Inflation Dynamics & Real Economic Activity: Examination of the Cost-Based Hybrid New Keynesian Phillips Curve for the Czech Republic

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Abstract. The New Keynesian Phillips Curve (NKPC) became a staple in the New Keynesian economics, assuming an existence of a short-term trade-off between inflation and real economic activity, either in a form of labor unit costs or output gap. Extending the cost-based NKPC with hybrid, backward-looking price setting to the Czech Republic, we aim to examine the impact of unit labor costs, inflation expectations, import prices and real effective exchange rate on the development of inflation between 2000M1 and 2020M12. Dealing with non-stationary and cointegrated time series, we compare results employing an Error Correction Model (ECM) and an Autoregressive Distributed Lag (ARDL) model with the variables integrated in order *I(1).* Our data result suggest that the labor unit costs, and the inflation expectations might have an impact on the evolution of inflation based on the ECM and ARDL in differences for the Czech Republic between 2000M1 and 2020M12, although the results are too uncertain to be unambiguous.

Keywords: expected inflation, real marginal costs, New Keynesian Phillips Curve, the Czech Republic

JEL classification: *C32, E31, F42*

1 Introduction

Ever since Phillips (1958) first observed a negative relationship between the unemployment rate and the rate of wage inflation in data for the United Kingdom,

Samuelson & Solow (1960: 192) presented what they coined the Phillips curve as a "menu" for policy-makers and Phelps (1967) along with Friedman (1968) upgraded this framework with expected inflation, the Phillips curve, or the short-run trade-off between inflation and real economic activity, became a cornerstone of the modern monetary policy. As the "original" Phillips curve seemed unable to provide cogent explanation to chronically high inflation rates and unemployment in the 1970s, new macroeconomic approaches started to emerge, mainly the New Keynesian Phillips curve (NKPC).

New Keynesianism, building mainly on the work of Fisher (1977) and Taylor (1980), emphasize forward-looking behavior, imperfect competition and Calvo's (1983) principle of "staggered prices". Naturally, these microeconomic foundations were incorporated into the NKPC as well, especially following the Lucas critique (Neiss & Nelson, 2002). In case of the NKPC, authors substituted inflation expectations for lagged inflation into the Phillips curve and showed short-run trade-off between the real economic activity and price inflation. The NKPC was first popularized by Roberts (1995, 2001), with follow up by Sbordone (1998, 2001), Galí & Getler (1999), Galí et al. (2001) and Galí & Monacelli (2005). Galí et al. (1999) pioneered the estimation of the so called "hybrid" NKPC, incorporating both forward- and backward-looking agents, trying to capture inflation persistence. The ample empirical evidence on the hybrid NKPC confirmed importance of incorporating the lagged inflation into the model (Rudd & Whellan, 2007).

Comparing the NKPC with the original Phillips curve, we are able to identify two distinct features. Firstly, New Keynesian models assume forward looking, in case of the hybrid NKPC also backward-looking agents, where firms set prices on the bases of their expectations about the future development of cost factors. Thereby, the (hybrid) NKPC is based on inflation expectations and lagged inflation. Secondly, the NKPC shifts from the relationship between inflation and unemployment to the short-run trade of between inflation and real economic activity. The real economic activity tends to be proxied either via real marginal costs or output gap. Empirical evidence seems to indicate that employment of the real marginal cost delivers more satisfying results than the output gap, resulting into preference of the cost-based NKPC over the gap-based NKPC (Gali & Gertler, 1999).

In this article, aim to examination short-run trade-off between inflation and real economic activity, using the cost-based hybrid NKPC in the case of the Czech Republic. The article is structured as follows. Firstly, we derive the cost-based hybrid NKPC equation, which will be examined for the Czech Republic. Subsequently, we review the literature dealing with the (hybrid) NKPC in general, and then specifically in the case of the Czech Republic. Secondly, we describe the data used in article, providing detailed account of our methodology and model-building. Lastly, we present results from the ECM and ARDL, both in differences and levels, models with regards to the cost-based hybrid NKPC in the Czech Republic between 2000M1 and 2020M12. All the calculations, data adjustments and modelling in this article were conducted using the R programming language.

