

Inflation dynamics in the Czech Republic: Estimation of the New Keynesian Phillips curve

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ABSTRACT²

This paper challenges previous empirical evidence on output-inflation trade-off described in the hybrid New Keynesian Phillips curve. I estimate key coefficients of the hybrid gap-based New Keynesian Phillips curve, with both the forward- and backward-looking inflation components, in the Czech Republic for the periods 2000Q1 - 2012Q4 using Kalman filtration. My findings come to surprising conclusions that (i) output gap has a (statistically) significant impact on Czech inflation dynamics (ii) there is a reversal in behavior of Czech agents, where share of forward-looking agents predominates over backward-looking ones in the Czech Republic and (iii) Czech inflation might be significantly driven by change in import prices. In addition, all my results come statistically significant and correctly sign-oriented, which contradicts majority of existing empirical evidence on output-inflation trade-off in the Czech Republic.

Keywords: output-inflation trade-off, inflation, inflation expectations, Kalman filtration, state space model

JEL classification: C32, C51, E17, E31, E37, E58

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Citation

Daniela Milucka (2014). Inflation dynamics in the Czech Republic: Estimation of the New Keynesian Phillips curve. *International Journal of Economic Sciences*, Vol. III, No. 2/2014, pp. 53-70.

¹ The views expressed in the article are the views of the author herself and may not correspond the views of the University of Economics in Prague. I want to express my greatest attitude to Jaromir Hurnik and Radoslav Peter for their valuable comments.

² I declare that this article is an excerpt taken from an unpublished Master Thesis: Milucka, D. *Inflation Dynamics in the Czech Republic: Estimating the New Keynesian Phillips Curve*. Unpublished

INTRODUCTION

Estimation of the Phillips curve has been an effective part of a toolkit of the monetary policy for description of the short-term inflation dynamics in economic research over the past decades. The traditional Phillips curve considers the short-run trade-off between lagged inflation and the real economic activity (or cyclical component), defined as a deviation of either output or unemployment rate from its trend. However, empirical evidence of the traditional Phillips curve appeared to be insufficient because it could not explain the U. S. accelerating inflation accompanied by stagnation after 1970 and therefore buried the traditional Phillips curve. Nowadays, the New Keynesian Phillips curve (NKPC) has become the draft-horse for approximation of the inflation dynamics in small open economies. Unlike the traditional Phillips curve, the New Keynesian Phillips curve is derived from strong microeconomic foundations³ (based on Lucas critique), which account 3 principal features: (i) rational expectations, (ii) imperfect (monopolistic) competition and (iii) Calvo's principle of the staggered prices. In response to Lucas critique, the New Keynesian models highlighted the importance of substituting inflation expectations for lagged inflation into the Phillips curve and they showed that there is a considerable short-run relationship between the real economic activity and price inflation, once inflation expectations are correctly added into the model. The match of the New Keynesian Phillips curve with data turned out to be, though, highly insufficient. The purely forward-looking version of the NKPC has been subject to criticism of many economists, e.g. Rudd and Whellan (2007), Gali and Gertler (1999), and Fuhrer and Moore (1995). This fact led economists to reconsider an adjusted form of the New Keynesian Phillips curve, hybrid version of the New Keynesian Phillips curve proposed by Gali and Gertler (1999), which incorporated both forward- and backward-looking agents. The vast empirical evidence on the hybrid version of the NKPC confirmed importance of the lagged inflation in the New Keynesian Phillips curve. Yet, the results came mostly statistically insignificant, biased and not correctly sign-oriented, which led to the ambiguously drawn conclusions. Majority of empirical evidence showed that the real marginal costs, as a representation of a driving force, deliver more satisfying results than the output gap due to their easier econometric approximation.⁴ This better fit with data caused that economists started prioritize the costs-based NKPC over the gap-based one. Only after, Neiss and Nelson (2002) confronted this trend and justified that "once output gap is defined consistently with the economic theory, it can produce results at least as good as marginal costs" (Neiss and Nelson 2002, pp.28). The contemporary limited empirical evidence on the gap-based NKPC in transition economies (especially in the Czech Republic) has also oriented in favor of the costs-based NKPC and rejects the concept of the output-inflation trade-off in the New Keynesian Phillips curve due to its weak statistical match with the data.

My paper challenges the previous empirical evidence and hypothesizes the output-inflation trade-off in the hybrid NKPC in the Czech Republic. My results show that once more sophisticated econometric method is used for approximation of output gap, then the gap-based NKPC provides at least as satisfying results as the costs-based NKPC, which confirms Neiss and Nelson's presumption. These estimations imply that due to high volatility of Czech output after financial crisis, the Czech New Keynesian Phillips curve cannot collapse as previous studies suggested. In addition, my paper shows a sudden reversal in the behavior of the Czech agents, who appear to be strictly forward-looking after the financial crisis in 2008. At last, my estimations confirm the belief

³ See Gali and Monacelli (2002) for more details.

⁴ See Gali and Gertler (1999)

that Czech inflation appears to be very sensitive to change in the import prices due to high openness of the Czech economy and its strong import - dependence on neighboring countries.

This paper is divided into three sections. Section I. introduces theoretical concepts of original and extended versions of the hybrid gap - based New Keynesian Phillips curve. Section II. describes adopted econometric estimation method of Kalman filtration and section III. justifies obtained results and draws conclusions.

1 Literature review

The New Keynesian Phillips curve can be defined as an output-inflation trade-off resulted from the dynamic general equilibrium New Keynesian model constructed from the utility maximizing households and profit-maximizing firms (Grohe and Uribe 2008, pp.440).

The purely forward-looking New Keynesian Phillips curve takes form

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \delta \hat{x}_t + u_t \quad (1)$$

where $E_t\{\pi_{t+1}\}$ are the inflation expectations observed at time t , \hat{x}_t is a cyclical component of economic activity (e.g. deviation of output or real marginal costs from its trend) and u_t is a disturbance term. Rotemberg and Woodford (1999) and Sbordone (2002) investigated that under particular assumptions there is a log-linearized (approximate proportional) relationship between the real marginal costs and output gap in the New Keynesian Phillips curve.⁵ Upholding this presumption, the coefficient δ can be substituted with coefficient κ , when output gap is a main inflation driving force (and with coefficient λ in case, where \hat{x}_t is represented by real marginal costs gap).⁶ After substitution, we get the output gap based New Keynesian Phillips curve for small open economy defined as

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa \hat{y}_t + u_t \quad (2)$$

Economists realized that inflation expectations are an important but not the only variable, which describes current domestic inflation movement. Gali and Gertler (1999) noticed that agents do not rely purely on inflation expectations in the economy but they also take past inflation into consideration. This observation led Gali and Gertler (1999) to establish an adjusted hybrid form of the NKPC, which mixes both the old (traditional) and the new (New Keynesian) version of the Phillips curve.

