(0.011)	(0.011)	(0.035)
ols	0.099***	0.097***	0.091***	0.062***	0.057***	0.062**
	(0.025)	(0.025)	(0.028)	(0.016)	(0.016)	(0.024)
bayes	-0.077	-0.083	-0.044	0.181***	0.181***	0.185***
	(0.069)	(0.069)	(0.054)	(0.043)	(0.043)	(0.063)
eel	0.103*	0.098	0.125**	-0.010	-0.014	-0.012
	(0.063)	(0.063)	(0.048)	(0.037)	(0.037)	(0.020)
gse	0.233***	0.227***	0.259*	0.001	0.005	-0.019
	(0.024)	(0.024)	(0.139)	(0.021)	(0.022)	(0.045)
tvc	0.253*	0.253*	0.248**	0.196**	0.196**	0.191*
	(0.136)	(0.137)	(0.104)	(0.079)	(0.079)	(0.096)
constant	-0.405	-0.192	-0.066	0.003	0.050	0.175
	(0.513)	(0.183)	(0.339)	(0.327)	(0.122)	(0.177)
obs	1,899	1,899	1,899	1,853	1,853	1,853
R^2 adj.		0.991	0.989		0.900	0.895
n groups	55	55	55	55	55	55
groups	countries	countries	countries	countries	countries	countries

Standard errors are reported in parenthesis. Upper index out stands for regression "without outliers".
ME - mixed-effects model, FE - fixed-effects model, OLSCL - ordinary least squares with clustered s.e.
* - significance at 10%, ** - 5%, *** - 1%.

Table 5.7: Effects by individual countries

Country		effect	s.e.	obs
Austria	at	0.474***	0.012	26
Australia	au	0.522***	0.087	7
Brazil	br	0.140	0.194	11
Canada	ca	0.496***	0.037	41
Swiss	ch	0.538***	0.092	21
Chile	cl	0.597***	0.033	23
China	cn	0.048	0.055	34
Czech Republic	cz	0.560***	0.013	77
Estonia	ee	0.430	0.264	7
EMU/EU	eu	0.486***	0.015	165
France	fr	0.604***	0.011	54
Germany	ge	0.308***	0.004	45
Greece	gr	0.253***	0.093	7
Hong Kong	hk	0.593***	0.060	43
Hungary	hu	0.633***	0.001	70
Israel	il	0.360***	0.024	48
India	in	0.581***	0.027	10
Italy	it	0.480***	0.003	78
Japan	jp	0.008	0.006	21
Korea	kr	0.617***	0.041	9
Lithuania	lt	1.131***	0.129	7
Latvia	lv	-0.080	0.269	7
Mexico	mx	0.533***	0.007	17
Netherland	ne	0.509***	0.096	7
Norway	no	0.091	0.458	8
OECD	oecd	0.584***	0.028	26
Poland	pl	0.667***	0.035	43
Portugal	pt	0.422***	0.042	7
Romania	ro	-0.174	0.304	9
Russia	ru	0.945***	0.067	56
Slovak Republic	sk	0.334***	0.008	18
Spain	sp	0.449***	0.035	29
Sweden	sw	0.434***	0.029	20
Tunisia	tn	0.682***	0.097	9
Turkey	tu	0.145	0.089	14
United Kingdom	uk	0.441***	0.009	151
USA	us	0.698***	0.007	613

Note: Standard errors are in parentheses.
* - significance at 10%, ** - at 5%, *** - at 1%.
Random-effects model for individual countries with > 6 estimates.

6 Conclusions

> *"And therefore the Philosopher [Aristotle] says in Metaphysics VI that good and evil, which are objects of the will, are in things, but truth and error, which are objects of the intellect, are in the mind."*
>
> – St. Thomas Aquinas

In the presented thesis we analyse monetary policy estimating the New Keynesian Phillips curve. We describe its derivation and the approximation of real marginal cost by different macroeconomic variables. Moreover, we summarize different approaches of the derivation or construction of the open economy NKPC. Finally, the theoretical part of the thesis ends with the overview of the literature developed during past twelve years since Galí and Gertler published their influential paper (Galí and Gertler, 1999).