2 Literature review

In its basic cost-based form, the NKPC, stemming from the New Keynesian dynamic stochastic general equilibrium model, which is based on the utility maximizing households and profit-maximizing firms.[1] Only a fraction of firms $(1-\theta)$ has a capacity to adjust prices in period *t*, where θ is a measure of price-stickiness, and future developments are discounted by a factor β. The NKPC can be expressed as:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda mc_t^r + \varepsilon_t \; ; \qquad (1)$$

where $E_t\pi_{t+1}$ are the inflation expectations observed at time t, mc_t^r real marginal cost with $\lambda = \frac{(1-\theta)(1-\theta\beta)}{\theta}$ and ε_t is a disturbance term.[2] Fuhrer (1997) and Galí & Gertler (1999), establishing an upgraded, "hybrid" form of the NKPC, argue that it is needed to take into consideration lagged inflation on top of the forward inflation expectations. Purely forward-looking NKPC would enable a costless trade-off between economic activity and inflation and omits the persistence of firms' behavior. Thus, the hybrid NKPC with its backward-looking price setting can be defined as follows:

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda mc_t^r + \varepsilon_t \; ; \qquad (2)$$

where π_{t-1} represents a lagged inflation, and coefficients γ are functions of structural parameters coming from the New Keynesian model of a small economy.[3] In order to ensure linear homogeneity of inflation, the assumption $\gamma_f + \gamma_b = 1$ must hold. Lagged variables prevent instantaneous inflation and output adjustments to unanticipated shocks.

The Czech Republic, not being a Eurozone member state, is exposed to exchange rate dynamics. External shocks, in a form of the exchange rate deviation, translate through the transmission mechanism inevitably into domestic inflation via two channels, directly through the import prices and indirectly through the impact of the real exchange rate on real economy. When added to the model in compliance with Milučká (2014), the NKPC can be expressed as:

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[1] These firms assumed to be in monopolistic competition, are identical with the exception of differenced products and pricing history and face the same constant elasticity demand.

[2] The coefficient λ depends negatively on θ and β. Thus, inflation is less sensitive to the value of real marginal cost if θ is large. In case of full price rigidity, $\theta = 1$, λ equals 0 and inflation does not depend on the real marginal costs anymore (Danišková & Fidrmuc, 2011: 3).

[3] The ability of policy-makers to have inflation under control is dependent on relative magnitudes of these coefficients (Hornstein, 2008). Galí & Getler (1999) describe them as follows: $\gamma f \equiv \theta\beta\varphi^{-1}$; $\gamma b \equiv \omega\varphi^{-1}$; $\lambda \equiv (1-\beta\theta)(1-\omega)(1-\theta)\varphi^{-1}$ and $\varphi \equiv \theta + \omega[1-\theta(1-\beta)]$.

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda mc_t^r + im_{t-1} + REER_{t-1} + \varepsilon_t \; ; \qquad (3)$$

where $REER_{t-1}$ is a lagged impact of the real exchange rate and im_{t-1} a lagged value of import prices, assuming the linear homogeneity of inflation $\gamma_f + \gamma_b = 1$ holds. Import prices im_t are an essential determinant of a supply side effect for inflation, especially in small open economy (Milučká, 2014). The hybrid NKPC in this form states that inflation rate depends on expected inflation (forward-looking component), lagged inflation (backward-looking component), real marginal cost, import prices and REER.

The literature assessing the hybrid NKPC is rather ample. Jondeau & Le Bihan (2005) estimates the hybrid NKPC specification with three lags and leads and a low degree of forward-looking expectations for continental Europe. Nason & Smith (2008) study the hybrid NKPC under GNM for the USA, the UK, and Canada and Jean-Babtiste (2012), for instance, estimates the hybrid NKPC using survey forecasts of inflation for United Kingdom, and concludes that these forecasts improve estimates of the hybrid MKPC. Kuester et at. (2007) and Roeger & Herz (2012) conduct similar research.

Numerous authors applied the NKPC in the context of the Czech Republic as well. One of the first were Arlt & Plašil (2005) concluding that the NKPC model is not suitable in conditions of the Czech Republic, since it does not describe the inflation process sufficiently. Danišková & Fidrmuc (2011), employing the GMM model and the FIML model, estimate the hybrid New Keynesian Phillips Curve for the Czech Republic during the period from 1996 to 2009 finding out that the GMM results are likely to be more biased when the output gap is used as a proxy for real marginal costs. They conclude that the NKPC is flatter in the Czech Republic, when compared to other EU countries. Vašíček (2011) explores the inflation dynamics of the V4 countries by means of econometric estimation of the NKPC, arguing that the output hap performs slightly better than the average real marginal costs (ULC) in determining inflation rate in the short-run. Milučká (2014) also estimates parameters of the hybrid output-based NKPC model, as opposed to traditional cost-based NKPC, for the Czech Republic between 2000 and 2012 using Kalman filtration.