Following Gali and Gertler (1999), the output gap based hybrid version of the NKPC can be expressed as

$$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \kappa \hat{y}_{t-1} + u_t \quad (3)$$

⁵ Relationship between output gap and real marginal costs gap is defined as $\widehat{mc}_t = (\sigma + \frac{\varphi+\alpha}{1-\alpha})(y_t - y_t^*)$, where φ measures risk aversion in household's utility function,

⁶ Following Gali and Monacelli (2002), coefficient κ for small open economy is defined as $\kappa = (\sigma_\alpha + \varphi)\lambda$ and $\lambda = (\frac{(1-\theta)(1-\beta\theta)}{\theta})$, where θ is a Calvo's price stickiness parameter, β is a discount factor, φ is a relative risk aversion parameter in household's utility function and parameter σ_α expressed relation of elasticity of substitution and share of domestic and foreign consumed goods in utility function of household.

where $E_t\{\pi_{t+1}\}$ are inflation expectations at time t , π_{t-1} is a lagged inflation, \hat{y}_{t-1} is a lagged output gap and u_t is disturbance term. Introducing lagged cyclical component is an important feature for inflation targeting. Condition $\gamma_f + \gamma_b = 1$ must hold in order to ensure linear homogeneity of inflation. By construction, lagged variable prevents instantaneous and complete inflation and output adjustment to unexpected shocks. Coefficients γ and κ are functions of structural parameters coming from the New Keynesian model for a small open economy. As Hornstein (2008) emphasizes, the ability of policy makers to control inflation depends on relative magnitudes of these coefficients. Equation (3) is a second-order stochastic difference equation in a log-linearized form. The hybrid NKPC includes lagged inflation as supplementary explanatory variable to current inflation movement. Gali and Gertler (1999) affirm that including term π_{t-1} is inevitable in order “to capture inflation persistence that is missing in the original New Keynesian Phillips curve”.

Hybrid version of the New Keynesian Phillips curve, as defined in equation (3), is usually used only as a baseline for more advanced models, which describe movement of domestic inflation more accurately. Additional exogenous variables can be added to the hybrid NKPC in order to capture additional external factors, which directly or indirectly influence inflation in the economy. Introducing the exchange rate dynamics into the model is crucial for Czech economy, as a non-member of European Monetary Union. All external shocks translate directly into the exchange rate deviation from its trend and through the transmission mechanism inevitably into domestic inflation. Effect of the exchange rate change influences domestic inflation through the two channels: (i) direct channel through the import prices and (ii) an indirect channel through the impact of the real exchange rate fluctuations on real economy.

Once effect of the real exchange rate fluctuations is added to the model, equation (3) transforms into

$$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \kappa \hat{y}_{t-1} + c \hat{z}_{t-1} + u_t \quad (4)$$

where \hat{z}_{t-1} is a lagged impact of the real effective exchange rate gap measured as a deviation of the real exchange rate from its trend ($\hat{z}_t = z_t - z_t^*$).⁷

Import prices, in general, are an essential determinant of a supply side effect for inflation, especially in such highly open economy like the Czech Republic⁸. If the effect of import prices is denoted with letter im_t , then modified version of the hybrid NKPC takes form

$$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + (1 - \gamma_f + \gamma_b) im_{t-1} + \kappa \hat{y}_{t-1} + c \hat{z}_{t-1} + u_t \quad (5)$$

⁷ Economic theory suggests that once the REER is above its trend (REER is increasing), there is positive exchange rate gap and real appreciation of domestic currency. Negative exchange rate gap indicates decrease of the REER. Decrease in the REER means that actual currency is weak, there is real depreciation of domestic currency and this depreciation consequently leads to the higher prices of imported goods and rise in domestic inflation. In case of positive REER gap, domestic currency is strong, it appreciates and domestic inflation should decrease.

⁸ Openness of the Czech Republic accounts around 157.1% of GDP in 2013, where producers and retailers are heavily dependent on imported goods and services, especially energy, machinery and chemicals from its neighboring countries. (Own calculations; Macroeconomic prediction of the Ministry of Finance CR. 2013)

where im_{t-1} is a lagged value of import prices. While import prices capture the direct effect of the change in the exchange rate on domestic inflation, condition $(1 + \gamma_f + \gamma_b) = 0$ must hold again in order to ensure the linear homogeneity of inflation.

Recent empirical evidence has confirmed that agents comprised in the hybrid New Keynesian Phillips curve do take substantial share of backward-looking behavior compared to forward-looking one. Simple calculation can estimate the share of the forward-looking agents on all agents as $\frac{\gamma_f}{(\gamma_f + \gamma_b)}$. Smets and Wouters (2007) set theoretical value of the ratio as $\beta < \gamma_f + \gamma_b \leq 1$. Table 1 shows that fraction of the forward-looking agents varies over time and cross-country.

TABLE 1: SHARE OF FORWARD AND BACKWARD LOOKING AGENTS IN RELATED CZECH STUDIES

Coefficient	FSS (2008)	HN (2005)	V (2011)	DF (2009)
γ_f	0.35 - 0.38	0.45 - 0.49	0.37 - 0.46	0.61 - 0.75
γ_b	0.42 - 0.47	0.44 - 0.82	0.56 - 0.59	0.24 - 0.38

Note: Franta, Saxa and Smidkova (2008), Hurnik and Navratil (2005), Vasicek (2011) and Daniskova and Fidrmuc (2009), respectively.

Franta, Saxa and Smidkova (2008) estimated that, in the Czech Republic and Hungary, agents were characterized with relatively strong backward-looking behavior until 2008. Additionally, they conclude that the strong forward-looking behavior is more related to behavior of agents who are in Euro Area Member States rather than to Non Euro Area Member States' agents. Hurnik and Navratil (2005a) estimated that share of forward-looking and backward-looking agents in the Czech Republic is relatively proportionally equal. Daniskova and Fidrmuc (2009), in turn, estimated higher share of forward-looking agents in the Czech Republic after year 2008 is included into time series. Smets and Wouters (2007) estimated forward-looking component $\gamma_f = 0.69$ for euro countries. Gali and Gertler's value of this component was within the interval (0.6;0.8) for US data.

