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Contents

Abstract

The paper provides estimates for the New Keynesian Phillips curve (NKPC) in Lithuania. The paper considers the baseline and hybrid NKPC, the latter accounting for inflation inertia, under the closed and open economy frameworks. The estimates highlight the importance of expected and lagged inflation in the inflation formation process. The role of real marginal cost is found to be limited in shaping the dynamics of inflation. The study yields estimates for the underlying characteristics of pricing behaviour in Lithuania. The estimates show that the price duration stands at around 2.2–2.8 quarters, while the fraction of firms that adjust prices in a backward looking way amounts to around one third.

Keywords: New Keynesian Phillips curve, price stickiness, real marginal cost, labour income share.
JEL classification: D40, E30.

Santrauka

Remiantis Lietuvos duomenimis, straipsnyje vertinama naujųjų keinsistų Phillipso kreivė – pagrindinė ir mišrioji. Pastaroji leidžia įvertinti infliacijos pastovumą. Analizė apima uždaros ir atviros ekonomikos atvejus. Ekonometrinis vertinimas rodo, kad infliaciją reikšmingai veikia laukiama ir ankstesnio laikotarpio infliacija. Realiųjų ribinių sąnaudų įtaka jai yra ribota. Straipsnyje pateikiami įmonių kainodaros Lietuvoje savybių kiekybiniai įverčiai. Iš šių įverčių matyti, kad kainų trukmė Lietuvoje yra apie 2,2–2,8 ketvirčio. Įmonės, kurios nustato kainas pagal ankstesnių laikotarpių kainas, sudaro maždaug trečdalį visų šalies įmonių.

Introduction

The New Keynesian Phillips curve (NKPC) provides a framework to analyse inflation in a structural way. NKPC relates inflation to real economic activity, inflation expectations and, possibly, inflation inertia. The considered models are theory-based. They evolve from optimising behaviour of monopolistically competitive firms that set the prices in a constrained way. These models thus incorporate nominal rigidities that can be analysed in more detail.

This paper considers a baseline NKPC, where the real marginal cost and the expected inflation govern inflation, and a hybrid NKPC, where the lagged inflation is accounted for, as outlined in Galí and Gertler (1999) and Galí et al. (2001). The paper covers a closed economy case and an open economy extension. The latter economy framework introduces the open economy effects by allowing for imported goods to be used in the consumption and the production, as in Leith and Malley (2007). Different economy setups render different real marginal cost measures. In the closed economy, the real marginal cost is proxied by labour income share or equivalently by real unit labour cost, while in the open economy the real marginal cost is a combination of labour income share, real GDP and domestic costs/prices relative to import prices.

The estimates for hybrid NKPC in Lithuania are reported in Dabušinskas and Kulikov (2007). The authors provide estimates under the real marginal cost proxies derived for the closed economy (as in Galí and Gertler, 1999, and Galí et al., 2001) and two open economy cases (one of them follows Leith and Malley, 2007, the other one incorporates the energy production factor). Baseline and hybrid NKPC for Lithuania are estimated in Mihailov et al. (2010). The authors consider the closed and open economy cases, where the latter case accounts for the terms of trade as in Galí and Monacelli (2005). The study of Mihailov et al. (2010) uses the real GDP series to construct the measure of real marginal cost.

The purpose of this paper is to identify the role of inflation factors in Lithuania as suggested by the NKPC. The paper estimates the baseline and hybrid NKPC. The undertaken study estimates the reduced-form parameters that represent the role of real marginal cost, lagged inflation and expected inflation in governing the inflation process. The paper also estimates the structural parameters that underlie the price setting. One of the structural parameters is the fraction of firms that keep prices unchanged. This is a parameter used in the Calvo (1983) price setting formulation, which is employed in the considered models. This parameter allows deduction of the estimate of price duration that is often viewed as a price stickiness measure. The other estimated structural parameter is the fraction of firms that

adjust prices following the backward looking rule of thumb. This parameter is used in the hybrid NKPC formulation to account for inflation inertia.

The paper is organised in the following way. Section 1 reconstructs the models of baseline and hybrid NKPC. As a starting case, the models are derived under the closed economy assumptions. The models are then extended to introduce the open economy effects. This section also outlines the measures for the real marginal cost of the closed economy and the open economy. Section 2 provides the empirical evidence on the parameters for the considered models in Lithuania. The main findings of the performed research are summarised in the concluding section.

1. Theoretical background

This section describes the economic setup that generates the baseline and hybrid NKPC. The theoretical background follows Galí and Gertler (1999), Galí et al. (2001) and Leith and Malley (2007) in reconstructing the structural relation between the inflation, the real economic activity, the inflation expectations and, in the hybrid NKPC case, the inflation inertia.

It is assumed a continuum of firms indexed by $j \in [0,1]$ acting in a monopolistically competitive market. Each firm is a monopolistic competitor producing a differentiated good Y_{jt} and selling it at time t for a nominal price P_{jt}. Each firm faces a constant-price-elasticity demand given by

$$Y_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\varepsilon} Y_t \qquad (1.1)$$

where Y_t is an aggregate production output represented by $Y_t = \left(\int_0^1 Y_{jt}^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$, P_t is an aggregate price level $P_t = \left(\int_0^1 P_{jt}^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}$, ε is a price elasticity of demand and an elasticity of substitution between differentiated goods.

Firms set the prices in a constrained way as in Calvo (1983). In particular, every period the firm is allowed to adjust its price with a probability $1-\theta$, irrespective of the fact whether the firm reset its price in the previous period. In other words, every period $1-\theta$ fraction of firms is allowed to change the price. At the same time θ fraction of firms keeps the prices

unchanged. The expected time that the price remains fixed, consequently, is $\frac{1}{1-\theta}$[1]. θ is, thus, used to measure the stickiness of prices. Under this setup the aggregate price level can be expressed as

$$P_t = \left((1-\theta)\left(P_t^*\right)^{1-\varepsilon} + \theta P_{t-1}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \tag{1.2}$$

where P_t^* is the newly set price chosen by firms, which are allowed to adjust their prices in period t. Log-linearization of the price index (1.2) around a zero-inflation steady state implies that the aggregate price level evolves as a weighted average of the newly set price level p_t^* and the price level observed in the previous period p_{t-1}, in particular

$$p_t = (1-\theta)p_t^* + \theta p_{t-1} \tag{1.3}$$

where the lower case letters, representing the variables, denote the variables in logs[2].

