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New Keynesian Phillips curve for Estonia, Latvia and Lithuania

Aurelijus Dabušinskas,
Dmitry Kulikov

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Dmitry Kulikov*

Abstract

This paper presents an empirical analysis of the inflation process in Estonia, Latvia and Lithuania within the framework of the New Keynesian Phillips Curve (NKPC) model of Galí and Gertler (1999) and Galí et al. (2001). An open economy extension by Leith and Malley (2003) and a NKPC model that explicitly incorporates energy into the average real marginal cost measure are also considered. The primary focus of the paper is to identify and compare the underlying structural parameters of the NKPC model across the three Baltic economies.

Empirical NKPC model estimates point to a limited role of the cost measure in determining inflation dynamics in the three Baltic countries. It has been found that the inflation process in these countries primarily depends on inflation expectations and past inflation rates. Price setting rigidity, as measured by the price stickiness parameter, tends to be lower than in the euro area but higher than in the US, while the share of backward-looking price setters is found to be higher on average.

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Keywords: New Keynesian Phillips Curve, inflation dynamics, open economy, GMM

Authors' e-mail addresses: aurelijus.dabusinskas@epbe.ee, dmitry.kulikov@epbe.ee

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Non-technical summary

The paper presents an empirical analysis of inflation in Estonia, Latvia and Lithuania during the period 1995–2005. The theoretical framework of the analysis is based on the New Keynesian Phillips Curve (NKPC) model of Galí and Gertler (1999) and Galí et al. (2001). The NKPC model is derived under assumptions of monopolistic competition and Calvo (1983) pricing. The first assumption enables one to treat the firms in an economy as having a degree of price control, as opposed to perfect competition where firms do not have any pricing power. The second assumption leads to nominal price stickiness: prices that are set now must be maintained for a random interval of time before they can be changed again according to the Calvo (1983) pricing model. As a result, profit-maximizing firms choose prices not only on the basis of current demand and marginal costs, but also on the basis of expected future marginal costs over a period during which they do not expect to be able to change their prices. In the context of the NKPC, this expected duration of prices can be interpreted as a measure of price stickiness, and as such is one of the two key structural parameters of the model.

The second key structural parameter in the NKPC is the share of so-called "rule-of-thumb" firms. In contrast to the profit-maximizing firms described above that set prices according to their expectations of future (real marginal) costs, it is assumed that rule-of-thumb firms set their prices on the basis of an indexation rule that relies on past inflation. The presence of such backward looking price setters implies that at the aggregate level, inflation depends not only on expected future inflation and current (real marginal) costs, but also on past inflation rates.

In addition to the Galí and Gertler (1999) and Galí et al. (2001) version of the NKPC model, which is derived for the case of a closed economy, the paper considers two extensions of the baseline model suitable for an open economy. The first open economy extension, borrowed from Leith and Malley (2003) generalizes the baseline framework, where goods are produced using domestic labour and capital only, by allowing for imported intermediate goods as a third input in domestic production. In addition to making the setup more appropriate for the Baltic economies, the modification introduces a channel through which the domestic production costs and inflation depend on the relative price of foreign goods. The second open economy extension of the NKPC model treats the imported production factor as energy, thereby emphasizing the contribution of world energy prices to domestic inflation. In the empirical analysis, the cost of energy is approximated using the price of crude oil.

All versions of the NKPC model imply a reduced-form equation, which

links current inflation to expected future inflation, past inflation and current (average) real marginal costs. The coefficients of the reduced-form NKPC model in turn depend on the structural parameters, which include the price stickiness parameter and the share of the rule-of-thumb firms. The main empirical goal of the paper is to estimate and compare these structural parameters, along with the reduced-form coefficients, for the three Baltic countries. A comparison of structural parameters is of interest because it may reveal whether differences in inflation dynamics, if any, can be attributed to some deeper, structural differences in the way individual prices are set. At the same time, examination of the reduced form coefficients allows one to compare other characteristics of inflation dynamics, such as its intrinsic persistence (measured by the contribution of past inflation to current inflation) and its sensitivity to the cyclical condition of the economy (i.e. the slope of the Phillips curve as implied by the coefficient next to the marginal cost term). All such insights have considerable policy relevance.