The output gap based hybrid New Keynesian Phillips curve has been subject to extensive empirical testing. The more advanced econometric techniques led to more accurate estimations of output gap and consequently the gap-based New Keynesian Phillips curve has been reconsidered again. Roberts (2005) estimated the gap-based hybrid New Keynesian Phillips curve described in equation (3) and confirmed positive (but rather insignificant) value of coefficient using the quarterly U.S. data. Gali, Gertler and Salido (2001a) estimated the same coefficient on quarterly euro data, however, with a negative sign. Another groundbreaking study by Neiss and Nelson (2002) upholds the notion that only little empirical evidence can be found for the marginal costs having a stronger appeal in predicting inflation dynamics than output gap. Jondeau and Bihan (2005) found that only the gap-based NKPC delivers estimations of coefficient of cyclical component at a statistically significant level for the Euro area countries.

TABLE 2: ESTIMATIONS OF COEFFICIENT κ IN RELATED STUDIES

Coefficient	DFa (2009)	DFb (2009)	JB (2005)	V (2011)
κ	(-0.035; -0.016)	(-0.001; 0.015)	(-0.029; 0.049)	(-0.17; 0.23)

Note: Daniskova and Fidrmuc (2009) using GMM method, Daniskova and Fidrmuc (2009) using FIML method, Jondeau and Bihan (2005) ML method, Vasicek (2011) GMM method, respectively.

2 Model, data and methodology

2.1 DATA

Analyzed data set consists of quarterly time series dated from 2000Q1 to 2012Q4 and was downloaded from the publicly available database of the Czech National Bank (CNB) and the Czech Statistical Office.⁹ Each time series is transformed into logarithms. Since logarithm is one-to-one function, there is not any loss in the information for my interpreted results. Output is measured by the seasonally adjusted logged GDP in constant prices 2005 in millions CZK. Inflation is proxied by the annualized quarterly change of seasonally adjusted logged Consumer Price Index (CPI) 2005 = 100. Import prices are proxied by annualized quarterly change of logged seasonally adjusted index of import prices. Both log CPI and log index of import prices are adjusted by the X12 process. Inflation expectations are not directly measurable. Inflation expectations are proxied by the variable “inflation expectations of the financial markets interviewed by the CNB with outlook for 12 months”, which is publicly available since May 1999.¹⁰ Real effective exchange rate is quantified by logged seasonally adjusted REER (defined as NEER of CZK deflated by index based on CPI, foreign trade turnover, year 2010=100). REER gap, which is used directly in the model, is then derived by subtracting trend REER from level REER. Trend REER is estimated using HP filter with $\lambda=1600$.

Usually, macroeconomic time series tend to be non-stationary. In my models, I cope with the mixture of stationary and non-stationary roots of the time series. Doan (2010) argues that this mixture of stationary and non-stationary time series is acceptable for state space models when observed data are applied. I carried out two types of statistical tests for stationarity, Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test and Adjusted Dickey-Fuller (ADF) test.¹¹ Results of the stationarity tests are available in the following Tables 3 and 4.

TABLE 3: KPSS STATIONARY TEST FOR APPLIED VARIABLES

	Level	Level and trend
π	0.0581**	0.0588**
\hat{z}	0.0683**	0.0683**
$E_t\{\pi_{t+1}\}$	0.5496	0.0937
im	0.1598**	0.0584**
y	0.8971	0.1981

Note: Author's calculations [Eviews 7], ** stationary at 5% significance level

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

⁹ Length of the data series is chosen based on the availability of the data. Time series for inflation expectations are publicly available since May 1999. In order to avoid case with differently long time series, the analysed data set starts from 2000Q1 and ends 2012Q4.

¹⁰ Mazunder (2011) argues that using inflation survey forecasts as proxy for unobserved inflation expectations provides biased and insufficient results. Estimated coefficients of the New Keynesian Phillips curve are then contra-intuitively signed and not consistent with economic theory. Despite the negative review of this proxy, I decided to use it for its simple public availability.

¹¹ KPSS uses H_0 : time series are stationary. ADF test uses H_0 : time series are not stationary.

TABLE 4: ADF STATIONARY TESTS FOR APPLIED VARIABLES

	Level	Level and trend
π	-4.8152 **	-4.773**
\hat{z}	-3.111**	-3.072**
$E_t\{\pi_{t+1}\}$	-2.202	-2.547
im	-6.357**	-6.592**
y	-1.483	-0.716

Note: Author's calculations [Eviews 7], ** stationary on 5% significance level

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

Tables 3 and 4 show that inflation expectations and log GDP are non-stationary time series. Domestic inflation, import prices inflation and REER gap are stationary on the statistical 5% significance level. Due to above-mentioned Doan's argument, the non-stationary time series do not need to be transformed into stationary form for application in my models.

2.2 METHODOLOGY

The hybrid New Keynesian Phillips curve described in the equation (3) is second-order difference equation in log-linearized form, with unobservable component, output gap, which follows a non-linear process. Therefore, Kalman filtration with maximum likelihood method estimation method can be applied. Enders (2003) and Canova (2007) provide a comprehensible introduction into the state space models and Kalman filtration, which serves as a manual for creating my state space models. The basic idea of the Kalman filtering and state space models suggests that if there are unobservable variables in economic structure, they can be estimated using observed data and information from the economic structure itself. In a basic dynamic macroeconomic model, there are usually two types of variables, state variables and control variables. The former is variable, which describes the current state and is usually the unobserved variable. The latter is observable variable. Necessarily, there must be a clear link between state and control variables in the model.