In the practical part, the thesis compares estimations methods, Generalized Method of Moments and Full Information Maximum Likelihood. The GMM is generally popular method for the estimation of the NKPC but last few years have brought a number of papers critical to this technique. Topics of these studies are mostly related to the weak instruments, small sample bias, instability and omitted variables problem, while potential omitted variables are included in the instrument set. Jondeau and LeBihan (2006) compare GMM and ML estimations of the NKPC and concludes that GMM leads to an overestimation of the forward-looking coefficient in their specifications. Some of these critical papers recommend FIML method in order to obtain robust results (Lindé, 2005, Menyhért, 2008).

We follow this approach and estimate NKPC for the Czech Republic between 1996 and 2009 (Danišková and Fidrmuc, 2011). Our findings show that the GMM results are likely to be overestimated because GMM is not able to dispose of the significant share of OLS bias. Moreover, the resulting estimates depends on the choice of instrumental variables. Results obtained by FIML confirm preferable status of FIML. They imply that real marginal cost are mostly unimportant in the inflation dynamic of the Czech Republic and estimates of structural parameters are comparable to those reported for other countries of the EU.

Presented thesis also examines heterogeneity among estimates of the NKPC. We focus on the coefficient of the expected inflation and collect almost two hundred papers dealing with hybrid version of the NKPC. Instead of literature survey we implement meta-analysis in order to dispose of possible subjective contribution often present in literature surveys (Stanley and Jarrell, 1989, Stanley, 2005, Feld and Heckemeyer, 2011).

Obtained results are mostly in line with our expectations but some findings are rather surprising (Fidrmuc and Danišková, 2012). Literature concerned with the NKPC seems to possess strong publication bias especially in the highly rated journals what suggests that publication process prefers significant and theoretically sound results.

Besides we also examine the influence of individual authors' and study's characteristics on collected estimates. The important determinants of inflation expectations term are estimation method, inflation measure, data range and publication characteristics. Contrary to these, survey measure of inflation expectations appears not to be statistically different from rational expectations. At last, meta-analysis detects that there are significant differences in inflation expectations term among different countries. The forward-looking coefficient is unimportant in some countries (Japan, China, Brazil) while others have small or insignificant inflation persistence (USA, Russia, Lithuania).

Resumé

Témou predloženej dizertačnej práce je emipirická analýza monetárnej politiky. Práca sa detailne zaoberá Novou Keynesiánskou Phillipsovou krivkou (NKPC), ktorá sa stala neoddeliteľnou súčasťou modelov modernej monetárnej politiky. NKPC je založená na modeli nepružných cien (Calvo, 1983) a odvodená na báze mikroekonomických modelov s racionálnymi očakávaniami. Trhové subjekty majú možnosť stanoviť svoje inflačné očakávania na báze očakávaného vývoja. Práve tieto vlastnosti odlišujú NKPC od tradičnej Phillipsovej krivky.

V práci sa zameriavame na hybridný model NKPC (Galí a Gertler, 1999), ktorý predpokladá diferencovaných účastníkov na trhu. Kým časť z nich stanovuje cenu na základe očakávaní o budúcom vývoji cien, druhá časť využíva informácie o minulom vývoji a tie aplikuje pri tvorbe cien. Výsledná hybridná krivka má nasledovný tvar

$$\pi_t = \gamma_f \, \mathbf{E}_t \, \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda mc_t^r + \varepsilon_t. \tag{6.1}$$

Súčasná inflácia π_t je vyjadrená ako súčet inflačných očakávaní $\mathbf{E}_t \, \pi_{t+1}$, minulej inflácie π_{t-1} a reálnych hraničných nákladov mc_t^r. Zároveň je možné vyjadriť jednotlivé koeficienty NKPC ako funkcie štrukturálnych parametrov

$$\begin{aligned}
\gamma_f &\equiv \theta\beta\phi^{-1} \\
\gamma_b &\equiv \omega\phi^{-1} \\
\lambda &\equiv (1-\beta\theta)(1-\omega)(1-\theta)\phi^{-1} \\
\phi &\equiv \theta + \omega[1-\theta(1-\beta)],
\end{aligned}$$

kde $(1-\theta)$ je pravdepodobnosť zmeny cenovej hladiny, $(1-\omega)$ definuje podiel účastníkov na trhu, ktorí stanovujú cenu na základe očakávaní o budúcom vývoji a β je diskontný faktor budúcich strát. Odvodením a interpretáciou klasickej a hybridnej NKPC sa zaoberáme v kapitole 2.