1.1. Optimal price setting under Calvo constraints

When prices are set with restrictions, optimal pricing involves the assessment of expected changes in the economic environment during a foreseeable future. The firm, which under the Calvo constraints is allowed to set the price at time t, picks up the optimal price P_{jt}^* to maximize the discounted stream of the expected future profits over the horizon, during which the price is to prevail. The firm faces the profit maximization problem

$$\max_{P_{jt}^*} E_t \sum_{k=0}^{\infty} (\beta\theta)^k \left(P_{jt}^* Y_{jt+k} - MC_{jt+k} Y_{jt+k}\right) \tag{1.4}$$

subject to the demand condition $Y_{jt} = \left(\frac{P_{jt}^*}{P_t}\right)^{-\varepsilon} Y_t$. Here β is a subjective discount factor, MC_{jt} is a nominal marginal cost of firm j.

Solution to the firm's maximization problem (1.4) and its log-linearization yields the optimal path for the newly set price chosen by the firm under the Calvo constraints. In particular, this price is determined by the mark-up $\mu = \frac{\varepsilon}{\varepsilon - 1}$ and the discounted stream of current and expected future nominal marginal cost of the firm

[1] To illustrate, if the periodicity is quarterly and every quarter the firm is allowed to adjust the price with probability $\theta = 0.5$, then the implied time period, during which the price remains fixed, is 2 quarters.

[2] In the rest of the paper the same notation (lower case letters) for variables in logs applies.

$$p_{jt}^{*} = \log\mu + (1-\beta\theta)E_t\sum_{k=0}^{\infty}(\beta\theta)^k mc_{jt+k}\,. \qquad (1.5)$$

The result (1.5) implies that in the limiting case when the prices are set in a fully flexible way, i.e. when all the firms are allowed to choose the prices in any given period $(\theta = 0)$, the prices move as much as the current nominal marginal cost. Only when the price stickiness is introduced, i.e. when $\theta > 0$, the expected future developments of nominal marginal cost obtain the weight.

1.2. Closed economy framework

1.2.1. Real marginal cost

In the assumed economy, as in Galí et al. (2001), the firms employ a production technology expressed as

$$Y_{jt} = A_t N_{jt}^{1-\alpha} \qquad (1.6)$$

where A_t denotes a common technological factor, N_{jt} is a labour input and α is an elasticity of substitution between labour and capital that is kept fixed[3].

In the economy where only labour is used to produce the output, the total cost function of the firm is defined as $W_t N_{jt}$, where W_t is a nominal wage. The real marginal cost then is

$$MC_{jt}^{r} = \frac{1}{1-\alpha}\frac{W_t N_t}{P_t Y_t}\left(\frac{P_{jt}}{P_t}\right)^{-\frac{\varepsilon\alpha}{1-\alpha}} \qquad (1.7)$$

varying among the firms depending on the ratio between the price set by each firm and the general price level (the framework follows Sbordone, 2002).

Log-linearization of (1.7) implies that in the given closed economy the real marginal cost of the firm follows a relationship between the real marginal cost in the economy and the price set by the firm relative to the general price level

$$\hat{mc}_{jt}^{r} = \hat{mc}_{t}^{r} - \frac{\varepsilon\alpha}{1-\alpha}(p_{jt} - p_t)\,. \qquad (1.8)$$

Here the lower case letters under "^" denote the log deviations of variables from their steady state values[4].

[3] This production technology is equivalent to $Y_{jt} = A_t N_{jt}^{1-\alpha} K^{\alpha}$ where capital K is fixed.

[4] In the rest of the paper the same notation (lower case letters under "^") for log deviations of variables from their steady state values applies.

Since $MC_t^r = \frac{1}{1-\alpha}\frac{W_t N_t}{P_t Y_t} = \frac{S_t}{1-\alpha}$, where S_t is a labour income share or equivalently a real unit labour cost, log-linear approximation of the real marginal cost in the given closed economy is proportional to the labour income share or equivalently the real unit labour cost

$$\hat{mc}_t^r = \hat{s}_t . \tag{1.9}$$

1.2.2. Baseline and hybrid New Keynesian Phillips curves

The Calvo formulation of sticky price setting and the outlined economy setup leads to a construction of structural relation between the inflation and the real marginal cost. This relation is obtained by making use of the above derived results for the aggregate price level (1.3), the newly set prices chosen by firms under the Calvo constraints (1.5) and the real marginal cost (1.8). Taken the results together lead to the variant of baseline NKPC, which relates the current inflation to the current real marginal cost and to the inflation, which is expected to prevail in the next period

$$\pi_t = \lambda \hat{mc}_t^r + \beta E_t \pi_{t+1} \tag{1.10}$$

where π_t is inflation rate defined as $p_t - p_{t-1}$, $\lambda = \frac{(1-\theta)(1-\beta\theta)(1-\alpha)}{\theta(1+\alpha(\varepsilon-1))}$.

Iterating (1.10) results in $\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k E_t \hat{mc}_{t+k}^r$ implying that the current inflation is governed by the discounted stream of current and expected future real marginal cost. Intuitively, it is justified by an assumption that the price resetting firms are forward looking and that some firms might end up without resetting their prices for a number of periods. The role of real marginal cost, in turn, depends on λ, which is related to the structural parameter θ. Since λ is decreasing to the parameter θ, higher fraction of firms, which are not allowed to reset the prices, implies more contained role of the real marginal cost in determining inflation. λ is also decreasing to the parameters α and ε. The more sensitive firms are to the deviation of prices from the aggregate price level, the lesser the role the real marginal cost plays in the inflation.

Baseline NKPC embodied in the result (1.10) relates the current inflation only to the current real marginal cost and to the foreseen inflation, which is expected to prevail in the next period. Baseline NKPC does not capture, however, the lagged inflation effects on the current inflation, which are often found as statistically significant. To account for inflation inertia, Galí and Gertler (1999) and Galí et al. (2001) suggest to assume that only a fraction of firms, which are allowed to reset their prices under the Calvo constraints, optimize their

decisions as described in (1.5), while the rest of price resetting firms follow a backward looking rule of thumb

$$p_t^b = p_{t-1}^* + \pi_{t-1} \tag{1.11}$$

where p_t^b is a price level set by the backward looking rule of thumb firms, p_{t-1}^* is a level of prices set by the firms, which were allowed to adjust the prices in the previous period (this includes both the optimizing and the rule of thumb firms).

As noted by Galí and Gertler (1999) and Galí et al. (2001), the rule of thumb (1.11) possesses a few appealing features. Namely, when the inflation is stationary the rule converges to the optimal price setting behaviour. The prices set by this rule are conditioned only on the information dated at $t-1$ or earlier (the backward looking feature of the rule), however the rule incorporates the information about the future developments by accounting for the newly set prices in the previous period, which were partly set by the optimizing firms.

As in the analysis above, the optimizing firms (or, in other words, the forward looking firms) set their prices according to equation (1.5). In this setup the price level of newly set prices evolves according to

$$p_t^* = (1-\omega)p_t^f + \omega p_t^b \tag{1.12}$$

where p_t^f is a price level set by the optimizing firms, $1-\omega$ is a fraction of firms that set the prices optimally, ω is a fraction of firms adjusting the prices according to the backward looking rule of thumb.