In order to estimate equations (3), (4) and (5), they must be first transformed into the state space representation. Each model has two observation equations: (i) the hybrid New Keynesian Phillips curve and (ii) decomposition of the real output into stationary trend and output gap (a cyclical non-stationary component). The two unobservable variables in observation equations are trend and output gap. Therefore, there are two transition laws. First transition law defines output gap. Output gap is defined as autoregressive AR(1) process. Second transition law describes evolution of trend over time. I assume trend to be a random walk with drift, where drift depends on average annual growth rate of the trend. The state space representation of the basic hybrid New Keynesian Phillips curve described in equation (3) can be rewritten in the following form

$$\begin{aligned}\pi_t &= \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \kappa \hat{y}_{t-1} + \epsilon_t \\ y_t &= y_t^* + \hat{y}_t\end{aligned}\tag{6}$$

$$\hat{y}_t = \nu \hat{y}_{t-1} + \eta_t\tag{7}$$

$$y_t^* = y_{t-1}^* + \Delta y^* + \zeta_t$$

$$\begin{aligned} \epsilon_t &\sim N(0, \sigma_\epsilon^2), \kappa > 0 \\ \eta_t &\sim N(0, \sigma_\eta^2), 0 < \nu < 1 \\ \zeta_t &\sim N(0, \sigma_\zeta^2) \end{aligned} \quad (8)$$

where gather (6) expresses observation equations for control variables and gather (7) transition laws for unobserved variables. Gather (8) assigns restrictions for all error terms in the model. Coefficient ν determines persistence of output gap over time. If size of parameter ν is approaching 1, output gap becomes a simple random walk. Coefficient κ is assumed to be positive as an implication from the economic theory. All models, which are estimated in this paper, are summarized in Table 5.

TABLE 5: STATE SPACE REPRESENTATIONS OF THE NKPC

MODEL 1	
Observation	$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \kappa \hat{y}_{t-1} + \epsilon_t$
equations	$y_t = y_t^* + \hat{y}_t$
Transition	$\hat{y}_t = \nu \hat{y}_{t-1} + \eta_t$
laws	$y_t^* = y_{t-1}^* + \Delta y^* + \zeta_t$
MODEL 2	
Observation	$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \kappa \hat{y}_{t-1} + c \hat{z}_{t-1} + \epsilon_t$
equations	$y_t = y_t^* + \hat{y}_t$
Transition	$\hat{y}_t = \nu \hat{y}_{t-1} + \eta_t$
laws	$y_t^* = y_{t-1}^* + \Delta y^* + \zeta_t$
MODEL 3 (with dummy)	
Observation	$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + (1 - \gamma_f + \gamma_b) im_{t-1} + \kappa \hat{y}_{t-1} + c \hat{z}_{t-1} + \epsilon_t$
equations	$y_t = y_t^* + \hat{y}_t$
Transition	$\hat{y}_t = \nu \hat{y}_{t-1} + \eta_t$
laws	$y_t^* = y_{t-1}^* + \Delta y^* + dummy + \zeta_t$

2.3 CALIBRATION

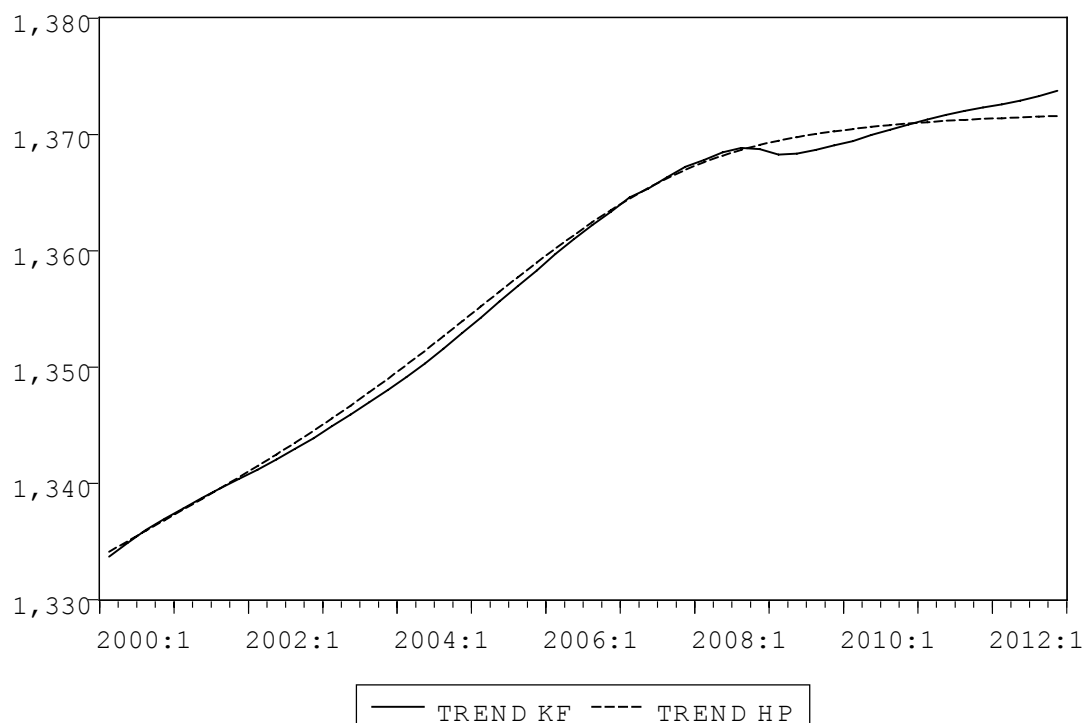
Calibration of a theoretical model is inevitable for correct estimation of the key coefficients of the New Keynesian Phillips curve. Calibration is performed as follows: researcher sets size of the remaining coefficients and parameters in observation equations, initial conditions and variances in the transition laws based on economic theory and previous empirical evidence.

