

# UNEMPLOYMENT HYSTERESIS IN THE CZECH REPUBLIC

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## Abstract

This paper analyses the unemployment hysteresis in the Czech Republic on data from 1999 to 2016. The hysteresis is modelled by allowing for the impact of cyclical unemployment on the non-accelerating inflation rate of unemployment. Models are estimated using the Bayesian approach and provide robust evidence in favour of the hysteresis. The estimates imply that in response to an increase in the cyclical unemployment of 1 percentage point, the non-accelerating inflation rate of unemployment increases by 0.18 percentage points.

**Keywords:** hysteresis, NAIRU, Phillips curve, state-space models, unemployment

**JEL Classification:** C11, C32, E24, E32

## 1. Introduction

Standard macroeconomic models assume that the aggregate unemployment rate can be decomposed into a cyclical component and a long-term equilibrium component, also known as the non-accelerating inflation rate of unemployment (NAIRU). Aggregate demand and monetary policy can induce deviations of unemployment from the NAIRU only in the short run. In the long run, unemployment converges back to the NAIRU, which is determined by structural characteristics of the economy and independent of monetary policy.

In contrast, unemployment hysteresis theory states that the cyclical unemployment and the NAIRU do not evolve independently. The concept of hysteresis builds on an idea that even transitory shocks may have permanent effects.<sup>1</sup> The NAIRU is also affected by cyclical shocks, in addition to its structural characteristics. Hysteresis brings important policy implications. Results of Kienzler and Schmid (2014) and Galí (2015) point to the adequacy of the dual mandate of the central bank in the presence of hysteresis. The empirical study by Ball (1999) then implies that passive economic policy during recessions brings high costs: not only temporarily but permanently high unemployment.

This paper aims to evaluate empirical relevance of the unemployment hysteresis on Czech Republic data. The Czech unemployment rate has steadily decreased from values around

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1 O'Shaughnessy (2011) presents an overview of mechanisms through which the hysteresis may work. Theoretical literature emphasizes the role of insiders in wage bargaining (Blanchard and Summers, 1986) and the role of long-term unemployment in wage bargaining (Pissarides, 1992).

7% after the year 2013 and reached 4% in the third quarter of 2016. This development questions validity of the standard macroeconomic approach to unemployment. Contrary to a Phillips curve relation, the decline in unemployment after 2013 did not propagate into higher inflation, which remained close to zero until the last quarter of 2016. The unemployment hysteresis theory may provide explanations for these events.

Until now, almost all authors who have investigated the hysteresis on Czech data used simple unit root tests. This part of the literature considers a unit root in unemployment to be a synonym for hysteresis, motivated by the insider-outsider model of Blanchard and Summers (1986, p. 29–44). The weak point of the unit root approach is in the fact that these tests are valid only against the alternative of constant NAIRU. Some tests control for structural breaks in the NAIRU by using dummy variables, but this approach is rather *ad hoc* and allows only for a small number of structural breaks. Unfortunately, conclusions about the hysteresis in the Czech Republic crucially depend on this weak point of the unit root approach. Hysteresis is usually rejected if tests control for structural breaks (see *e.g.*, León-Ledesma and McAdam, 2004; Camarero *et al.*, 2008), and tests support hysteresis otherwise (*e.g.*, Gozgor, 2013; Furuoka, 2014).

The unobserved component modelling strategy to hysteresis introduced by Jaeger and Parkinson (1994) offers solutions to problems of the unit root approach. This approach specifies hysteresis from its definition as a situation where the cyclical shocks affect the NAIRU, allowing for progressive structural changes in the NAIRU. It also does not require specification of the NAIRU determinants, or additional information about the timing or shape of the structural changes. Until now, this approach has not been applied to Czech data. Model-based investigations of hysteresis are presented by Němec (2010), Pošta (2015) and Marjanovic *et al.* (2015), whose results support hysteresis in the data.<sup>2</sup>

Our empirical strategy in this paper follows the unobserved component approach of Jaeger and Parkinson (1994), specifies hysteresis as the impact of the cyclical unemployment on the NAIRU, and at the same time allows for the presence of the structural changes in the NAIRU. We investigate the two following questions. Is the unemployment rate in the Czech Republic evolving according to the unemployment hysteresis theory? If yes, how strong is the hysteresis effect?

In a nutshell, our results provide robust evidence in favour of the hysteresis effect in the Czech unemployment data. Estimates of key parameters indicate that the hysteresis effect is relatively weak, but its precise size is surrounded by relatively large uncertainty. The estimates imply that in response to an increase in the cyclical unemployment of 1 percentage point, the NAIRU increases on average by 0.18 percentage points. Our model is estimated jointly with the hybrid Phillips curve identified by using survey forecast data as a proxy for the inflation expectations. The estimate of the expectation parameter of 0.66 indicates the forward-looking nature of the Czech Republic's inflation dynamics.