Taken together the key equations, describing the economy with the backward looking rule of thumb price setting firms, yield the variant of hybrid NKPC, which relates the current inflation to the current real marginal cost, the lagged inflation and the inflation, which is expected to prevail in the next period

$$\pi_t = \tilde{\lambda} m\hat{c}_t^r + \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} \tag{1.13}$$

where $\tilde{\lambda} = \dfrac{(1-\omega)(1-\theta)(1-\beta\theta)(1-\alpha)}{(\theta+\omega(1-\theta(1-\beta)))(1+\alpha(\varepsilon-1))}$, $\gamma_b = \dfrac{\omega}{\theta+\omega(1-\theta(1-\beta))}$,

$\gamma_f = \dfrac{\beta\theta}{\theta+\omega(1-\theta(1-\beta))}$.

Present value of (1.13) amounts to $\pi_t = \delta_1 \pi_{t-1} + \left(\dfrac{\tilde{\lambda}}{\delta_2 \gamma_f}\right) \sum_{k=0}^{\infty} \left(\dfrac{1}{\delta_2}\right)^k E_t m\hat{c}_{t+k}^r$, where

$\delta_1 = \dfrac{1-\sqrt{1-4\gamma_b\gamma_f}}{2\gamma_f}$ and $\delta_2 = \dfrac{1+\sqrt{1-4\gamma_b\gamma_f}}{2\gamma_f}$ are respectively the stable and the unstable

roots of the associated characteristic equation[5]. Similarly as in the baseline NKPC, the present value representation shows that in addition to the lagged inflation the current inflation is determined by the discounted sum of the current and expected future real marginal cost.

The specification (1.13) implies that in the limiting case when all the firms, which are allowed to choose the prices, are forward looking, i.e. when $\omega = 0$, the hybrid NKPC falls into the baseline model (1.10), which relates the current inflation only to the current real marginal cost and to the inflation, which is expected to prevail in the next period. And only when there is some fraction of firms, which reset their prices according to the backward looking rule, i.e. when $\omega > 0$, the lagged inflation obtains the weight in governing the present inflation. The proportion of rule of thumb firms affects the weight of both the lagged and the expected inflation. γ_b is increasing and γ_f is decreasing to ω, therefore higher fraction of the backward looking firms implies stronger role of the lagged inflation and weaker role of the expected inflation in determining the current inflation. The impact of the fraction of firms, which are not allowed to reset the prices, is the opposite. γ_b is decreasing and γ_f is increasing to the parameter θ, therefore if proportion of firms, which keep their prices unchanged, is higher, the role of the lagged inflation is weaker and the role of the expected inflation is stronger.

1.3. Extension to open economy

The following economy extension incorporates the open economy effects by allowing for imported goods to be used in the consumption and the production as in Leith and Malley (2007). It is assumed that a consumption basket is a CES aggregate

$$C_t = \left(\chi \left(C_t^d\right)^{\frac{\sigma-1}{\sigma}} + (1-\chi)\left(C_t^m\right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{1.14}$$

where $C_t^d = \left(\int_0^1 \left(C_{jt}^d\right)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$ and $C_t^m = \left(\int_0^1 \left(C_{jt}^m\right)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$ refer to the consumption of domestically produced and imported goods respectively, χ is a parameter representing the home bias in the consumption, and σ is an elasticity of substitution between the goods produced in the home country and abroad.

[5] The associated characteristic equation in lag operator L terms is $L^{-1} - \frac{1}{\gamma_f} + \frac{\gamma_b}{\gamma_f} L = 0$.

The associated price indices of domestically produced and imported goods are given by $P_t^d = \left(\int_0^1 \left(P_{jt}^d \right)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}$ and $P_t^m = \left(\int_0^1 \left(P_{jt}^m \right)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}$ respectively, and the corresponding consumption price index is

$$P_t = \left(\chi^\sigma \left(P_t^d \right)^{1-\sigma} + (1-\chi)^\sigma \left(P_t^m \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \tag{1.15}$$

As in Leith and Malley (2007), imported goods are viewed as substitute for labour in the production technology

$$Y_{jt} = \left(\alpha_N N_{jt}^{\frac{\rho-1}{\rho}} + \alpha_{IM} IM_{jt}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}(1-\alpha)} \tag{1.16}$$

[6]

where IM_{jt} is imports of goods used in the production of firm j, α_N and α_{IM} are the shares of labour and imported goods respectively in the production, and ρ is an elasticity of substitution between these inputs.

Similarly as in the home country, the consumers and the firms abroad use the imported goods in the consumption and the production, implying an additional demand for domestic production output. The total demand for goods produced by domestic firm j therefore is

$$Y_{jt} = \left(\frac{P_{jt}^d}{P_t^d} \right)^{-\varepsilon} Y_t = \left(\frac{P_{jt}^d}{P_t^d} \right)^{-\varepsilon} \left(C_t^d + C_t^* + IM_t^* \right) \tag{1.17}$$

where C_t^* and IM_t^* represent the foreign countries' imports of domestically produced goods used for the consumption and for the production respectively.

1.3.1. Real marginal cost

Given the inputs used in the production, in the considered economy the firm is minimizing its cost function $W_t N_{jt} + P_t^m IM_{jt}$ subject to the production technology constraint (1.16). Optimal solution to the cost minimization problem leads to the relation for the firm's real marginal cost, which consists of the element that is firm-specific (reflects the firm's position on its production function) and the element that is common across the firms (it is associated with the input prices that are common for all the firms)

[6] This production technology is equivalent to $Y_{jt} = \left(\alpha_N N_{jt}^{\frac{\rho-1}{\rho}} + \alpha_{IM} IM_{jt}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}(1-\alpha)} K^\alpha$ where capital K is fixed.

$$MC_{jt}^{r}=\frac{1}{1-\alpha}Y_{jt}^{\frac{\alpha}{1-\alpha}}\left(\frac{W_t}{P_t}\left(\left(\frac{\alpha_{IM}W_t}{\alpha_N P_t^m}\right)^{\rho-1}\alpha_{IM}+\alpha_N\right)^{\frac{\rho}{1-\rho}}+\right.$$

$$\left.+\frac{P_t^m}{P_t}\left(\left(\frac{\alpha_{IM}W_t}{\alpha_N P_t^m}\right)^{1-\rho}\alpha_N+\alpha_{IM}\right)^{\frac{\rho}{1-\rho}}\right). \qquad (1.18)$$

Log-linearization of the outcome (1.18) delivers a relation that reflects the effects of the relative costs (prices) and the production output on the real marginal cost of the firm

$$\hat{mc}_{jt}^{r}=\frac{\frac{W}{P}}{\frac{W}{P}+\frac{P^m}{P}\left(\frac{\alpha_{IM}W}{\alpha_N P^m}\right)^{\rho}}\left(\hat{w}_t-\hat{p}_t\right)+\frac{\left(\frac{\alpha_{IM}W}{\alpha_N P^m}\right)^{\rho}\frac{P^m}{P}}{\frac{W}{P}+\frac{P^m}{P}\left(\frac{\alpha_{IM}W}{\alpha_N P^m}\right)^{\rho}}\left(\hat{p}_t^m-\hat{p}_t\right)+$$

$$+\frac{\alpha}{1-\alpha}\hat{y}_{jt}. \qquad (1.19)$$

As implied by (1.19) firm's real marginal cost is influenced by the level of wages relative to consumer prices and the level of import prices relative to consumer prices. The shares of labour and import cost in the total cost determine the weights of both of these factors[7]. Apart from the cost factors, the real marginal cost is also influenced by the level of firm's production output.