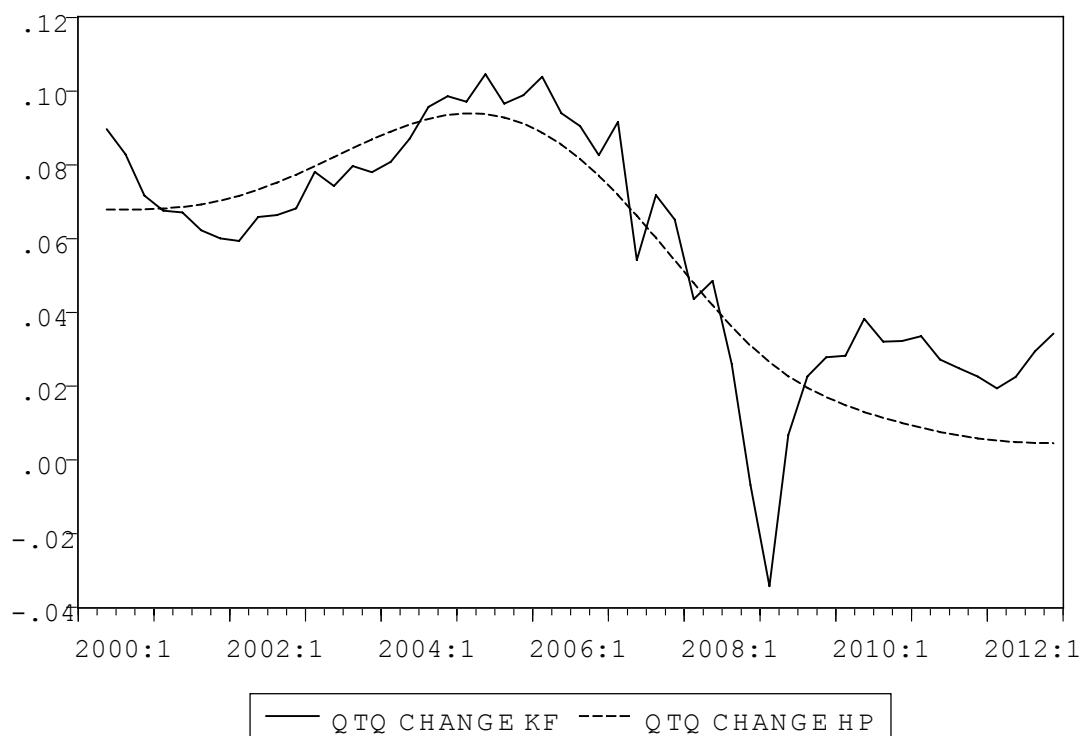
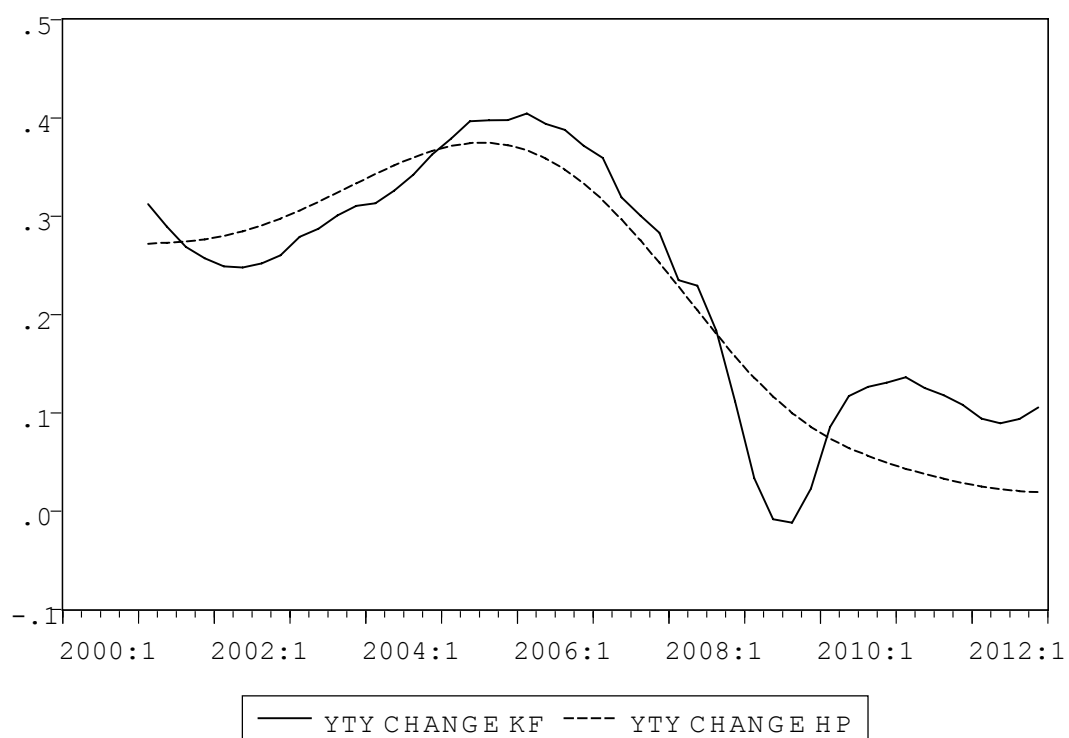
First, I set initial conditions for logarithm of output and percentage q-t-q change of CPI at time $t(0)$ for values 1335 and 3, respectively. This implies, that initial condition for y_t at time $t(0)$ is set at 1335 and initial condition for π_t at time $t(0)$ is 3 percentage points. Both values are approximate values obtained from time series of particular variable at 1999Q4 (one period before

the start of my time series). Additionally, I set specific values of coefficient c , and parameters ν and Δ . Coefficient c describes impact of the exchange rate change on Czech domestic inflation through the indirect channel. Following McCarthy (2007), coefficient c should be relatively small and possibly positive. Hurnik and Navratil (2005a) estimated impact of the real exchange rate on Czech inflation in the range (0.05, 0.26). Positive sign is result of long-term appreciation of Czech domestic currency. I set value of coefficient c to 0.144 as a result of a long term appreciation of the Czech currency within my data set which was caused by transformation process of the Czech Republic.

For parameters ν and Δ , I undertook several steps. First, I use logarithm of Czech real gross domestic product (GDP) at constant prices 2005=100 and calculate two different measures of trend: (i) HP filtered trend ($\lambda=1600$) and (ii) Kalman filtered trend. Figure 1a displays estimations of HP and Kalman filtered trend in logarithms. Figure 1b shows percentage y-t-y change and Figure 1c percentage q-t-q change in trend, respectively. Each statistical filter gives differently smooth trend. Critical are especially periods in 2008-2009Q3 and 2011-2012Q4. Obviously, Kalman filtered trend responds to all shocks of output level much faster than HP filtered trend, which causes that bumps transmit directly into the size of output gap.