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2 In particular, Němec (2010) estimated a model of a hysteretic Phillips curve, a reduced-form open economy model with rational expectations, and an error correction model of wage bargaining between firms and unions. Pošta (2015) then investigated hysteresis specified as impact of the long-term unemployment on the NAIRU. Marjanovic *et al.* (2015) estimate the NAIRU and investigate its stationarity.

The remainder of this paper is organized as follows. Section 2 introduces our econometric framework and data. Section 3 presents results for our baseline model. Sensitivity and robustness of these baseline results are then investigated in Section 4. Section 5 concludes.

## 2. Model

This section outlines our model, the specification of which combines approaches proposed by Jaeger and Parkinson (1994) and Logeay and Tober (2006). Similarly to Jaeger and Parkinson (1994, p. 331), we decompose the observed unemployment rate  $u_t$  in (1) into a sum of a nonstationary NAIRU component  $u_t^N$  and a stationary cyclical component  $u_t^C$

$$u_t = u_t^N + u_t^C, \quad (1)$$

$$u_t^C = 2A \cos\left(\frac{2\pi}{\tau}\right) u_{t-1}^C + (-A^2) u_{t-2}^C + \varepsilon_t^C, \quad (2)$$

$$u_t^N = u_{t-1}^N + \alpha u_{t-1}^C + \varepsilon_t^N. \quad (3)$$

The cyclical unemployment  $u_t^C$  in Equation (2) follows the AR(2) process. We use a polar parameterisation similarly to Planas *et al.* (2008, p. 19), which allows more natural interpretation of the coefficients.  $A$  denotes amplitude and  $\tau$  the period of the cyclical unemployment. The NAIRU in Equation (3) is specified as the random walk process. A standard trend-cycle model is extended with the parameter  $\alpha$ , which allows for the hysteresis effect specified as the impact of the cyclical unemployment on the NAIRU. It measures in percentage points by how much NAIRU increases after a 1 percentage point increase in the cyclical unemployment.<sup>3</sup>

The shocks  $\varepsilon_t^C$  and  $\varepsilon_t^N$  are mutually independent, normally distributed and with variances  $\sigma_C^2$  and  $\sigma_N^2$ . The shock  $\varepsilon_t^N$  is interpreted as a permanent shock affecting the NAIRU, whereas  $\varepsilon_t^C$  represents a transitory shock which primarily affects the cyclical unemployment.

As is discussed by Jaeger and Parkinson (1994, p. 332), the unobserved component model (1)–(3) specifies the unemployment hysteresis as a situation where the transitory (cyclical) shocks have permanent effects. Within this model, a unit root in unemployment is a necessary but not sufficient condition for hysteresis. The unemployment rate may also include a unit root only due to the presence of permanent shocks to the NAIRU but with no permanent effect of the transitory shocks, when  $\alpha = 0$ . Our approach is thus more general than the methodology used by Marjanovic *et al.* (2015), and also more flexible than the unit root tests used by other authors who have investigated the hysteresis on Czech data.

3 As can be seen from Equation (3), the hysteresis is specified as a symmetric linear phenomenon, independent of the unemployment level. Non-linearities could be introduced into the model by means of the threshold autoregressive approach of Pérez-Alonso and Di Sanzo (2011). We decided to use the more parsimonious linear specification of Jaeger and Parkinson (1994) and Logeay and Tober (2006) mainly because estimation of the non-linear model on the quite sparse Czech data would be very problematic.

The unobserved component model (1)–(3) is generally not identified unless the parameter  $\alpha$  equals zero, and additional information from an observable variable related to the NAIRU or the cyclical unemployment is needed. We follow Logeay and Tober (2006, p. 414) and employ a Phillips curve relationship as the last equation of the model.<sup>4</sup> Traditionally, the backward-looking Phillips curve specified in the spirit of Gordon's (1997) triangle model has been employed in the literature on hysteresis. However, as was shown in the seminal paper of Galí *et al.* (2001), the hybrid version of the New Keynesian Phillips Curve (NKPC) can successfully capture the euro area inflation dynamics, with an important role of inflation expectations. Similar conclusions are reported by Milučká (2014) for the Czech Republic. Hurník and Navrátil (2005, p. 28) then argue that omission of significant forward-looking expectations from the model may result in downward-biased estimates of the NAIRU.