The empirical part of this study uses a range of advanced econometric techniques to obtain statistical estimates of both the structural and reduced-form parameters of the NKPC models for Estonia, Latvia and Lithuania. The period chosen for the empirical implementation of the models covers the years 1995 to 2005. Among the structural parameters of the model, only the coefficient of price stickiness, that is the probability of a price change within the framework of the Calvo (1983) model, and the share of backward-looking price setting firms are estimated. Because of the limited number of observations, other structural parameters are either preset to their theoretical values or the sample average.

Empirical results suggest the real marginal cost measure plays a limited role in determining inflation dynamics in the three Baltic economies, even though the open economy version of the NKPC model yields statistically significant estimates of the corresponding parameter for all three countries. It was found that the inflation process is primarily driven by inflation expectations, while the lagged inflation only feeds about 30% to 50% back into the current inflation dynamics. Price setting flexibility, as measured by the stickiness coefficient, implies an average price duration of around 4 quarters, which is lower than in the euro area but higher than in the US, see Galí et al. (2001). This result applies to all three Baltic countries, corroborating earlier price setting survey evidence for Estonia in Dabusinskas and Randveer (2006). Estimates of the share of backward-looking price setting firms are less precise and vary from 80% in Estonia to 20% in Lithuania.

Contents

1. Introduction

This paper estimates and tests the New Keynesian Phillips Curve model, henceforth abbreviated as NKPC, for Estonia, Latvia and Lithuania during the period 1995 to 2005.[1] The theoretical framework of the NKPC model is laid down in Galí and Gertler (1999) and Galí et al. (2001), where the inflation process is driven by the expected future inflation, a measure of real marginal cost, and possibly lagged inflation, where the latter is referred to as the hybrid NKPC model. As suggested in Galí and Gertler (1999) and Galí et al. (2001), real marginal costs are proxied by the labour income share, equivalently real unit labour cost, under the assumption of Cobb-Douglas technology. In addition, a modified real marginal cost measure for an open economy subject to changes in relative input prices is considered, see Leith and Malley (2003), along with a marginal cost series implied by the energy augmented production technology. These real marginal cost measures are used to estimate parameters for three empirical NKPC models using Eurostat data on the Baltic economies. A carefully implemented GMM estimator allows a statistical inference on both the structural and reduced-form parameters of the NKPC model. Among the structural parameters of the model, the coefficient of price stickiness[2] and the share of backward looking price adjustments are of particular interest. Owing to the limited sizes of available series, other structural parameters, including the discount rate, were either preset to their theoretical values or calibrated to fit the sample average.

Empirical results suggest that the real marginal cost measure plays a rather limited role in determining inflation dynamics in the three Baltic economies, even though the open economy version of the NKPC model yielded statistically significant estimates for all three countries. The inflation process is found to be driven by inflation expectations, with past inflation only feeding about 30% to 50% back into current inflation dynamics. Price setting flexibility, as measured by the stickiness coefficient, is in line with the euro area results presented by Galí et al. (2001) and implies an average price duration of around 4 quarters. This result applies to all three Baltic countries, corroborating earlier price setting survey evidence for Estonia. However, additional investigation is required to determine the effect of rapid disinflation experienced by the three

[1] A recent study of inflation dynamics in the Baltics was conducted by Masso and Staehr (2005), where they estimate reduced-form Phillips Curve models for Estonia, Latvia and Lithuania using panel data methods. In contrast to Masso and Staehr (2005), the NKPC approach in this paper is centered around a structural relationship between inflation and cost factors within the framework of nominal price stickiness. The empirical aim of this paper is to estimate and compare underlying structural parameters governing the inflation process in Estonia, Latvia and Lithuania.