3 Data and Methodology

3.1 Data

Data used in this article consists of monthly time series from 2000M1 to 2020M12, retrieved from the Czech National Bank (ARAD) and the Czech Statistical Office (CSZO). Each time series is transformed into logarithms and seasonally adjusted using the x11 regression from the "X-13ARIMA-SEATS" R package. As an inflation proxy, we opted for the annualized monthly change of seasonally adjusted logged Consumer Price Index (logCPI), where 2015=100. Import prices (logIM) are proxied by change of logged seasonally adjusted index of import prices (2015=100). As a proxy for expected inflation, we use the CNB's monthly data from Survey of Professional

Forecasters. These data represent financial market inflation expectations for one-year horizon (logSPF_1y). Even though the SPF tends to be disregarded for the most part, they were used as a proxy for inflation expectations, for instance, by Babtiste (2012), Binder (2015), Coibion & Gorodnichenko (2015) or Ball & Mazumder (2018). The logged seasonally adjusted real effective exchange rate (REER) is defined as a monthly nominal effective exchange rate of the CZK deflated by CPI and weighted by foreign trade turnover, where 2015=100. Lastly, the real marginal costs are practically unobservable. Danišková & Fidrmuc (2011), however argue that the real marginal costs under the assumption of the Cobb-Douglas production technology can take a form of labor income share or equivalently real unit labor costs. In our model, labor costs are proxied via logged and seasonally adjusted real unit labor cost (RULC) index, defined as real labor productivity per person, where 2015=100. Since only quarterly data are available, we disaggregate them into monthly time series using Denton-Cholette method, employing "tempisagg" R package (Dagum & Cholette, 2006). All the data are displayed in Figure 1.

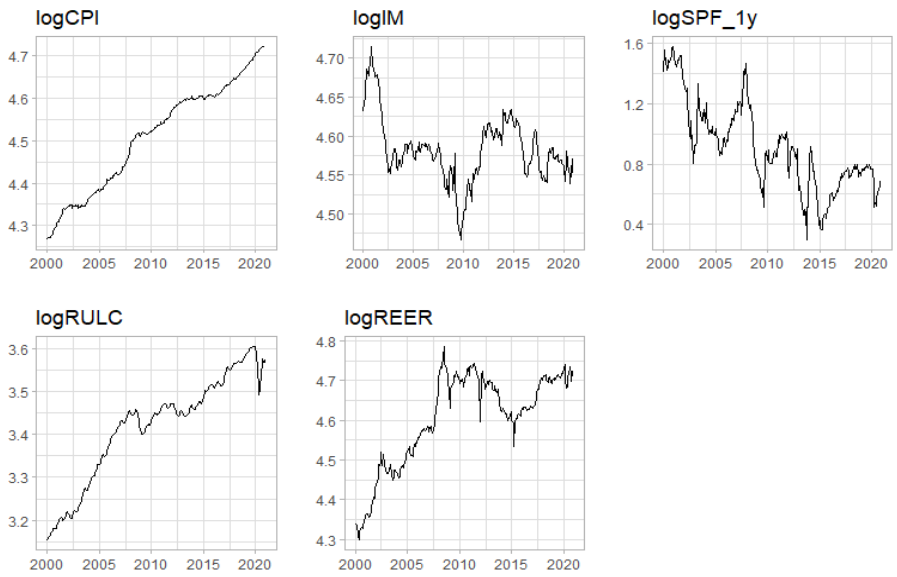

Fig. 17. Selected monthly time series for the Czech Republic, 2000-2020
Source: Authors' elaboration based on the ARAD and CZSO data.

Macroeconomic time series tend to be non-stationary, what can be seen also in Table 1., comparing two statistical tests for stationarity, Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test.[4] One way to make non-

[4] There is one technical difference between the two. ADF test uses H_0: "the series has a unit root", while KPSS formulates H_0:"the process is trend stationary". Thereby, in case of the ADF test rejecting the null hypothesis means that the time series is

stationary data stationary is to correct them by differencing.[5] Employing the ndiffs function from the R "forecast" package, we estimate the number of differences needed for the non-stationary time series, and we run the tests again. The unit root tests in column (3) and (4) show us that non-stationarity subsequently disappears with the time series integrated of order 1.