The Phillips curve used in this paper for identification of the unemployment hysteresis effect will be therefore specified in the spirit of the hybrid NKPC.<sup>5</sup> We will use the following specification:

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + (1 - \gamma_f - \gamma_b) im_{t-1} + \lambda_1 u_{t-1}^C + \lambda_2 \widehat{er}_{t-1} + \lambda_3 \hat{\pi}_{t-1}^{EA} + \varepsilon_t^\pi, \quad (4)$$

where  $\pi_t$  represents the inflation rate,  $E_t \pi_{t+1}$  stands for the inflation expectations observed at the time  $t$ ,  $\pi_{t-1}$  is one-period lagged inflation rate,  $im_{t-1}$  is a lag of the import price inflation, and  $u_{t-1}^C$  is the lagged cyclical unemployment rate. The one-period lag of the real effective exchange rate is represented by  $\widehat{er}_{t-1}$ . Finally,  $\hat{\pi}_{t-1}^{EA}$  stands for one-period lagged euro area inflation gap, and  $\varepsilon_t^\pi$  is a normally distributed shock with the variance  $\sigma_\pi^2$ , independent of the other shocks.

## 2.1 Econometric framework

The unobserved component model (1)–(3) together with the Phillips curve (4) can be cast into the following state-space representation:

$$\mathbf{y}_t = \mathbf{c}z_t + \mathbf{H}\mathbf{x}_t + \mathbf{G}\mathbf{u}_t, \quad (5)$$

$$\mathbf{x}_t = \mathbf{a} + \mathbf{F}\mathbf{x}_{t-1} + \mathbf{R}\mathbf{u}_t, \quad (6)$$

where  $\mathbf{y}_t$ ,  $\mathbf{z}_t$ , and  $\mathbf{x}_t$  represent vectors of endogenous, exogenous and state variables.  $\mathbf{u}_t$  is the vector of shocks, and the matrices  $\mathbf{c}$ ,  $\mathbf{H}$ ,  $\mathbf{G}$ ,  $\mathbf{a}$ , and  $\mathbf{R}$  are determined by parameters of our model.

Assuming a Gaussian distribution of the shocks, one can in principle estimate parameters of the state-space model (5)–(6) using the Kalman filter and the classical maximum

4 Parameters of the model (1)–(3) estimated simultaneously with the Phillips curve (4) are identified. This result follows from Theorem 1b in Nowak (1992, p. 716). A more detailed discussion in the context of the model (1)–(3) is presented by Jaeger and Parkinson (1994, p. 333).

5 The original Phillips curve is the relationship between unemployment and wage inflation, *i.e.*, not inflation as such. A comprehensive overview of evolution of the Phillips curve from its original wage inflation version to the state-of-the-art NKPC is presented by Gordon (2011).

likelihood. However, our model includes a relatively large number of parameters and our dataset consists of relatively short time series, which makes maximization of the sample likelihood function quite problematic. We therefore use an alternative approach, employ prior information about the parameters and analyse the state-space model from the Bayesian point of view. We use a Fortran program DMM for the Bayesian estimation.<sup>6</sup>

The significance of the unemployment hysteresis effect is evaluated in this paper using the Bayes factor. To obtain results comparable with the classical likelihood ratio tests, we follow Kass and Raftery (1995, p. 776–777) and estimate our model in two versions. Under our null hypothesis, the model is non-hysteretic, the parameter  $\alpha$  is restricted to 0, and the marginal likelihood associated with this model is denoted as  $pr(D|H_0)$ . Under our alternative hypothesis, the model is hysteretic, it is estimated without restrictions, and its marginal likelihood is  $pr(D|H_1)$ . The Bayes factor is given by

$$B_{10} = \frac{pr(D|H_1)}{pr(D|H_0)}. \quad (7)$$

The Bayes factor thus summarizes evidence provided by the data against the null hypothesis of no hysteresis. Kass and Raftery (1995, p. 777) suggest considering twice the natural logarithm of the Bayes factor. According to these authors,  $2 < 2 \ln(B_{10}) \leq 6$  can be interpreted as a positive evidence against  $H_0$ ;  $6 < 2 \ln(B_{10}) \leq 10$  as a strong evidence against  $H_0$ ; and  $10 < 2 \ln(B_{10})$  as a very strong evidence against  $H_0$ .