Nevýhodou uvedeného modelu je nedostupnosť dát pre reálne hraničné náklady. Tento problém sa zvyčajne rieši aproximáciou pomocou reálnych jednotkových nákladou práce alebo produkčnej medzery. Časť autorov preferuje tradičný prístup a použí-

vajú nezamestnanosť namiesto reálnych hraničných nákladov (Blanchard a Galí, 2007, Russel, 2011). Detailnejšie sa týmito prístupmi zaoberáme v kapitole 2.3.

Vyššie prezentovaná Nová Keynesiánska Phillipsova krivka v sebe nezahŕňa atribúty otvorenej ekonomiky ako napr. ceny importovaných tovarov, výmenný kurz, zahraničnú mieru inflácie, atď. Rôzne prístupy ku konštrukcii NKPC pre otvorenú ekonomiku diskutujeme v kapitole 2.4.

V kapitole 3 ponúkame prehľad literatúry, ktorá sa zaoberá klasickou alebo hybridnou NKPC. Najčastejšie diskutované témy je možné rozdeliť do niekoľkých okruhov: (1) predpoklad racionálnych očakávaní v porovnaní s použitím reálnych očakávaní o budúcej inflácii, (2) aproximácia reálnych hraničných nákladov, (3) porovnanie klasickej a hybridnej NKPC, (4) výber vhodnej metódy odhadu, (5) porovnanie s NKPC pre otvorenú ekonomiku.

V kapitole 4 sa zaoberáme odhadom Novej Keynesiánskej Phillipsovej krivky pre Českú republiku v rokoch 1996 až 2009 (Danišková a Fidrmuc, 2011). Porovnávame dve metódy odhadu NKPC, zovšeobecnú metódu momentov (GMM) a metódu maximálnej vierohodnosti s úplnou informáciou (FIML). Napriek tomu, že metóda GMM sa bežne používa pri odhadoch NKPC, má niekoľko vlastností, ktoré boli podrobené silnej kritike (Fuhrer et al., 1995, Menyhért, 2008). Podarilo sa nám potvrdiť, že metóda odhadu GMM v prípade NKPC nie je spoľahlivou metódou kvôli tzv. slabým inštrumentom. Naviac, výsledky sú závislé aj od použitej aproximácie reálnych hraničných nákladov. Naopak, metóda FIML je robustná a vedie k signifikatným odhadom štrukturálnych parametrov. Zároveň potvrdzuje silný vplyv očakávanej inflácie na súčasnú infláciu. Preferované výsledky pre Českú republiku sú porovnateľné s ostatnými krajinami Eurozóny a konštatujeme, že Česká republika úspešne konverguje k rozvinutým ekonomikám.

Výsledky rôznych autorov venujúcich sa NKPC sú často veľmi odlišné, a preto v kapitole 5 skúmame takmer 200 štúdií zaoberajúcich sa Novou Keynesiánskou Phillipsovou krivkou a dôvody ich heterogenity (Fidrmuc a Danišková, 2012). Zameriavame sa na koeficient očakávanej inflácie γ_f a analyzujeme jeho hodnoty pochádzajúce z rôznych štúdií pomocou metódy meta-analýzy (Stanley a Jarrell, 1989, Stanley, 2005, Feld a Heckemeyer, 2011). Potvrdzujeme existenciu publikačnej odchýlky v prácach publikovaných v časopisoch, ktorá je ešte výraznejšia v prípade najprestížnejších časopisov. Podobná odchýlka nie je pozorovateľná v prípade najcitovanejších štúdií a autorov.