Table 27. Unit-Root ADF and KPSS Tests

	ADF (1)	**KPSS** (2)	**ADF$_{diff}$** (3)	**KPSS$_{diff}$** (4)
logCPI	0.6179	0.01	0.01**	0.1**
logIM	0.4379	0.0201	0.01**	0.1**
logSPF_1Y	0.0625	0.01	0.01**	0.1**
logRULC	0.6305	0.01	0.01**	0.1**
logREER	0.6267	0.1**	0.01**	0.1**

Note: ** stationary at 5% significance level. Test equations include both intercept and trend. Incorporation adf.test and kpss.test function in "tstimes" R package.

Source: Authors' elaboration based on the ARAD and CZSO data.

Since the variables are stationary of order 1, that is $\{Y_{CPI}, X_{SPF}, X_{RULC,} X_{REER}, X_{IM}\} \sim I(1)$, we test for coordination vectors between them based on Johansen & Juselius (1990). Running Johansen's cointegration test (Table 2.), the trace and maximum eigenvalue type demonstrate that there is one cointegration relationships at 5% critical value and there exist a long-term relationship between the variables .

Table 2. Johansen's Cointegration Test

Rank	λ_{Trace}	**5% value**	$\lambda_{Max\ Eigen}$	**5% value**
r <=4	7.72	9.24	7.72	9.24
r <=3	16.34	19.96	8.62	15.67
r <=2	27.60	34.91	11.26	22.00
r <=1	51.63	53.12	24.03	28.14
r =0	113.14	76.07	61.51	34.40

Note: Using VARselect command, 5 lags chosen as the optimal lag based on AIC (Akaike information criterion) minus 1. For the cointegration test, ca.jo() command is used from "urca" R package.

Source: Authors' elaboration based on the ARAD and CZSO data.

stationary, while in case of the KPSS rejecting the null hypothesis means that the time series is non-stationary.

[5] Differencing can help stabilize the mean of a time series by removing changes in the level of a time series. A single difference means $\Delta x_t = x_t - x_{t-1}$.

3.2 Methodology

Since the time series are multivariate - I(1) - and there exists a cointegration relationship between them ($\hat{u}_t \sim I(0)$), we can dutifully avoid spurious regression by applying constructing an *Error Correction Model* (ECM). The general form of an ECM is:

$$\Delta Y_t = \alpha_0 + \beta_1 \Delta X_{1,t} + \ldots + \beta_i \Delta X_{i,t} + \pi \hat{u}_{t-1} + e_t \quad (4)$$

The ECM includes both short-run and long-run information Shrestha & Bhatta (2018). The β_1 represents short-run effect measuring the immediate impact a change in $X_{i,t}$ will have on a change in Y_t. On the other hand, π is the feedback effect, showing how quickly does the dependent variable return to the equilibrium once it oscillated. Lastly, $\hat{u}_{t-1}$ measures the long-run response. We run the ECM based on the hybrid NKPC from the equation (3).

Additionally, we compare these results with the simple *Autoregressive Distributed Lag* (ARDL) model using the first difference of the non-stationary variables, as we have showed in the Table 1. that all the variables are integrated in order I(1).[6] The simple differenced ARDL model describing the behavior of Y in terms of variables X_i be considered as follows:

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta Y_{t-2} + \ldots + \gamma_0 \Delta X_{i,t-1} + \gamma_1 \Delta X_{i,t-2} + u_t \quad (5)$$

where $u_t \sim iid(0, \sigma^2)$; γ denotes short run reaction of Y_t to changes in $X_{i,t}$.

4 Results

ECM and ARDL models trying to estimate the short-run relationship between inflation and real unit labor costs in the Czech Republic during the period 2000M1-2020M12 are depicted in the Table 3. Running the unit-root AFD and KPSS tests as well as the Johansen's cointegration test proved useful in rejecting utilization of models based on *ax ante* stationary data. Taking a look at column (iii) in Table 3., non-stationary data with simple ARDL in levels create *spurious* regression results falsely indicating strong relationship between lagged logCPI, logged expected inflation and logged real labor unit costs on the short-term development of inflation, as described by the general equation (3). Interestingly, neither the lagged import prices, nor the lagged real effective exchange rate have an impact on the inflation development in the spurious ARDL, as suggested by Milučká (2014). These two variables, according to the ECM (i) model, seem to influence the inflation only in the short-run, and even then, only in lagged and differenced form.

Turning our attention on the ECM (i) and ARDL in differences (ii) model, we can immediately notice that both models generate vey low multiple R^2. Comparing the two models, the ECM indicates longer-term statistical significance of the lagged

[6] The first order differencing might remove certain aspects in the educational information from the data.

logSPF_1y, our proxy for the expected inflation, and lagged log RULC, the proxy we choose to employ instead of the real marginal costs. The inflation expectations are statistically significant also in the ARDL model, in its differenced form, when getting rid of the non-stationarity. Differenced RULC, the key concept of the NKPC, on the other hand, does not seem to be plausible in neither of the two models.