**Table 1 | Data**

Variable		Definition	Source
$u_t$	Unemployment rate	Active population 15–74 years, downloaded SA from source	Eurostat (table une_rt_q)
$\pi_t$	Inflation rate	All items HICP, 2005=100, SA by X-13ARIMA, QoQ inflation rate, annualized	Eurostat (prc_hicp_midx)
$E_t \pi_{t+1}$	Expected inflation	Inflation expectations of financial markets at the one-year horizon, SA by X-13ARIMA	Czech National Bank
$\pi_t^{EA}$	Euro area inflation rate gap	All items HICP, 2005=100, SA by X-13ARIMA, HP filter gap of QoQ annualized inflation rate	Eurostat (prc_hicp_midx05)
$im_t$	Import price inflation rate	Imports of goods and services deflator, 2005=100, SA by X-13ARIMA, QoQ inflation	Eurostat (namq_10_gdp)
$er_t$	Real effective exchange rate gap	REER index, deflator: CPI indexes of 42 trading partners, 2005=100, SA by X-13ARIMA, HP gap	Eurostat (ert_eff_ic_q)

Notes: SA refers to the seasonal adjustment (except unemployment, we adjust all variables using the X-13ARIMA procedure). HP gap stands for the Hodrick-Prescott filter gap computed using the parameter  $\lambda = 1600$ . We report source tables for data from Eurostat

Source: Eurostat and Czech national bank database.

<sup>6</sup> Technical details about algorithms used within the DMM are presented by its authors in Fiorentini *et al.* (2015).

Our dataset is presented in Table 1. It consists of quarterly time series, running from 1999:Q2 to 2016:Q3. The inflation rates are measured as the annualized quarter-on-quarter log differences in price indices. The gap measure for the euro area inflation is used to control for potential trend inflation. Importantly, we use a direct measure of the inflation expectations published by the Czech National Bank. For the sake of simplicity, we follow Milučká (2014) and treat the survey forecasts as an exogenous variable.<sup>7</sup>

## 2.2 Prior distribution of parameters

The prior distribution for the parameters of the model is described in Table 2 using the prior mean and standard deviation. These priors are set according to the economic theory and previous empirical studies. Parameters of the Phillips curve (4) are characterized by the truncated normal distributions and restricted to be (in absolute values) not higher than one. In their meta-regression analysis of the NKPC, Danišková and Fidrmuc (2012, p. 26) report country-specific results for the parameter  $\gamma_f$ . We use their estimate for the Czech Republic and set the prior mean of this parameter to 0.56. The prior mean for  $\gamma_b$  is set to 0.25, which is the highest value estimated by Milučká (2014). The prior standard deviations for both parameters are set to 0.05. The prior mean for  $\lambda_1$  is set to  $-0.55$  according to the results of Hurník and Navrátil (2005). The standard deviation of 0.15 then reflects our higher uncertainty about the impact of the unemployment gap on the inflation. The prior mean for  $\lambda_2$  is set to  $-0.2$  according to the results of Hurník and Navrátil (2005). Finally, we set the prior mean for  $\lambda_3$  to 0.6 based on estimates of Vašíček (2011).

The next three parameters characterize the unemployment dynamics. The prior mean for the parameter  $\alpha$ , the measure of the unemployment hysteresis, is set to 0.18. This prior is based on results of Jaeger and Parkinson (1994, p. 337) and of Logeay and Tober (2006, p. 416). The prior mean for the cyclical unemployment period is set close to 20 quarters, which is the most important periodicity found in the investigation of the Czech business cycle by Poměnková and Maršálek (2011). The support for the period is restricted to [6, 32] quarters, which is a standard periodicity associated with business cycles. The prior mean for the amplitude of the cycle is set to 0.8, similarly to Planas *et al.* (2008, p. 23) for the US and the euro area. We assign relatively high prior standard deviations to all these parameters.

As Guichard and Rusticelli (2011, p. 11) claim, the authors who investigate the NAIRU using the Kalman filtration do not usually estimate all variances of the shocks. The usual practice is calibration of the so-called signal-to-noise ratio  $\sigma_N^2 / \sigma_\pi^2$ . It compares the relative variation in the NAIRU and in the inflation, and thus determines the smoothness of the estimated NAIRU. We follow this approach only partially, parameterize  $\sigma_N^2$  in terms of the signal-to-noise ratio, and estimate this ratio as another parameter of the model.

<sup>7</sup> For justification of this choice, see Mavroeidis *et al.* (2014, p. 166–168), who conclude that this approach tends to provide the best identification of the NKPC from all techniques used so far in the empirical literature.

Laubach (2001) and Gordon (1997) calibrate this parameter between 0.05 and 0.15. We specify the prior mean of this parameter as 0.1, with the prior standard error 0.05.

The prior mean for  $\sigma_\pi^2$  is specified as 0.9, according to the results of Milučká (2014), and the prior mean for  $\sigma_C^2$  is set to 0.6, very close to the value used by Beneš and N'Diaye (2004). We set relatively large prior standard deviations to these parameters.