Ďalej ukazujeme, že vybrané charakteristiky štúdií a autorov majú signifikantný vplyv na publikované výsledky. Pri odhadovaní koeficientu budúcej inflácie je viditeľný jasný pozitívny trend odhadu γ_f. Z charakteristík autorov sa ako signifikantné javí len pracovisko autora. Výsledky publikované v časopisoch sú vyššie ako iné výsledky a signifikantný je aj vplyv výberu aproximácie reálnych hraničných nákladov. Taktiež aj metóda odhadu má vplyv na dosiahnuté výsledky. Tvrdenie Jondeau a LeBihan (2006) o tom, že GMM vedie k vyšším odhadom ako FIML, sa potvrdilo v prezentovanej meta-analýze. Výsledky tiež naznačujú, že metóda GMM nie je signifikatne odlišná od metódy OLS. Nakoniec sme prekvapujúco nenašli signifikantný rozdiel medzi predpokladom racionálnych očakávaní a použitím dát o skutočných inflačných očakávaniach.

V závere práce sumarizujeme dosiahnuté výsledky.

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A

Standard log-linearization method

Here we introduce the standard log-linearization method to derive the aggregate price level. Assume the equation in the following form

$$f(X_t, Y_t) = g(W_t)$$

where X_t, Y_t and W_t are strictly positive variables at time t. This equation is clearly also valid at the steady state

$$f(X, Y) = g(W). \tag{A.1}$$

Identity $X_t = e^{log(X_t)}$ and logs on both sides are used to re-write equation as follows

$$log(f(e^{log(X_t)}, e^{log(Y_t)})) = log(g(e^{log(W_t)})) \tag{A.2}$$

and the Taylor approximation of the left side of the equation (A.2) around the steady state yields

$$log(f(X, Y)) + \frac{1}{f(X, Y)}[f_1(X, Y)Xx_t + f_2(X, Y)Yy_t], \tag{A.3}$$

where $x_t \equiv logX_t - logX$ and $y_t \equiv logY_t - logY$. Similarly, the right side of equation leads to

$$log(g(W)) + \frac{1}{g(W)}[g'(W)Ww_t], \tag{A.4}$$

where $w_t \equiv logW_t - logW$. Equating (A.3) and (A.4) and using (A.1) implies the following expression

$$[f_1(X, Y)Xx_t + f_2(X, Y)Yy_t] \simeq [g'(W)Ww_t]. \tag{A.5}$$

Now, (A.5) can be applied on the equation (2.2) where $X_t = Z_t^*$, $Y_t = P_{t-1}$ and $W_t = P_t$. Then

$$f(Z_t^*, P_{t-1}) = \Big((1-\theta)(Z_t^*)^{(1-\eta)} + \theta P_{t-1}^{(1-\eta)}\Big)^{\frac{1}{1-\eta}}$$

and

$$g(P_t) = P_t.$$

Following the previous procedure we derive

$$\frac{1}{1-\eta}\Big((1-\theta)Z^{*(1-\eta)} + \theta P^{(1-\eta)}\Big)^{\frac{\eta}{1-\eta}}[(1-\theta)(1-\eta)Z^{*-\eta}Z^* z_t^* + \theta(1-\eta)P^{-\eta}Pp_{t-1}] = Pp_t$$

$$\frac{1}{1-\eta}\Big((1-\theta)Z^{*(1-\eta)} + \theta P^{(1-\eta)}\Big)^{\frac{\eta}{1-\eta}}(1-\eta)[(1-\theta)Z^{*(1-\eta)} z_t^* + \theta P^{(1-\eta)}p_{t-1}] = Pp_t$$

$$P^{\eta}[(1-\theta)Z^{*(1-\eta)} z_t^* + \theta P^{(1-\eta)}p_{t-1}] = Pp_t.$$

Applying assumption under which $Z^* = P$ in a steady state, we obtain

$$P^{\eta}[(1-\theta)P^{(1-\eta)} z_t^* + \theta P^{(1-\eta)}p_{t-1}] = Pp_t$$

$$P^{\eta}P^{(1-\eta)}[(1-\theta)z_t^* + \theta p_{t-1}] = Pp_t$$

$$(1-\theta)z_t^* + \theta p_{t-1} = p_t$$

what is similar to the equation (2.3).