Table 3. ECM and ARDL results of the hybrid NKPC in the Czech Republic

	ECM (i)	**ARDL in differences** (ii)	**ARDL in levels** (iii)
(Intercept)	-0.045	-0.025*	-0.029
	(0.036)	(0.012)	(0.037)
$logCPI_{t-1}$	-0.004	-	0.994***
	(0.006)		(0.006)
$logSPF\_1y_{t}$	-	0.005***	0.004***
		(0.001)	(0.001)
$logSPF\_1y_{t-1}$	0.005***	-	-
	(0.001)		
$logRULC_{t-1}$	0.0144**	-	-
	(0.005)		
$logRULC_{t}$	-	0.019**	0.015**
		(0.005)	(0.005)
$logIM_{t-1}$	-	-	0.002
			(0.007)
$logREER_{t-1}$	-	-	-0.003
			(0.004)
$logIM_{t-2}$	0.005	-	-
	(0.007)		
$logREER_{t-2}$	-0.002	-	-
	(0.004)		
$\Delta logCPI_{t-1}$	-	0.058	-
		(0.066)	
$\Delta logSPF\_1y_{t}$	-0.005*	-0.001***	-
	(0.002)	(0.003)	
$\Delta logRULC_{t}$	0.024	0.019	-
	(0.027)	(0.028)	
$\Delta logIM_{t-1}$	0.095***	0.016	-
	(0.022)	(0.023)	
$\Delta log\ REER_{t-1}$	0.049***	0.003	-
	(0.013)	(0.013)	
Observations	242	241	245
R^2	0.263	0.177	0.9995

Note: *, **, *** indicates significance at the 90%, 95%, and 99% level, respectively. Standard errors in parentheses. ECM model built using ecm function from the "ecm" R package, ARDL dynardl function from the "dynamic" R package.

Source: Authors' elaboration based on the ARAD and CZSO data.

As was already mentioned, the ECM model assigns short-term significance to the differenced and lagged REER and import prices, and to a lesser extent differenced expected inflation as well. Subsequently, only the lagged expected inflation and lagged RULC prevail in the longer run in terms of their impact on the inflation. The case of the ARDL in differences, model with variables integrated in order *I(1)*, empirically supports the expected inflation as a driver of inflation, although not the RULC. Also, neither the lagged REER and import prices are significant in the ARDL model with differences. The REER is overall surprisingly unimpactful, in all three models. The reason behind this might be that it was not until the November 2013, when the Czech National Bank (CNB) decided to introduce a one-sided floor on the exchange rate as an additional monetary policy instrument. However, it was not until the August 2015 the CNB starts pursuing continuous foreign exchange interventions policy. Therefore, even if Caselli (2017) argues that the CNB was relatively successful in fighting deflationary pressures via the real exchange rate, the period between the second half of 2015 and the end of 2020 is relatively short to influence the results, although the ECM indicates something.

Another paradox is that none of the models, when omitting the spurious ARDL regression, provides evidence for backward-looking inflation behavior, as suggested by the *hybrid* NKPC. We can carefully conclude that there is an indication that the expected inflation and RULC might have an impact on the inflation when employing the ECM and $ARDL_{Diff}$ for the Czech Republic between 2000M1 and 2020M12, although the results are too weak to be unambiguous and conclusive, especially in the case of labor unit costs.

5 Concluding Remarks

Implicitly agreeing with Arlt & Plašil (2005), we conclude that results from the hybrid NKFC for the Czech Republic between 2000M1 and 2020M12 are utmost ambiguous. Examining the trade-off between inflation on the one hand; and inflation expectations, labor unit costs, import prices and the real effective exchange rate on the other, we found out that results from the ECM and differenced ARDL models trying to deal with non-stationary and cointegrated time series integrated in of order *I(1)* are inconclusive. The ECM model indicates that in the shorter-run, only lagged import prices, the lagged REER and to a lesser extend inflation expectations influence the inflation , while in the longer-run, the lagged seasonally adjusted real unit labor cost (RULC) and the lagged inflation expectations for one-year horizon prevail. The ARDL model with first order differencing provides evidence only for the expected inflation. The RULC and non-differenced inflation expectations seem to generate a spurious regression results. Paradoxically, none of the models give weight to the lagged inflation, as a proxy for backward-looking price setting, despite being one of the cornerstones of the *hybrid* NKPC models.

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