### 3. Results

This section presents estimates of our baseline model. To obtain the results, we sample 300,000 draws from the posterior distribution, burn the initial 150,000 draws to ensure convergence, and from the remaining 150,000 draws we record every fifth draw to address the potential autocorrelation in the chain. The posterior inference is thus based on 30,000 draws. The convergence was checked using Geweke's (1991) convergence statistics, and we also inspected autocorrelations between draws. Posterior distributions of the parameters are summarized in Table 2.

The first five parameters in Table 2 characterize the Phillips curve (4). The parameters  $\gamma_f$  and  $\gamma_b$  show that the forward-looking inflation term is more important than the backward-looking one. The posterior mean of  $\gamma_f$  is 0.66. In the literature investigating Czech data, the survey forecast proxy has been used so far only by Milučká (2014), who also reports an estimate of  $\gamma_f$  of 0.66. We thus confirm her conclusions about the dominant role of forward-looking expectations, even with the unemployment gap and not the output gap as the domestic forcing variable. The parameters  $\lambda_1$ ,  $\lambda_2$  and  $\lambda_3$  capture impacts of the lagged cyclical unemployment, real effective exchange rate and euro area inflation gap on the inflation rate  $\pi_t$ . These estimates are consistent with economic intuition and are not dramatically different from our priors.

The estimate of the hysteresis effect  $\alpha$  implies that increase in the cyclical unemployment rate of 1 percentage point leads to a permanent increase in the NAIRU of 0.18 percentage point. The Bayes factor  $2\ln(B_{10})$  of 2.01 then shows that the data provide positive evidence against the restriction of no hysteresis in the Czech Republic. Jaeger and Parkinson (1994, p. 337) and Logeay and Tober (2006, p. 416) report estimates of the hysteresis effect which are directly comparable with our parameter  $\alpha$ . These authors estimate models for the euro area, Germany, the United Kingdom, Canada and the USA. Their estimates of the hysteresis effect vary between 0.18 and 0.26, with the exception of the USA with the insignificant effect of 0.02. The hysteresis in the Czech Republic is thus significant, but relatively weak in comparison with other countries. Comparison of the prior and posterior distributions for the parameter  $\alpha$  then may suggest that the posterior is largely driven by the prior. Sensitivity of the hysteresis effect to the prior selection is therefore investigated in Section 4.3.

The period and amplitude parameters describe dynamics of the filtered cyclical unemployment. The unemployment exhibits cycles with an average periodicity around 18 quarters. The last three parameters describe variances of the shocks. The data are strongly informative especially about the signal-to-noise ratio and about  $\sigma_\pi^2$ .



**Table 2 | Prior Distributions and Results for the Baseline Model**

Parameter	Description	Prior distribution			Posterior distribution		
		Distr.	Mean	Sd.	Mean	90% HPDI	
$\gamma_f$	Forward-looking expectations	TN	0.56	0.05	0.66	0.60	0.72
$\gamma_b$	Backward-looking expectations	TN	0.25	0.05	0.29	0.23	0.35
$\lambda_1$	Impact of unemployment	TN	-0.55	0.15	-0.45	-0.67	-0.23
$\lambda_2$	Impact of real exchange rate	TN	-0.20	0.05	-0.18	-0.25	-0.10
$\lambda_3$	Impact of euro area inflation	TN	0.60	0.05	0.56	0.48	0.64
$\alpha$	Hysteresis effect	TN	0.18	0.07	0.18	0.05	0.29
$\tau$	Period	BE	19.7	4.00	17.76	12.86	23.0
$A$	Amplitude	BE	0.80	0.16	0.75	0.58	0.93
$\sigma_N^2 / \sigma_\pi^2$	Signal-to-noise ratio	BE	0.10	0.05	0.02	0.01	0.03
$\sigma_\pi^2$	Variance of inflation shock	IG	0.90	0.18	3.44	2.68	4.16
$\sigma_c^2$	Variance of cyclical shock	IG	0.60	0.12	0.63	0.48	0.78

Notes: Table presents prior distributions for parameters and summarizes posterior distributions. Prior distribution (Distr.) for each parameter of the model is defined over finite support and characterized by prior mean and standard deviation (Sd.). TN denotes truncated normal distribution, BE represents beta, and IG stands for inverse gamma distribution. Posterior distributions are characterized by posterior means and 90% highest posterior density intervals (HPDI). Hysteresis is captured by  $\alpha$ , measuring the effect of the lagged cyclical unemployment on the NAIRU. Bayes factor  $2\ln(B_{10}) = 2.01$ .