1.3.2. Baseline and hybrid New Keynesian Phillips curves

The introduction of the imported goods into the consumption implies that the consumer prices and the domestically produced goods' prices evolve in a different way. This has an impact on the formulation of the baseline and hybrid NKPC in the considered economy. Since it is assumed that the firms are owned by the consumers, the nominal marginal cost of the domestic firms is deflated by the consumer prices rather than by the domestically produced goods' prices. It follows that in the considered open economy the baseline NKPC is

$$\pi_t^d=\lambda\left(\hat{mc}_t^r+\hat{p}_t-\hat{p}_t^d\right)+\beta E_t\pi_{t+1}^d \qquad (1.20)$$

where $\pi_t^d=p_t^d-p_{t-1}^d$, $\lambda=\frac{(1-\theta)(1-\beta\theta)(1-\alpha)}{\theta(1+\alpha(\varepsilon-1))}$, and the hybrid NKPC is

[7] Notice that, owing to the optimal solution to cost minimisation problem, the following holds $\frac{\left(\frac{\alpha_{IM}W}{\alpha_N P^m}\right)^{\rho}\frac{P^m}{P}}{\frac{W}{P}+\frac{P^m}{P}\left(\frac{\alpha_{IM}W}{\alpha_N P^m}\right)^{\rho}}=\frac{1}{\frac{W}{P^m}\left(\frac{\alpha_{IM}W}{\alpha_N P^m}\right)^{-\rho}+1}=\frac{1}{\frac{W}{P^m}\frac{N}{IM}+1}=\frac{P^m IM}{W\,N+P^m IM}$.

$$\pi_t^d = \tilde{\lambda}\left(m\hat{c}_t^r + \hat{p}_t - \hat{p}_t^d\right) + \gamma_b \pi_{t-1}^d + \gamma_f E_t \pi_{t+1}^d \tag{1.21}$$

where $\tilde{\lambda} = \frac{(1-\omega)(1-\theta)(1-\beta\theta)(1-\alpha)}{(\theta+\omega(1-\theta(1-\beta)))(1+\alpha(\varepsilon-1))}$, $\gamma_b = \frac{\omega}{\theta+\omega(1-\theta(1-\beta))}$,

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

Utilizing the relation for the labour income share in GDP $S_t = \frac{W_t N_t}{P_t^d Y_t^*}$ and the relation for the share of imported goods in GDP $I_t^m = \frac{P_t^m IM_t}{P_t^d Y_t^*}$ as well as noticing that the relation between firms' production output and GDP is $Y_t = Y_t^* + \frac{P_t^m IM_t}{P_t^d}$ (here Y_t^* is GDP), the term that appears in the baseline and in the hybrid NKPC formulations (1.20) and (1.21) might be expressed as

$$\begin{aligned} m\hat{c}_t^r + \hat{p}_t - \hat{p}_t^d = {} & \hat{s}_t - \frac{\alpha}{1-\alpha}\frac{I^m}{1-\frac{\alpha}{1-\alpha}I^m}\hat{y}_t^* - \\ & - \left(\rho\frac{I^m}{1-\frac{\alpha}{1-\alpha}I^m}\frac{S}{S+I^m} - (\rho-1)\frac{I^m}{S+I^m}\right)\left(\hat{w}_t - \hat{p}_t^m\right) + \\ & + \frac{I^m}{1-\frac{\alpha}{1-\alpha}I^m}\left(\hat{p}_t^d - \hat{p}_t^m\right). \end{aligned} \tag{1.22}$$

Owing to the undertaken rearrangements, the outcome (1.22), which is thereafter referred to the open economy real marginal cost measure, distinguishes the role of the labour income share in pricing behaviour envisaged in the NKPC formulations. In addition to the labour income share, the price setting behaviour appears to be influenced by the real GDP and by the relative costs (prices). Pricing is now affected by the level of wages relative to import prices and the level of domestic prices relative to import prices. The specification of the open economy real marginal cost measure encompasses the measure derived for the closed economy. Once the imported goods are not considered, i.e. when $I^m = 0$, the open economy real marginal cost measure (1.22) falls into the respective proxy in the closed economy.

2. Empirical evidence

2.1. Estimation

The baseline and hybrid NKPC are estimated by undertaking the assumption of rational expectations of the firms, which reset the prices in a forward looking way. Forward looking firms use all the information available at time t so that all the expectation errors $e_{t+1} = \pi_{t+1} - E_t\pi_{t+1}$ are not correlated with the information used at the time when prices are reset. If firms use the information represented by vector of variables x_t, under rational expectations this vector is orthogonal to NKPC formulations (1.10), (1.13), (1.20) and (1.21) yielding

$$E_t\left(\left(\pi_t - \lambda m\hat{c}_t^r - \beta\pi_{t+1}\right)x_t\right) = 0, \tag{2.1}$$

$$E_t\left(\left(\pi_t - \tilde{\lambda} m\hat{c}_t^r - \gamma_b\pi_{t-1} - \gamma_f\pi_{t+1}\right)x_t\right) = 0, \tag{2.2}$$

$$E_t\left(\left(\pi_t^d - \lambda\left(m\hat{c}_t^r + \hat{p}_t - \hat{p}_t^d\right) - \beta\pi_{t+1}^d\right)x_t\right) = 0 \tag{2.3}$$

and

$$E_t\left(\left(\pi_t^d - \tilde{\lambda}\left(m\hat{c}_t^r + \hat{p}_t - \hat{p}_t^d\right) - \gamma_b\pi_{t-1}^d - \gamma_f\pi_{t+1}^d\right)x_t\right) = 0. \tag{2.4}$$

The assumption of rational expectations gives a rise to the orthogonality conditions (2.1)–(2.4), implying that the baseline and hybrid NKPC can be estimated employing the generalized method of moments.