FIGURE 1: POTENTIAL OUTPUT IN THE CZECH REPUBLIC (1A. LOG TREND GDP, 1B. Y-T-Y CHANGE, 1C. Q-T-Q CHANGE IN (%)) USING DIFFERENT ESTIMATION METHODS (KALMAN AND HP TREND, RESPECTIVELY)



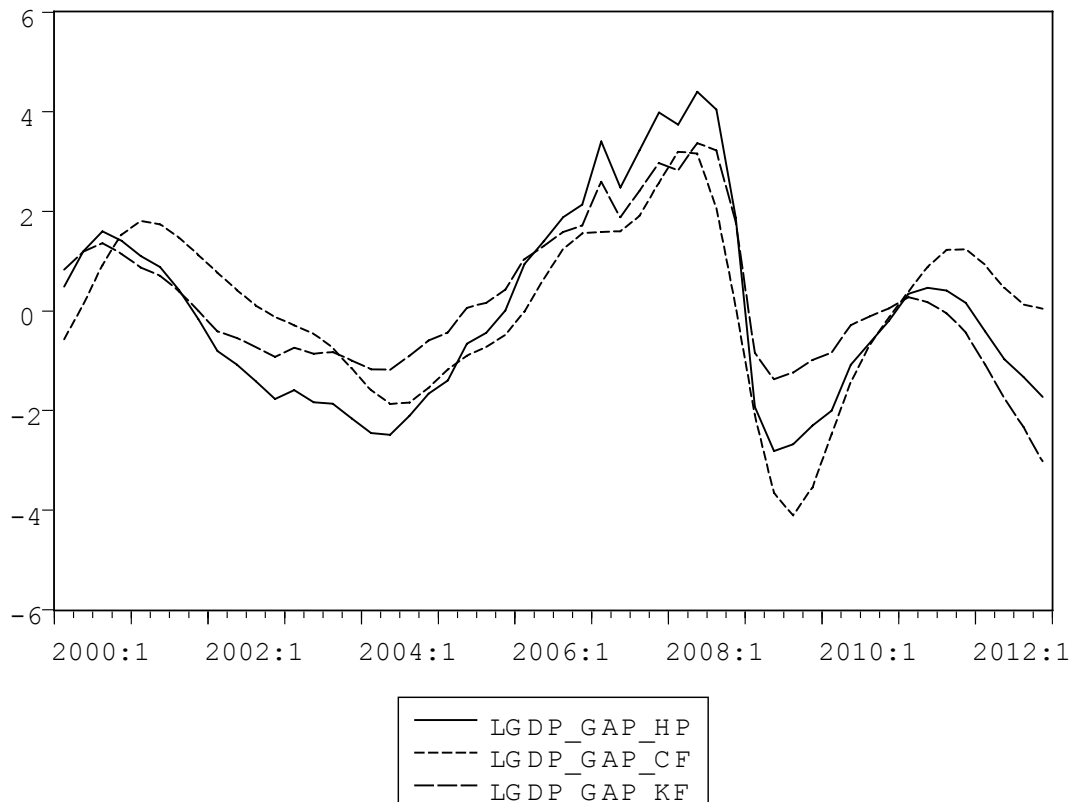


Note: Author's calculations [Eviews 7]

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

Second, I estimate three different types of output gaps (available in Figure 2). Basistha and Nelson (2007) give detailed summary of different estimation methods of output gap. I follow the statistical approach of estimation of output gap. For HP and Kalman filtered output gap I calculated output gap as a difference between logarithm of real GDP and estimated trend. Third version of output gap is output gap estimated using Christiano-Fitzgerald filter (CF filter).

FIGURE 2: OUTPUT GAP IN THE CZECH REPUBLIC (IN % OF GDP) USING DIFFERENT ESTIMATION METHODS (HP, CF AND KALMAN FILTERS, RESPECTIVELY)



Note: Author's calculations [Eviews 7]

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

The difference in differently estimated output gaps is visible and can have considerable weight in my further estimations. Therefore, all versions of output gaps are first tested for stationarity and then their correlation.

TABLE 6: STATIONARY TESTS FOR ESTIMATED OUTPUT GAPS

	KPSS
KF output gap	0.1351**
CF output gap	0.0630**
HP output gap	0.0927**

Note: Author's calculations [Eviews 7], ** stationary at 5% level

Source: the Czech Statistical Office

TABLE 7: CORRELATION MATRIX OF OUTPUT GAPS UNDER DIFFERENT GAP ESTIMATIONS (KALMAN, CF AND HP FILTERS, RESPECTIVELY)

	KF output gap	CF output gap	HP output gap
KF output gap	1		
CF output gap	0.6344	1	
HP output gap	0.9174	0.8377	1

Note: Author's calculations [Eviews 7]

Source: the Czech Statistical Office

Parameter ν measures persistence of output gap over time. Based on Dittmar, Gavin and Kydland (1999), I set benchmark interval for persistence parameter ν and then calibrate proper value of parameter ν . Dittmar et al. estimate persistence parameters for G10 countries using HP filter and a simple quadratically detrended output. Their persistence parameters with HP filtered output gap ranged from 0.41 for France to 0.82 for Japan for periods 1957-1997. I calibrate the persistence parameter to 0.7.

Parameter Δ depicts the percentage average quarterly growth of trend over time. Its value is set as a simple average size of a percentage annual growth of trend for periods from 2003Q1 to 2007Q4, intentionally excluding periods hit by financial crisis. Mathematically, value of parameter Δ is assigned to $\Delta = 4.2/4$, where 4.2 is a percentage average annual growth of trend and 4 is number of quarters. Based on correlation value between KF output gap and HP output gap I conclude that calibration of parameters ν and Δ seems acceptable and I use these values for calibration of the models.

Values of the variances are calibrated to $\sigma_\epsilon = 0.9$, $\sigma_\eta = 0.62$ and $\sigma_\zeta = 0.112$, respectively. The variances simply compare volatility of the output gap with respect to trend. I assume the volatility of the output gap to be much higher than volatility of trend, more than 5 times more volatile to be more precise.

3 Results

Following section summarizes the results of all models represented in Table 9 and gives justification of obtained results.

TABLE 9: SUMMARY RESULTS

	γ_f	γ_b	$(1 - \gamma_f - \gamma_b)$	κ
Model 1	0.8869	0.1131	-	0.2740
	-	(0.0414)	-	(0.0290)
Model 2	0.8611	0.1389	-	0.3262
	-	(0.1389)	-	(0.0309)
Model 3a	0.6620	0.1581	0.182	0.2749
(without dummy)	0.0571	0.0461	-	(0.0341)

Model 3b	0.6069	0.2467	0.1464	0.0961
(with dummy)	(0.0363)	(0.0253)	-	(0.0264)

Note: Author's calculations [Eviews 7], S.E. in parentheses.