Source: Own computations.

Figure 1 shows our estimates of the NAIRU.<sup>8</sup> The NAIRU follows the actual unemployment rate closely due to the effect of the hysteresis. Periods of high unemployment are associated with an increase in the NAIRU, while periods of low unemployment are associated with a decreasing NAIRU.<sup>9</sup> Regarding the current situation in the Czech Republic, our estimates show that the NAIRU peaked at 6.8% in 2011:Q2, remained relatively stable until 2013:Q2, and then had fallen to 5% by 2016:Q3.

8 We follow Berger and Everaert (2008) and report the mean and the 5% and 95% percentiles of the posterior distribution as estimates of the state variable and its 90% confidence band.

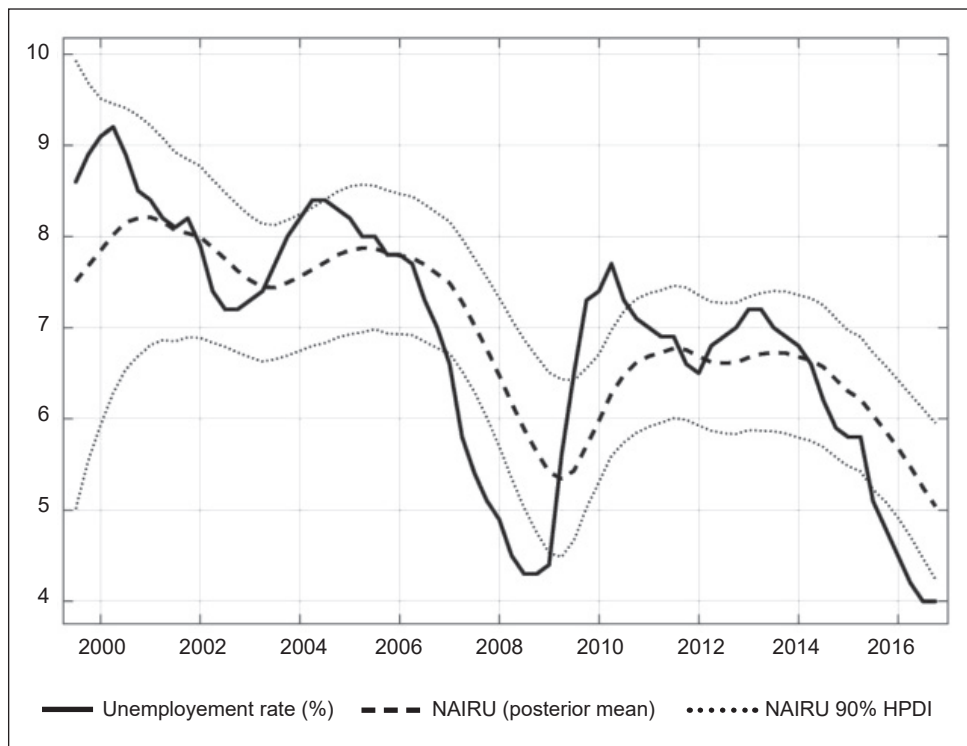
9 The initial estimate of the NAIRU 7.5% is associated with a high uncertainty. Its 90% confidence band spans almost from 5% to 10%, but it shrinks after several initial quarters. This higher uncertainty about the initial estimate of the NAIRU was typical of all the hysteresis models we attempted to estimate, probably due to the more complicated dynamics of the state variables which is implied by the hysteresis.



## 4. Sensitivity and Robustness

This section presents several extensions to our baseline model, investigating its sensitivity and robustness. Selected results are reported in Table 3. We start with the backward-looking Phillips curve.

**Figure 1 | Estimates of NAIRU for Czech Republic**



Source: Own computations.

### 4.1. Backward-looking Phillips curve

Our baseline Phillips curve (4) is motivated by the hybrid NKPC. However, the backward-looking triangle model of inflation proposed by Gordon (1997) has been traditionally used in the literature on NAIU estimation. As the first sensitivity test, we re-estimate our baseline model together with the following backward-looking Phillips curve:

$$\pi_t = \gamma_0 + \sum_{p=1}^4 \gamma_p \pi_{t-p} + \left(1 - \sum_{p=1}^4 \gamma_p\right) im_{t-1} + \lambda_1 u_{t-1}^C + \lambda_2 \widehat{er}_{t-1} + \lambda_3 \hat{\pi}_{t-1}^{EA} + \varepsilon_t^\pi \quad (8)$$

where  $\pi_{t-p}$  is the  $p$ -quarter lagged inflation rate, and the remaining variables are the same as in the case of Phillips curve (4).