[2] The probability of a price change within the framework of the Calvo (1983) model.

Baltic countries in the mid–nineties on the specification and estimation of the NKPC model.

The rest of the report is structured as follows. Section 2 introduces some key elements of the NKPC theory in closed and open economy settings. Section 3 describes empirical methodology and data, while Section 4 presents the results of the estimation. These include structural NKPC estimates corresponding to the closed economy as well as the open economy model. Section 5 concludes.

2. Theoretical framework

In this section, we lay out the theoretical foundations of the NKPC models that form the basis for the empirical analysis of our paper. As mentioned in the introduction, we consider a closed economy setup and two extensions of the model for an open economy. Although the models have very much in common, to streamline the discussion, we present them as three separate cases, emphasizing that the main differences between them arise from different assumptions about production technology in order to model openness (trade). Otherwise, the modelling frameworks are similar enough to be considered as variations of the same model. For example, all of them assume monopolistic competition in the goods market, iso-elastic demand curves for differentiated goods, the same nature of price stickiness, etc. As a consequence, the resulting closed and open economy Phillips curves have essentially the same structure but differ in terms of the real marginal cost measure, the key driving variable in the NKPC framework. Given a direct link between production technology and the corresponding real marginal cost, open economy considerations matter because, as discussed below, openness is modelled by introducing trade in intermediate goods. We begin by reviewing the characteristics that are common for all the variants of the model. Since openness is not an issue at this point, the description refers to a generic market without specifying what exactly that market is. Then we consider the closed and open economy cases by focusing on the effects that modelling openness has on the real marginal cost term.

Consider a monopolistically competitive goods market with a unit mass of firms indexed by $j \in [0, 1]$. Each firm produces a differentiated good $Y_t(j)$ and faces a downward-sloping constant-price-elasticity demand curve $Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon} Y_t$, where $P_t(j)$ is the price firm j sets for its good, Y_t is aggregate output given by $Y_t = \left[\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$ and P_t is the price level $P_t = \left[\int_0^1 P_t(j)^{1-\epsilon} dj\right]^{\frac{1}{1-\epsilon}}$. In this setup, parameter ϵ is both the constant price elasticity of demand and the elasticity of substitution between the differentiated goods.

We assume that the ability of firms to adjust prices in response to shocks is constrained as in Calvo (1983). In particular, each firm faces a constant probability $1-\theta$ of adjusting its price in any given period. This probability is independent of the history of previous price changes and implies that the expected average duration of prices is $\frac{1}{1-\theta}$. Applying the law of large numbers and log-linearizing the price index around a zero-inflation steady state, the (log) price level p_t can be written as a weighted average of the (log of) newly chosen price p_t^* and the (log) aggregate price level in the previous period:

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

Following Galí and Gertler (1999), we also assume that not all firms adjusting prices in a given period choose new prices as fully rational profit maximizers. Instead, only a fraction $1-\omega$ of the price-adjusting firms choose the new price in a fully optimal way, while the remaining price-changing firms (ω) adopt the following backward-looking rule of thumb: $p_t^b = p_{t-1}^* + \pi_{t-1}$, where p_t^b is the (log) price that the ω fraction of the backward-looking price setters choose in period t, p_{t-1}^* is the (log) average price chosen (across both fully rational and "rule-of-thumb" price setters) in $t-1$ and $\pi_{t-1} = \Delta p_{t-1}$ is the inflation rate in period $t-1$.