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

TABLE 10: ADF STATIONARY TEST FOR RESIDUALS

	Level
Residuals (model 3a)	-6.9225**

Note: Author's calculations [Eviews 7], ** stationary at 5% significance level

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

Table 9 shows that all estimated coefficients are statistically significant on 95% confidence interval. Moreover, residuals are stationary at 5% significance level, as presented in Table 10 which indicates that the models are not underspecified. Interestingly, size of all estimated coefficients is different from previous empirical studies in the Czech Republic presented in Table 1. In my results, figures of coefficients at inflation expectations predominate coefficients at lagged inflation in the New Keynesian Phillips curve. This implies that *nowadays the share of forward-looking agents prevails share of backward-looking agents in the Czech Republic*. This conclusion corresponds with the latest study of Daniskova and Fidrmuc (2009) where authors conclude that the gap specified NKPC for the Czech Republic implies “a high weight of forward-looking agents”. They estimated corresponding coefficients γ_f between 0.613 and 0.756 for forward-looking agents and γ_b between 0.244 and 0.387 for backward-looking agents, respectively. Generally, results about predominance of forward-looking agents have two main implications. First, agents indeed appear to have a strong forward-looking behavior in the Czech Republic after year 2008. Second, there is a remarkable change in behavior of Czech agents over a very short time. There are several reasons, which can justify these presumptions. First, compared to previously mentioned studies, my data set consists from time series, which include quarters after Czech economy was hit by financial crisis. Hurnik and Navratil (2005a) used data set from 1994Q1 till 2004Q4, Vasicek (2011) used 1998Q1 till 2007Q3 and Franta, Saxa and Smidkova (2009) used 1993Q2 till 2006Q1. My data set, on the other hand, ranges from 2000Q1 to 2012Q4. First extraordinary time period is from 2008Q1 to 2009Q4 and second period is from 2011Q1 to 2012. The former period is relevant due to its sudden fall of aggregate demand, slowdown in output growth and short recession in the Czech economy. The latter is known for repeated fall in output growth. During both these time periods, output was exceptionally volatile and with high percentage q-t-q changes. Similarly, Daniskova and Fidrmuc (2009) used time series ranged from 1996Q1 to 2009Q1. Therefore, as mentioned before, including periods after year 2008 can significantly influence estimated coefficients at inflation expectations within few quarters. Second argument states that inflation expectations change over time. Trehan and Zorrilla (2012) emphasize that one-year inflation expectations significantly differ from inflation target of the central bank after the economy is hit by the unexpected external shock. However, this effect of large dispersion of the short-run inflation expectations should diminish over longer horizon. Knowing, that my models work with 12 months inflation expectations and that applied time series include time periods when Czech economy was hit by the financial crisis, recognizable divergence of share of forward- and backward-looking agents to previous studies should be expected. Taking Trehan and Zorrilla's argument into account, it is also possible that the discussed effect of the change in behavior of the Czech agents may deteriorate over next few quarters and it may reverse back to the previous backward-looking behavior of Czech agents.

Effect of change in import prices has a considerable influence on inflation dynamics in the Czech Republic. This finding is consistent with Vasicek (2011) who claims that Czech inflation seems to be driven by exogenous factors. Even though coefficient at import prices is relatively low, it does not necessarily indicate that prices of imported goods have a small impact on domestic inflation. One must have in mind that effect of import inflation transmits also through inflation expectations.¹² However, substantial impact of import prices changes on inflation gives clear indicator that the Czech Republic is very sensitive to changes in prices of imported good due to extremely high openness of Czech economy.

By definition, coefficient κ is assumed to be positive. Theoretically the lower the size of coefficient κ , the lower impact of monetary policy on domestic inflation. In extreme case, when κ approaches zero, evolution of inflation becomes independent from monetary policy. Based on previous empirical research of the gap based NKPC presented in Table 2, I expected coefficient κ to be below 0.1 and possibly statistically insignificant. Sign at coefficient κ turned out to be positively oriented for all models. Positive signs at all estimated coefficients κ confirm primary hypothesis that positive output gap leads to increase in the domestic price level. Additionally, positive sign of coefficient κ suggests that *the slope of the New Keynesian Phillips curve is increasing in the Czech Republic*. However, this conclusion might seem arguable due to study Kuester et al. (2007), which claim that the New Keynesian Phillips curve is “quite flat despite frequent price adjustments suggested by the microeconomic theory”. The only concerning fact is exceptionally high value of coefficient κ in models 1-3a. These high values of coefficient κ might be caused by high volatility of output gap after 2008Q2 as seen in Figure 2. This presumption is confirmed in results of model 3b. After adding year dummy variable into the model structure, value of coefficient κ decreases rapidly down to value $\kappa = 0.09$. Value of coefficient κ stays correctly signed and statistically significant on 95% confidence interval. Year dummy “erased” highly volatile periods in time of output gap. Direct corollary of adding year dummy into the models can be the idea that the Phillips curve can hold only when output gap has a high variance. Once this variance is statistically low, low coefficient κ should be expected, which would directly transfuse into low impact of output gap on inflation dynamics.

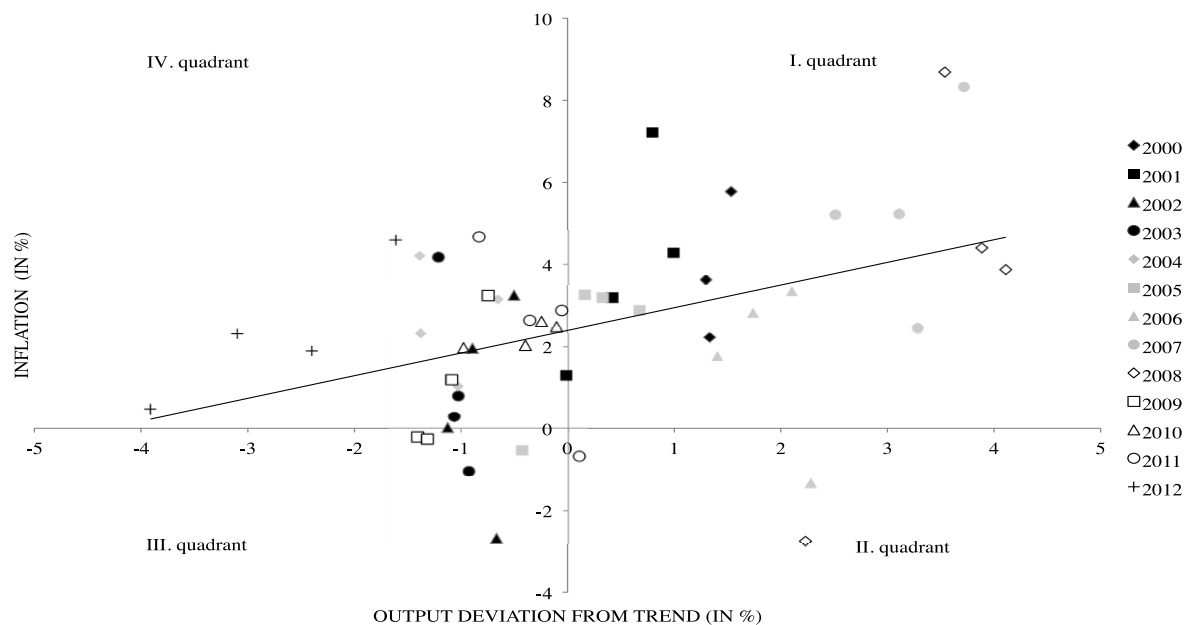
Furthermore, supplementary exogenous variable real exchange rate gap does not play significant role in changes of sizes of relevant key coefficients.