The impact of the cyclical unemployment on the inflation is now 0.1 units weaker in comparison with the baseline model. More importantly, even though the hysteresis parameter  $\alpha$  increased slightly, the Bayes factor now indicates that the data do not provide evidence against the restriction of no hysteresis in the data. This result shows that appropriate forward-looking specification of the Phillips curve is crucial for the assessment of the significance of the hysteresis effect.

**Table 3 | Sensitivity and Robustness**

Model	$\gamma_f$	$\gamma_b$	$\lambda_i$	$\alpha$	$2\ln(B_{10})$
<b>Baseline model</b>	0.66 [0.60; 0.72]	0.29 [0.23; 0.35]	-0.45 [-0.67; -0.23]	0.18 [0.05; 0.29]	2.01 –
<b>Backward-looking PC</b>	– –	– –	-0.41 [-0.65; -0.19]	0.20 [0.09; 0.31]	1.99 –
<b>Prior sensitivity: <math>\alpha</math></b>	0.65 [0.59; 0.71]	0.31 [0.25; 0.37]	-0.49 [-0.71; -0.27]	0.25 [0.01; 0.65]	2.02 –
<b>Prior sensitivity: all</b>	0.77 [0.63; 0.92]	0.21 [0.06; 0.34]	-0.45 [-0.75; -0.13]	0.38 [0.01; 0.78]	2.01 –
<b>1994–2015 sample</b>	0.55 [0.48; 0.62]	0.30 [0.23; 0.37]	-0.42 [-0.63; -0.18]	0.19 [0.04; 0.31]	2.01 –

Notes: Table presents posterior means and 90% highest posterior density intervals [in parentheses] for selected parameters of the baseline model, and for five models from the Sensitivity and robustness section.  $\gamma_f$  captures the weight of the expected inflation in the Phillips curve,  $\gamma_b$  is then the weight of the lagged inflation.  $\lambda_i$  measures the impact of the cyclical unemployment on the inflation and  $\alpha$  captures the impact of the lagged cyclical unemployment on the NAIRU. We also present the Bayes factor for each model.

Source: Own computations.

## 4.2 Prior sensitivity of hysteresis

The comparison of the prior and posterior distributions presented in Table 2 indicated one slightly problematic property of the estimates for the parameter  $\alpha$ , which measures the strength of the hysteresis. The Bayes factor indicates that the hysteresis is significant in our baseline model, but the posterior distribution of  $\alpha$  is largely driven by the prior. We therefore re-estimate the baseline model using the flat prior for the parameter  $\alpha$ .<sup>10</sup> Results of this estimation are presented in Table 3, Prior sensitivity:  $\alpha$ . The Phillips curve parameters are practically unchanged. The posterior mean of the hysteresis parameter  $\alpha$  increased to 0.25 in comparison with the baseline model, and the Bayes factor still

<sup>10</sup> The prior distribution for  $\alpha$  is thus specified as the uniform distribution defined over the [0;1] interval. For remaining parameters of the model, we use the same priors as we used for estimation of the baseline specification.

indicates that the hysteresis effect is significant. However, the 90% highest posterior density interval now spreads from 0.01 to 0.65, which indicates that the precise size of the hysteresis effect is surrounded by relatively large uncertainty in absence of the prior information. The 90% HPDI is almost three times wider in comparison with the baseline model.

Secondly, we also estimated the whole model using the flat prior for  $\alpha$ , and twice higher prior standard deviations for the remaining parameters of our baseline model. The results are presented in Table 3, Prior sensitivity: all. Most importantly, the Bayes factor indicates that the hysteresis effect is significant even in the case of this model estimated using very loose priors. The hysteresis parameter  $\alpha$  increases even more to 0.38, but the 90% HPDI is again quite wide. The impact of the expected inflation increases as well and the backward-looking inflation term shrinks, while the impact of the cyclical unemployment on the NAIRU remains relatively stable. Note that all the parameters are now surrounded by much higher uncertainty.

### 4.3 Sample from 1994 to 2015

Due to limited availability of the inflation expectation data, our baseline model was estimated on a sample starting in 1999:Q2. However, because the Czech unemployment rate increased sharply after a recession in the second half of the 1990s, re-estimation of our baseline model on a longer time series may provide another relevant robustness check. In particular, we investigate the sample which spans from 1994:Q2 to 2015:Q3. The analysis of the longer time series data brings several complications. As the import price indices are available only since 1998, we follow Hurník and Navrátil (2005, p. 29) and use the log-difference in the nominal exchange rate data from Eurostat as a proxy for the import price inflation in Phillips curve (4).