The baseline and hybrid NKPC are estimated using quarterly data available from Bloomberg Professional, Eurostat, Organisation for Economic Co-operation and Development and Russian Federation Federal State Statistics Service. The data used in estimations is seasonally adjusted. Estimations are performed for the period starting from the first quarter of 1999 up to the fourth quarter of 2011.

The variable of quarterly inflation is constructed as a logarithmic difference of GDP deflator. The estimations are undertaken using a demeaned inflation series. This serves as a proxy for inflation's deviation from its steady state value. This variable is shown in Figure 1.

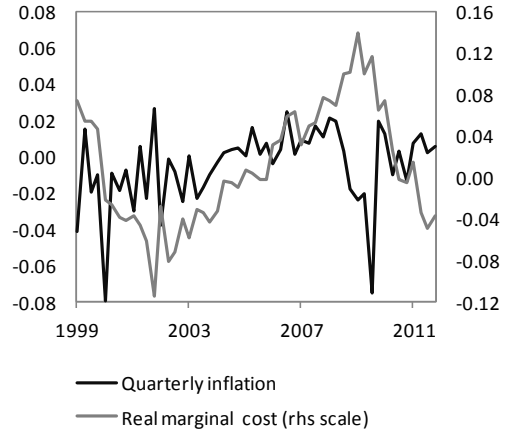
In the case of closed economy, the real marginal cost is proxied by the labour income share (a ratio of compensation of employees over nominal GDP) following equation (1.9). Its deviation from a steady state value is computed by taking a logarithmic difference between the labour income share and its sample average.

The open economy real marginal cost variable is constructed as a combination of labour income share, real GDP and relative costs/prices (formulation (1.22)). Deviations of the real GDP, the wage level, the import price level and the domestic price level from their

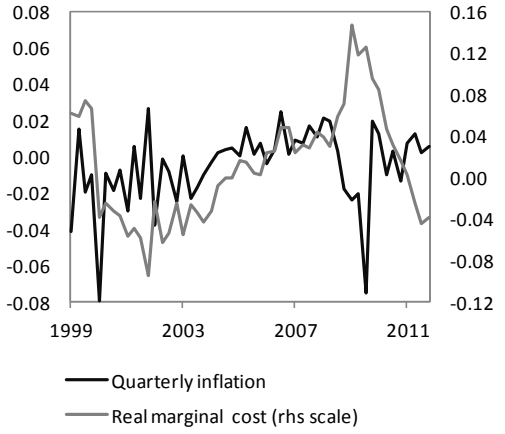
steady state values are computed as logarithmic differences between these variables and their respective smoothened counterparts. The latter ones are derived applying the Hodrick-Prescott filter. The level of wages is calculated as a ratio of compensation of employees over the number of employees. The import price level of the imported intermediate goods is not available in the national accounts, therefore the import deflator is used instead.

Figure 1. Deviation of inflation and real marginal cost from their respective steady state values

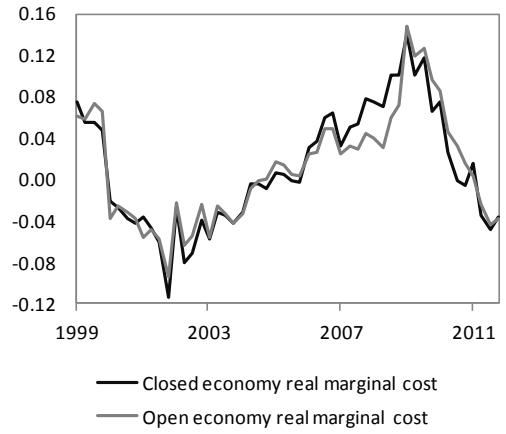
(a) inflation and closed economy real marginal cost



(b) inflation and open economy real marginal cost



(c) closed economy and open economy real marginal cost

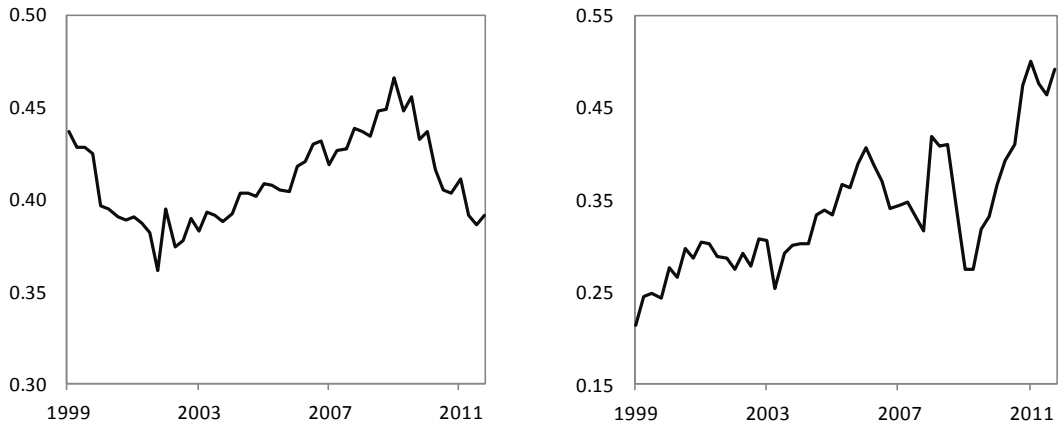


Notes: quarterly inflation is calculated as a logarithmic GDP deflator difference; real marginal cost in the closed economy is proxied by the labour income share; real marginal cost in the open economy is proxied by a combination of labour income share, real GDP and relative costs/prices; in the open economy case the price mark-up is set to 1.2, the elasticity of substitution between labour and imported goods is set to 0.5.
Sources: Eurostat and author's calculations.

The computation of the open economy real marginal cost also includes the steady state values of the labour income share and the imported intermediate goods' share in the nominal GDP. The values of the imported intermediate goods are not provided in the national accounts. As a proxy for these values the available data from the external trade statistics is

used[8]. As shown in Figure 2, the imported intermediate goods' share in the nominal GDP exhibited an upward trend during the considered period. Therefore, the time-varying imported intermediate goods' share as well as the time-varying labour income share is used in the construction of the open economy real marginal cost measure.

Figure 2. Labour income share and intermediate goods' imports share
(a) labour income share *(b) intermediate goods' imports share*



Notes: labour income share and intermediate goods' imports share are computed as ratios of the compensation of employees and the intermediate goods' imports respectively over the nominal GDP.
Sources: Eurostat and author's calculations.