B

Derivation of the hybrid NKPC

Combining equation (2.13)

$$p_t^f = \frac{1}{1-\omega}(z_t^* - \omega p_t^b)$$

with equation (2.15)

$$p_t^f = \theta\beta\,\mathbf{E}_t\,p_{t+1}^f + (1-\theta\beta)(\mu + mc_t),$$

we get

$$\frac{1}{1-\omega}(z_t^* - \omega p_t^b) = \frac{\theta\beta}{1-\omega}\,\mathbf{E}_t\{z_{t+1}^* - \omega p_{t+1}^b\} + (1-\beta\theta)(\mu + mc_t). \tag{B.1}$$

Next we can substitute (2.16)

$$p_t^b = z_{t-1}^* + \pi_{t-1}$$

to (B.1) what yields

$$\begin{aligned} &\frac{1}{1-\omega}(z_t^* - \omega(z_{t-1}^* + \pi_{t-1})) \\ &\quad = \frac{\theta\beta}{1-\omega}\,\mathbf{E}_t\{z_{t+1}^* - \omega(z_t^* + \pi_t)\} + (1-\beta\theta)(\mu + mc_t). \end{aligned} \tag{B.2}$$

The final step is to rewrite (2.12) as

$$z_t^* = \frac{1}{1-\theta}(p_t - \theta p_{t-1})$$

and combine it with (B.2) to complete initial equation

$$\begin{aligned}&\frac{1}{1-\omega}\left(\frac{1}{1-\theta}(p_t-\theta p_{t-1})-\omega\left(\frac{1}{1-\theta}(p_{t-1}-\theta p_{t-2})+\pi_{t-1}\right)\right)\\&\quad=\frac{\theta\beta}{1-\omega}\,\mathbf{E}_t\left\{\frac{1}{1-\theta}(p_{t+1}-\theta p_t)-\omega\left(\frac{1}{1-\theta}(p_t-\theta p_{t-1})+\pi_t\right)\right\}+(1-\beta\theta)(\mu+mc_t).\end{aligned}$$

Then p_t, p_{t-1}, θp_t and θp_{t-1} are added and subtracted and the equation is multiplied by $(1-\omega)$:

$$\begin{aligned}&\frac{1}{1-\theta}(p_t-p_{t-1}+p_{t-1}-\theta p_{t-1})-\omega\left(\frac{1}{1-\theta}(p_{t-1}-\theta p_{t-1}+\theta p_{t-1}-\theta p_{t-2})+\pi_{t-1}\right)\\&\quad=\theta\beta\,\mathbf{E}_t\left\{\frac{1}{1-\theta}(p_{t+1}-p_t+p_t-\theta p_t)-\omega\left(\frac{1}{1-\theta}(p_t-\theta p_t+\theta p_t-\theta p_{t-1})+\pi_t\right)\right\}\\&\quad+(1-\beta\theta)(1-\omega)(\mu+mc_t).\end{aligned}$$

Subsequently, the term p_t-p_{t-1} is substituted by inflation π_t:

$$\begin{aligned}&\frac{1}{1-\theta}\pi_t+p_{t-1}-\omega p_{t-1}-\frac{\omega\theta}{1-\theta}\pi_{t-1}-\omega\pi_{t-1}\\&\quad=\theta\beta\,\mathbf{E}_t\left\{\frac{1}{1-\theta}\pi_{t+1}+p_t-\omega p_t-\frac{\omega\theta}{1-\theta}\pi_t-\omega\pi_t\right\}+(1-\beta\theta)(1-\omega)(\mu+mc_t).\end{aligned}$$