More importantly, the inflation expectation survey data are available only since 1999. We thus follow the approach of Baxa *et al.* (2015), use the assumption of perfect rationality, and replace the expectations  $E_t\pi_{t+1}$  with the realization  $\pi_{t+1}$ . As Baxa *et al.* (2015, p. 119) explain, this approach leads to endogeneity because the future inflation is then by construction correlated with an error term of the Phillips curve. We thus apply a two-step procedure of Baxa *et al.* (2015, p. 120) to overcome this endogeneity. The first step consists of a simple OLS regression of the endogenous variable  $\pi_{t+1}$  on a set of instruments. The second step consists of the standard joint estimation of our unobserved component model and of the Phillips curve, which includes the standardized residuals from the first-step OLS regression as the endogeneity correction term.

The results show that the parameter remains stable even in the 1994–2015 sample, and that the data still provide positive evidence against the restriction of no hysteresis according to the Bayes factor. However, the impact of the cyclical unemployment on the inflation decreased slightly in comparison with the baseline model, similarly to the weight of the forward-looking expectations.

## 4.4. Summary of sensitivity and robustness

This section presented three modifications of our baseline model, and its most important results can be summarized as follows. The parameter of primary interest  $\alpha$  was relatively stable across different specifications. All the models indicated that the hysteresis effect is relatively weak, even though its precise size is largely affected by the priors and uncertain. The Bayes factor showed, with only one exception, that the data provide positive evidence against the restriction of no hysteresis in the Czech data; and this result is not sensitive to informativeness of the priors.

## 5. Conclusion

This paper presented an empirical analysis of the unemployment hysteresis in the Czech Republic, using quarterly data from 1999 to 2016. Our model specified hysteresis as the impact of the cyclical unemployment on the NAIRU. The model was estimated jointly with the hybrid Phillips curve using the state-space techniques and the Bayesian approach. The main contributions of the paper can be summarized as follows.

Firstly, we contribute to the literature which uses unobserved component models of hysteresis (Jaeger and Parkinson, 1994; Alon and Sanzo, 2011; Logeay and Tober, 2006; Berger and Everaert, 2008). These authors used backward-looking models for estimation of the NAIRU and hysteresis. We contributed to this literature by using the hybrid Phillips curve, which also incorporates forward-looking expectations, motivated by the New Keynesian theory.

Secondly, we are the first authors to investigate, on Czech data, the hysteresis effect specified as the impact of the cyclical unemployment on the NAIRU. Our baseline results imply that this effect is present in the data and that in response to a 1 percentage point increase in the cyclical unemployment, the NAIRU increases on average by 0.18 percentage points. The significance of the hysteresis effect (measured by the Bayes factor) was robust across the different modifications of our model. However, our robustness checks revealed that the precise size of the hysteresis effect is surrounded by large uncertainty and largely affected by the priors.

Our unobserved component approach is the most closely related to a recent paper by Marjanovic *et al.* (2015). Similarly to our paper, these authors also specify an unobserved component model for unemployment dynamics and estimate the NAIRU and the cyclical unemployment for the Czech Republic. Marjanovic *et al.* (2015) conclude that the Czech unemployment data support hysteresis because their estimate of the NAIRU is not stationary. However, this is not the most appropriate method to test the hysteresis according to our opinion. The NAIRU may be non-stationary simply due to the presence of structural breaks.<sup>11</sup> Instead of this, our model specifies hysteresis as the impact of the cyclical

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11 The non-stationarity of the estimated NAIRU should not be surprising either because, before estimation of the NAIRU by Kalman filtration, Marjanovic *et al.* (2015, p. 5) in fact specify that unobservable NAIRU follows the random walk.

unemployment on the NAIRU, and at the same time allows for the presence of structural breaks in the NAIRU.

Thirdly, we used survey forecasts as a proxy variable for the inflation expectations in the Phillips curve. In the literature investigating Czech data, this approach has only been used by Milučká (2014). Our estimates confirm her conclusions about the dominant role of forward-looking expectations in the Czech Phillips curve, even though we used the unemployment gap as the domestic forcing variable and not the output gap as Milučká (2014). Our estimate of the inflation expectation parameter was 0.66.

Our robust result that hysteresis is present in Czech data may have important implications for policymakers because the hysteresis allows for long-term effects of cyclical deviations. Our results may also offer a partial explanation for the current situation in the Czech economy, where even the historically low unemployment rate around 4% did not induce inflation pressures until the end of 2016. It is possible that the NAIRU declined together with the actual unemployment rate, due to the hysteresis effect. Our calculations suggest that the NAIRU should be close to 5% by 2016:Q3.

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