Production technology parameter α, used in the measure of open economy real marginal cost, is obtained by rearranging the steady state aggregate counterpart of marginal cost formulation (1.18). Combining this formulation with the steady state relation between the firms' production output and the GDP as well as with the steady state relation for open economy price mark-up $\mu = \frac{\varepsilon}{\varepsilon - 1} = \frac{P^d}{MC^r P}$ yields

$$\alpha = 1 - \mu \frac{S + I^m}{1 + I^m}. \qquad (2.5)$$

Analogously, the parameter α in the closed economy is computed by making use of the steady state aggregate counterpart of marginal cost relation (1.7) and the steady state formulation of the closed economy price mark-up $\mu = \frac{\varepsilon}{\varepsilon - 1} = \frac{1}{MC^r}$. It follows that in the closed economy

[8] Relevant data is sourced from the external trade statistics classified according to the Broad Economic Categories. The categories assigned to the intermediate goods are: (111) primary food and beverages (mainly for industry); (121) processed food and beverages (mainly for industry); (21) primary industrial supplies not specified elsewhere; (22) processed industrial supplies not specified elsewhere; (31) primary fuels and lubricants; (322) processed fuels and lubricants (other than motor spirit); (42) parts and accessories of capital goods (except transport equipment); (53) parts and accessories of transport equipment.

$$\alpha = 1 - \mu S . \quad (2.6)$$

To compute α, as it is common in the analogous studies (Galí et al., 2001; Leith and Malley, 2007), the price mark-up μ is assumed to be fixed. The value of μ is set to 1.2. This implies that the value of price elasticity of demand ε is 6. In the open economy the parameter α is computed using the time-varying labour income share and the time-varying imported intermediate goods' share.

Similarly as in Leith and Malley (2007), the value of elasticity of substitution between labour and imported goods is also assumed to be fixed. In the computations ρ is set to 0.5.

Real marginal cost measures in the closed economy and the open economy are compared in Figure 1. These measures move quite close to each other largely driven by the labour income share variation. At the higher frequency some differences in the dynamics of these measures, however, are apparent.

The fixed values of mark-up μ and elasticity of substitution between labour and imported goods ρ affect the computation of open economy real marginal cost measure and, thus, the reduced-form estimates of the open economy baseline and hybrid NKPC. The assumed values of μ also affect the structural parameters of the closed economy and the open economy baseline and hybrid NKPC. Apart from setting the values of μ and ρ, the structural parameters of the closed economy and open economy hybrid NKPC are estimated by fixing the discount factor value. This leaves only two structural parameters to be estimated, namely, the fraction of firms that keep prices unchanged θ and the fraction of firms that adjust prices following the backward looking rule of thumb ω. In estimating the structural parameters of the hybrid NKPC the discount factor value is set to 0.98.

Following the rational expectations formulation, NKPC estimations can be carried out using the instruments dated at time t or earlier. The complete information dated at time t, however, might not be available at the moment when the firms are building up their expectations. Therefore all the estimations are performed using the lagged variables as the instruments.

Models with different instrument sets are compared using two moment selection criteria proposed by Andrews (1999). One of them is the Schwarz-based criterion, and the other one is the Hannan-Quinn-based criterion. The selected models are presented in Tables 1-2. In these models the instrument sets include four lags of inflation, four lags of unemployment rate, four lags of trading partners' inflation and one lag of oil price inflation in the United States dollars. All these variables represent deviations from their respective steady

state values. Similarly as the general price inflation, the trading partners' inflation[9] and the oil price inflation is computed as a logarithmic difference of trading partners' GDP deflator and oil price level respectively. The estimations are performed using the demeaned trading partners' inflation and oil price inflation series. Unemployment rate deviation from its steady state is computed as a difference between the unemployment rate and its smoothened counterpart, which is obtained using the Hodrick-Prescott filter.

To test the appropriateness of the instrument sets, the test of over-identifying restrictions is applied. The model is over-identified if the number of orthogonality conditions is larger than the number of parameters to be estimated, which is the case in the considered models. J-statistic is used to determine whether the set of instruments, used in the estimations, is adequate. In the selected models, as shown in Tables 1-2, the null hypothesis is not rejected indicating an appropriate use of the instruments.

Ljung-Box Q-statistic and Durbin-Watson (DW) statistic are used to test whether the residuals of the estimated models are not serially correlated. Ljung-Box test null hypothesis is rejected for all the estimated models indicating the presence of serial correlation in the residuals. Serial correlation is also suggested by the DW test. All the estimations, therefore, are performed using the heteroscedasticity and autocorrelation robust standard errors.

Estimates for the baseline NKPC indicate rather similar role of real marginal cost and expected inflation in shaping the inflation formation in the closed economy framework and the open economy framework (see Table 1). In both economy setups the real marginal cost appears to be statistically significant, however the reduced-form parameters, representing the importance of this cost, are quite low. Such kind of finding is common in the related literature.

The estimates show a highly important role of inflation expectations, as reflected by the parameter β. This parameter stands at 0.96 in the closed economy case and close to a unity in the open economy case. The estimations yield statistically significant estimates for the structural parameter representing the fraction of firms that keep prices unchanged. The estimates are 0.54 in the closed economy and 0.61 in the open economy. Such values of θ imply a price duration of around 2.2-2.6 quarters. The implied duration is lower than that found for the euro area and close to the one found for the United States as the baseline NKPC estimates show in Galí et al. (2003) under the closed economy framework.

[9] The variable representing the trading partners' inflation is based on GDP deflator data of nineteen countries accounting for more than 85 percent of Lithuania's foreign trade in goods. These countries are: Austria, Belgium, Canada, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy, Latvia, the Netherlands, Norway, Poland, Russia, Spain, Sweden, the United Kingdom and the United States. The GDP deflators are weighted by the four-quarter moving averages of shares of these countries in the Lithuania's imports and exports of goods.

Hybrid NKPC estimates show that in addition to inflation expectations the inflation is also governed by its inertia (see Table 2). The reduced-form parameters, reflecting the importance of lagged inflation, are of considerable size and statistically significant in the closed economy framework and the open economy framework. The magnitude of these parameters, however, is lower than that of the parameters corresponding to inflation expectations – one more result typical for the related literature. Unlike in the baseline case, the role of the real marginal cost is not found to be statistically significant.