And then the equation is modified in the following way

$$\begin{aligned}&\frac{1}{1-\theta}\pi_t+p_{t-1}-\omega p_{t-1}-\frac{\omega}{1-\theta}\pi_{t-1}\\&\quad=\theta\beta\,\mathbf{E}_t\left\{\frac{1}{1-\theta}\pi_{t+1}+p_t-\omega p_t-\frac{\omega}{1-\theta}\pi_t\right\}+(1-\beta\theta)(1-\omega)(\mu+mc_t)\end{aligned}$$

$$\begin{aligned}&\frac{1}{1-\theta}\pi_t+p_{t-1}-\omega p_{t-1}-\frac{\omega}{1-\theta}\pi_{t-1}\\&\quad=\frac{\theta\beta}{1-\theta}\,\mathbf{E}_t\,\pi_{t+1}+\theta\beta p_t-\theta\beta\omega p_t-\frac{\omega\theta\beta}{1-\theta}\pi_t+(1-\beta\theta)(1-\omega)(\mu+mc_t).\end{aligned}$$

Now we add $-p_t+\omega p_t$ to the both sides of the equation and substitute the term p_t-p_{t-1} by π_t again:

$$\begin{aligned}&\frac{1}{1-\theta}\pi_t+p_{t-1}-p_t+\omega p_t-\omega p_{t-1}-\frac{\omega}{1-\theta}\pi_{t-1}\\&\quad=\frac{\theta\beta}{1-\theta}\,\mathbf{E}_t\,\pi_{t+1}-p_t+\omega p_t+\theta\beta p_t-\theta\beta\omega p_t-\frac{\omega\theta\beta}{1-\theta}\pi_t+(1-\beta\theta)(1-\omega)(\mu+mc_t)\end{aligned}$$

$$\begin{aligned}
&\frac{1}{1-\theta}\pi_t - \pi_t + \omega\pi_t - \frac{\omega}{1-\theta}\pi_{t-1} \\
&\qquad = \frac{\theta\beta}{1-\theta}\,\mathbf{E}_t\,\pi_{t+1} - \frac{\omega\theta\beta}{1-\theta}\pi_t + (1-\beta\theta)(1-\omega)(\mu + mc_t - p_t).
\end{aligned}$$

We move all terms containing π_t on the left side of the equation and all terms containing π_{t-1} on the right side of the equation what yields

$$\begin{aligned}
&\frac{1}{1-\theta}\pi_t - \pi_t + \omega\pi_t + \frac{\omega\theta\beta}{1-\theta}\pi_t \\
&\qquad = \frac{\theta\beta}{1-\theta}\,\mathbf{E}_t\,\pi_{t+1} + \frac{\omega}{1-\theta}\pi_{t-1} + (1-\beta\theta)(1-\omega)(\mu + mc_t - p_t)
\end{aligned}$$

$$\begin{aligned}
&\frac{\theta + \omega[1-\theta(1-\beta)]}{1-\theta}\pi_t \\
&\qquad = \frac{\theta\beta}{1-\theta}\,\mathbf{E}_t\,\pi_{t+1} + \frac{\omega}{1-\theta}\pi_{t-1} + (1-\beta\theta)(1-\omega)(\mu + mc_t - p_t).
\end{aligned}$$

Finally, we multiply the equation by $(1-\theta)$:

$$\begin{aligned}
&(\theta + \omega[1-\theta(1-\beta)])\pi_t \\
&\qquad = \theta\beta\,\mathbf{E}_t\,\pi_{t+1} + \omega\pi_{t-1} + (1-\beta\theta)(1-\omega)(1-\theta)(\mu + mc_t - p_t).
\end{aligned}$$

Let $\phi \equiv \theta + \omega[1-\theta(1-\beta)]$ and the final form of the hybrid NKPC might be rewritten as follows

$$\pi_t = \gamma_f\,\mathbf{E}_t\,\pi_{t+1} + \gamma_b\pi_{t-1} + \lambda mc_t^r,$$

where reduced-form coefficients are functions of structural parameters $(1-\theta)$, $(1-\omega)$ and β:

$$\begin{aligned}
\gamma_f &\equiv \theta\beta\phi^{-1} \\
\gamma_b &\equiv \omega\phi^{-1} \\
\lambda &\equiv (1-\beta\theta)(1-\omega)(1-\theta)\phi^{-1} \\
\phi &\equiv \theta + \omega[1-\theta(1-\beta)].
\end{aligned}$$