The estimated New Keynesian Phillips curve describes output-inflation trade-off for the Czech Republic. Estimated output-inflation trade-off can be displayed also in the graphical representation. It is easier to draw conclusions about the business cycle of output with respect to inflation dynamics in the Czech Republic. Figure 3 shows combinations of output-inflation trade-off in the New Keynesian Phillips curve for the Czech Republic. The possible New Keynesian Phillips curve describes movements of the inflation rate with respect to output gap in the Czech Republic from 2000Q1 to 2012Q4. The area in first quadrant describes expansion in the business cycle. Conversely, area in third quadrant characterizes recession in economy. Striking deviation of high inflation, which is accompanied by high deviation of output from its potential, is a result of overheated Czech economy in periods 2007Q1 - 2008Q2. In this period of time, Czech economy was experiencing economic boom represented by first positive output gap since 1998. Positive output was result of plummeting unemployment and high utility of production capacities in the Czech industry. From 2009Q1 to 2009Q2 was Czech economy in recession quadrant. Primary cause of the recession lies in a slowdown in production capacities utility and lower total factor

¹² Hurnik and Navratil (2005a)

productivity.¹³ From 2009Q3 to 2012Q4 was Czech economy in fourth quadrant, slowly approaching recession quadrant again in 2012Q4. Highest concentration of output-inflation combinations is visible around the 1.5 - 4% (annualized) inflation rate. This suggests that the Czech National Bank is trying to effectively coordinate its monetary policy in order to maintain its primary objective of price stability and to keep domestic inflation in acceptable range of inflation targets. Years 2008 and 2009 are also characterized by strong economic turmoil, which could possibly aggressively affect behavior of agents in the Czech Republic.

FIGURE 3: OUTPUT INFLATION TRADE-OFF IN THE CZECH REPUBLIC (CPI, ANNUALISED Q-T-Q CHANGE IN % AND OUTPUT GAP IN % OF GDP)



Note: Author's calculations [Eviews 7, Excel]

Source: the Czech National Bank (ARAD) and the Czech Statistical Office

I address that presented results, though, should be considered with caution because they suffer from several econometric limitations. First, my data set includes 52-quarters-long time series, which represent approximately only one business cycle in the Czech Republic. However, due to short existence of publicly available inflation expectations in the Czech Republic, longer time series were not possible for my analysis. Second, inflation expectations are proxied with a measurable and

¹³ Ministry of Finance CR. 2009. *Macroeconomic prediction of the Ministry of Finance (2009)* [Accessed February 2014]. Available from: <http://www.mfcr.cz/cs/verejny-sektor/prognozy/makroekonomicka-predikce/2009/makroekonomicka-predikce-rijen-2009-8025>.

directly observable variable. Enhanced mathematical form of the state space representation of the hybrid NKPC, which could directly model unobserved inflation expectations, can possibly lead to arguably different results. Moreover, inflation expectations and lagged inflation may suffer from spurious correlation in the hybrid NKPC once coefficient γ_f approaches 1 as argued in Hall, Hondroyannis, Swamy and Tavlás (2009), but tests for spurious correlation are omitted in this paper. All mentioned econometric limitations partially restrain utilization of my results; on the other hand, they open doors to further and possibly deeper investigation of the gap-based hybrid New Keynesian Phillips curve in the Czech Republic.

CONCLUSION

This paper verifies primary hypothesis on output-inflation trade-off expressed in the New Keynesian Phillips curve. Study estimates three key coefficients of the gap-based hybrid New Keynesian Phillips curve in the Czech Republic from 2000Q1 to 2012Q4 using Kalman filtration. My estimations show that Czech data support the hypothesis about positive link between inflation and output gap described in the hybrid New Keynesian Phillips curve. All estimates turn out to be surprisingly statistically significant and correctly sign-oriented, which contradicts majority of the previous empirical studies on the gap-based hybrid NKPC in the Czech Republic. Furthermore, confirming positive relation between output gap and inflation implies that the slope of the New Keynesian Phillips curve is increasing in the Czech Republic in the short run.

There are three main conclusions that can be drawn from my estimates. First, significantly high magnitude of the output-inflation trade-off coefficient appears to be result of high volatility of output during periods 2008-2011, when Czech economy was hit by financial crisis. During this period of time, there was a significant slowdown in both domestic and foreign demands and consequently slower pace of Czech economy. High volatility of domestic output, though, arguably ensures that the NKPC does not collapse and that inflation does not evolve independently from output, which might give an advantage in further utilization for the Czech monetary policy, especially for inflation targeting. Second, because of Czech economy being highly open, I also study impact of exchange rate fluctuations through both direct and indirect channels on domestic inflation. My estimates suggest that import prices, which describe direct channel, play crucial role in describing inflation dynamics in the Czech economy. Conversely, effect of the real effective exchange rate fluctuations, which capture the indirect channel of exchange rate change on inflation, turns out to be very small. Lastly, the coefficients of the NKPC also decide about the share of forward- and backward-looking agents. My estimates suggest a sudden reversal in the latest trend about behavior of the Czech agents, where forward-looking agents predominate over backward-looking ones. Reason for this reversal in agents' behavior can be a direct consequence of high output gap volatility during periods when the Czech Republic suffered from low domestic demand and rapid decrease in output level.

Despite few econometric limitations, this study offers a fresh look at the empirical verification of output-inflation trade-off in the hybrid New Keynesian Phillips curve after financial crisis and consequently opens room for further empirical investigation of the gap-based New Keynesian Phillips curve in the Czech Republic.

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