Table 1. Estimates for baseline New Keynesian Phillips curve
(estimation period – 1999Q1 through 2011Q4)

	Closed economy				*Open economy*			
	reduced-form estimates		*structural estimates*		*reduced-form estimates*		*structural estimates*	
	λ	*0.057**	θ	*0.539****	λ	*0.071**	θ	*0.609****
	β	*0.963****	β	*0.963****	β	*0.997****	β	*0.998****
J-statistic		*9.257*		*9.257*		*9.427*		*9.375*
Prob. (J-statistic)		*0.681*		*0.681*		*0.666*		*0.671*
Q(1)-statistic		*19.833*		*19.833*		*19.241*		*19.436*
Prob. (Q(1)-statistic)		*0.000*		*0.000*		*0.000*		*0.000*
Q(4)-statistic		*27.437*		*27.437*		*26.878*		*27.087*
Prob. (Q(4)-statistic)		*0.000*		*0.000*		*0.000*		*0.000*
DW-statistic		*3.097*		*3.097*		*3.078*		*3.084*
Number of observations		*52*		*52*		*52*		*52*

*Notes: * indicates statistical significance at the level of 10 percent, ** indicates statistical significance at the level of 5 percent, *** indicates statistical significance at the level of 1 percent; p-values are computed using heteroscedasticity and autocorrelation robust standard errors; instruments include four lags of inflation, four lags of unemployment rate, four lags of trading partners' inflation and one lag of oil price inflation in the United States dollars; all variables represent deviations from their respective steady state values; price mark-up is set to 1.2, elasticity of substitution between labour and imported goods is set to 0.5.*
Source: author's estimations.

The hybrid NKPC analysis yields statistically significant estimates for the fraction of firms that keep prices unchanged in the closed economy case and the open economy case. These structural estimates are somewhat higher than those obtained under the baseline NKPC formulation. The estimate for the fraction of firms that keep prices unchanged in the closed economy is 0.58, and the estimate in the open economy is 0.65. The estimates imply that the price duration under the hybrid NKPC formulation amounts to around 2.4-2.8 quarters, somewhat less than implied by the estimates of Dabušinskas and Kulikov (2007). The implied price duration is again lower than that in some European countries and close to the one in the United States as indicated by the hybrid NKPC estimates in Galí et al. (2003) and Leith and Malley (2007) under the closed economy and the open economy frameworks.

The study shows rather tangible fraction of price resetting firms that adjust prices following the backward looking rule of thumb. The estimates of this fraction of firms stand at

0.29 and 0.35 under the closed economy and the open economy frameworks respectively, in line with the ones reported by Dabušinskas and Kulikov (2007). The estimates are higher than those found for some European countries and are close to the ones found for the United Sates in both the closed economy and the open economy setups (Galí et al., 2003; Leith and Malley, 2007).

Table 2. Estimates for hybrid New Keynesian Phillips curve
(estimation period – 1999Q1 through 2011Q4)

	Closed economy				*Open economy*			
	reduced-form estimates		*structural estimates*		*reduced-form estimates*		*structural estimates*	
	$\tilde{\lambda}$	*0.021*	θ	*0.580****	$\tilde{\lambda}$	*0.024*	θ	*0.647****
	γ_b	*0.333****	ω	*0.288**	γ_b	*0.360****	ω	*0.352**
	γ_f	*0.646****			γ_f	*0.625****		
J-statistic		*7.315*		*7.291*		*7.306*		*7.300*
Prob. (J-statistic)		*0.773*		*0.838*		*0.774*		*0.837*
Q(1)-statistic		*29.890*		*29.983*		*30.327*		*30.317*
Prob. (Q(1)-statistic)		*0.000*		*0.000*		*0.000*		*0.000*
Q(4)-statistic		*43.913*		*44.049*		*44.765*		*44.724*
Prob. (Q(4)-statistic)		*0.000*		*0.000*		*0.000*		*0.000*
DW-statistic		*3.397*		*3.400*		*3.410*		*3.410*
Number of observations		*52*		*52*		*52*		*52*

*Notes: * indicates statistical significance at the level of 10 percent, ** indicates statistical significance at the level of 5 percent, *** indicates statistical significance at the level of 1 percent; p-values are computed using heteroscedasticity and autocorrelation robust standard errors; instruments include four lags of inflation, four lags of unemployment rate, four lags of trading partners' inflation and one lag of oil price inflation in the United States dollars; all variables represent deviations from their respective steady state values; price mark-up is set to 1.2, elasticity of substitution between labour and imported goods is set to 0.5, discount factor is set to 0.98.*
Source: author's estimations.

The estimates for the fraction of firms that keep prices unchanged and the implied price duration stand close to the survey evidence as reported by Virbickas (2009). According to the survey, which referred to the period of 2007, most of the firms in Lithuania – around one quarter – change the prices quarterly to half yearly, approximately one fifth of the firms change the prices once a year, and somewhat more than one tenth of the firms change the prices less frequently than once a year.

2.2. Model assessment

To assess the performance of estimated models the actual inflation is compared to the model-implied – or, as called by Galí and Gertler (1999) and Galí et al. (2001), fundamental – inflation. The way to deduce the fundamental inflation rests on the work of Campbell and

Shiller (1987) who propose an approach to derive the fundamental stock prices. The fundamental inflation, separately under the baseline and hybrid NKPC, is obtained using the present value representations of current inflation. As the expected future real marginal cost is not directly observable, its measure is generated from a bivariate first order vector autoregression (VAR) of the real marginal cost and the inflation. Denoting $z_t = \left[\hat{mc}_t^r, \pi_t\right]$[10], the fundamental inflation under the baseline and hybrid NKPC is computed as

$$\pi_t = \lambda v_1' \left(I - \beta M\right)^{-1} z_t \tag{2.7}$$

and

$$\pi_t = \delta_1 \pi_{t-1} + \left(\frac{\tilde{\lambda}}{\delta_2 \gamma_f}\right) v_1' \left(I - \frac{1}{\delta_2} M\right)^{-1} z_t \tag{2.8}$$

respectively. Here v_1' is a vector retrieving the forecast of the real marginal cost, I is an identity matrix, M is a companion matrix of the estimated VAR.

Actual and fundamental inflation under the baseline and hybrid NKPC in the closed economy and the open economy is plotted in Figure 3. The models-implied inflation is generally tracking the actual inflation rather satisfactorily – the models capture the rise in inflation during the first decade and they yield lower inflation in the last years of the estimation period. The mismatches, however, are evident at the higher frequency, especially during the sudden drop in inflation in 2008–2009 – at the time when extraordinary turbulences in the economic activity occurred.

The model-implied inflation is compared to the actual inflation using three statistical measures: root mean square error (RMSE), ratio of standard deviations and correlation[11]. Computed values of the statistical measures are provided in Table 3. The fundamental inflation under the hybrid NKPC models appears to be tracking the actual inflation somewhat more closely than under the baseline NKPC models as suggested by the RMSE. The correlation between the model-implied inflation and the actual inflation is higher in the baseline NKPC framework as compared to the outcome in the hybrid framework in the closed economy, while the opposite is found in the open economy, though the correlation between the investigated series is rather low in all the frameworks. Comparing the predictions of the models in the closed economy and the open economy, the accuracy of the implied inflation, shown by the RMSE, is to some extent higher under the former economy setups. The correlation between the fundamental and the actual inflation is also higher in the closed economy cases. In terms of variation, the inflation fluctuation predicted by the baseline

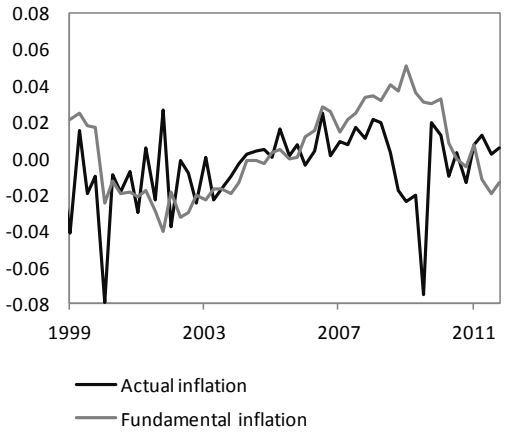
[10] In the open economy case this matrix corresponds to $z_t = \left[\hat{mc}_t^r + \hat{p}_t - \hat{p}_t^d, \pi_t^d\right]$.

[11] The latter two statistical measures, used to assess the inflation dynamics under the Calvo-type models, were suggested by Kurmann (2005).

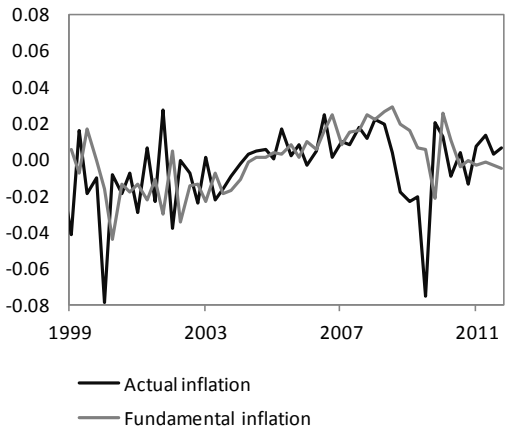
NKPC in the closed economy stands particularly closely to the actual one, while the inflation variability predicted by the other models is somewhat more different.

Figure 3. Actual and fundamental inflation

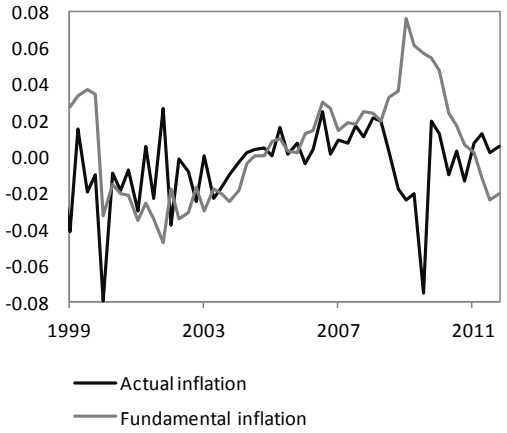
(a) actual and fundamental quarterly inflation under the baseline NKPC in the closed economy



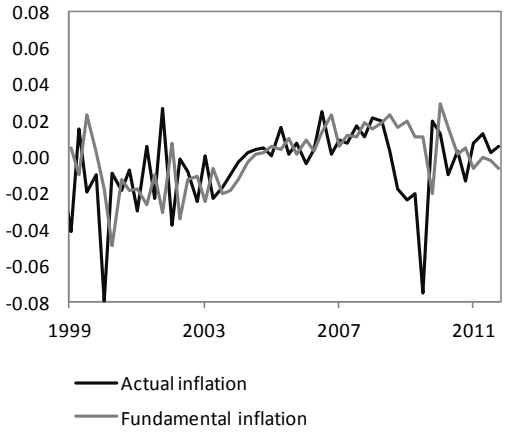
(b) actual and fundamental quarterly inflation under the hybrid NKPC in the closed economy



(c) actual and fundamental quarterly inflation under the baseline NKPC in the open economy



(d) actual and fundamental quarterly inflation under the hybrid NKPC in the open economy



Notes: quarterly inflation is calculated as a logarithmic GDP deflator difference; actual and fundamental inflation represent the deviations from their steady state values.
Sources: Eurostat and author's calculations.

Table 3. Comparison of predicted outcomes under the models of New Keynesian Phillips curve
(comparison period – 1999Q1 through 2011Q4)

	Closed economy		*Open economy*	
	baseline NKPC	*hybrid NKPC*	*baseline NKPC*	*hybrid NKPC*
Root mean square error	*0.030*	*0.025*	*0.036*	*0.026*
Ratio of standard deviations	*0.929*	*1.297*	*0.744*	*1.285*
Correlation	*0.163*	*0.146*	*0.052*	*0.074*

Notes: all the measures compare the actual inflation with the fundamental inflation; actual and fundamental inflation represent the deviations from their steady state values; ratio of standard deviations is computed as the ratio of the standard deviation of actual inflation over the standard deviation of fundamental inflation.
Source: author's calculations.

Comparison of the estimated models indicates that the predictions by the baseline NKPC are possibly superior to the ones yielded by the hybrid model in the closed economy, while the opposite appears to be evident in the open economy. Somewhat unexpectedly, the inflation generated within the open economy setups does not present a better track of the actual inflation compared to the performance of the implied inflation within the closed economy frameworks. The caveats, however, of rather simplistic data generation process, used to produce the expected future real marginal cost, and the shortcomings of the statistical measures, used to compare the model predictions, should be kept in mind.

Conclusions

The paper investigates inflation formation in Lithuania employing the NKPC framework. The paper reconstructs the baseline NKPC as well as the hybrid NKPC version, which accounts for inflation inertia, as in Galí and Gertler (1999) and Galí et al. (2001). The analysis considers the closed economy framework and the open economy framework by allowing for imported goods to be used in the consumption and the production following Leith and Malley (2007).

The models allow examining the role of real marginal cost, expected inflation and, in the hybrid NKPC case, lagged inflation in governing the current inflation. The adopted economy setups provide a basis to investigate the structural parameters that underlie the price setting.

The estimates indicate a limited role of real marginal cost in the inflation formation in Lithuania. This is a common result in the related literature. The inflation appears to be primarily driven by inflation expectations and, under the hybrid NKPC formulation, past inflation with the magnitude of parameters, reflecting the importance of lagged inflation, lower than that of the parameters corresponding to expected inflation.

The analysis yields statistically significant estimates for the fraction of firms that keep prices unchanged, a Calvo (1983) parameter used in the considered models. These estimates range between 0.54 and 0.65. This corresponds to the price duration of around 2.2–2.8 quarters, lower than that found for some European countries and close to the one found for the United States.

The conducted research provides estimates of the fraction of firms that adjust prices according to the backward looking rule of thumb, a parameter used in the hybrid NKPC formulation to account for inflation inertia. These estimates vary between 0.29 and 0.35, standing above those obtained for some European countries and close to the ones obtained for the United States.

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