It can be shown that this setup implies the hybrid version of NKPC that relates the current rate of inflation to past inflation, the current expectation of future inflation and the present level of real marginal cost:

$$\begin{aligned} \pi_t &= \gamma_b\, \pi_{t-1} + \gamma_f\, \mathbb{E}_t\, \pi_{t+1} + \tilde{\lambda}\, \widehat{mc}_t^{avg}, \qquad (1) \\ \gamma_b &\equiv \frac{\omega}{\phi}, \quad \gamma_f \equiv \frac{\beta\theta}{\phi}, \\ \tilde{\lambda} &\equiv \frac{(1-\omega)(1-\theta)(1-\beta\theta)\zeta}{\phi}, \\ \phi &\equiv \theta + \omega[1-\theta(1-\beta)]. \end{aligned}$$

Here $\gamma_b \equiv \frac{\omega}{\phi}$ shows that the influence of past inflation on current inflation increases with the share of backward-looking price setters (ω), while $\gamma_f \equiv \frac{\beta\theta}{\phi}$ indicates that the importance of expected inflation increases with the degree of price stickiness, here measured by θ, the fraction of firms that do not adjust prices in period t. Finally, the relationship between current inflation and the *average* marginal cost $\widehat{mc}_t^{avg}$ (in log-deviation from the steady state) is characterized by $\tilde{\lambda} \equiv \frac{(1-\omega)(1-\theta)(1-\beta\theta)\zeta}{\phi}$, where $\phi \equiv \theta + \omega[1-\theta(1-\beta)]$.[3] Parameter ζ

[3]Note that in the case of no backward-looking price setters, the hybrid NKPC reduces to the purely forward-looking version of NKPC.

in the expression for $\tilde{\lambda}$ can be referred to as the aggregation factor that adjusts the observed *average* measure of marginal costs for the fact that marginal costs vary across firms when prices are sticky and some factors of production, say capital, is fixed (Sbordone, 2002; Gagnon and Khan, 2001). If, on the other hand, marginal costs are constant, no aggregation is required, and ζ is equal to one. Importantly, the aggregation factor is generally different for different production technologies. As a result, it will also differ between closed and open economy cases because the latter will allow for imported intermediate inputs. Next, we introduce the three variants of the NKPC model one at a time.

2.1. Closed economy model

In a closed economy setup, firms are assumed to use labour and capital according to the Cobb-Douglas technology $Y_t(j) = \tilde{A}_t N_t(j)^{1-\alpha} \overline{K}^{\alpha}$. Assuming that the stock of capital is predetermined, the production function can equivalently be written as $Y_t(j) = A_t N_t(j)^{1-\alpha}$, which is the production technology considered by Galí et al. (2001). The aggregation factor ζ that corresponds to this closed economy case with the Cobb-Douglas production technology and fixed capital is given by $\zeta = \frac{1-\alpha}{[1+\alpha(\epsilon-1)]}$, where ϵ is the price elasticity of demand as well as the elasticity of substitution between differentiated goods. Since $\mu = \frac{\epsilon}{\epsilon-1}$ is the steady state mark-up, the aggregation factor can alternatively be written as $\zeta = \frac{1-\alpha}{[1+\frac{\alpha}{(\mu-1)}]}$. Finally, it can be shown that for this economy, the average real marginal cost MC_t^{avg} is proportional to the average labour income share or, equivalently, real unit labour cost:

$$MC_t^{avg} = \frac{1}{1-\alpha}\frac{W_t N_t}{P_t Y_t} = \frac{S_t}{1-\alpha},$$

where W_t is the nominal wage rate, N_t is the labour input, P_t and Y_t are the aggregate price level and output, respectively, and $S_t \equiv \frac{W_t N_t}{P_t Y_t}$ is the labour income share. Letting lower case letters denote log-deviations from the steady state, we get:

$$\widehat{mc}_t^{avg} = \widehat{s}_t. \tag{2}$$

Finally, since $MC = \frac{1}{\mu}$ in the steady state, the technology parameter α can be calibrated by choosing the mark-up and utilizing the sample information on the labour income share as $\alpha = 1 - \mu\, S$.

2.2. Open economy extensions

When considering the open economy case, we follow Leith and Malley (2003) who allow for trade in both intermediate inputs and final consumption goods. In particular, the final consumption basket is now a CES aggregate of the bundles of domestically produced and imported varieties:

$$C_t = \left[\chi \left(C_t^d\right)^{\frac{\eta-1}{\eta}} + (1-\chi)\left(C_t^f\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}},$$

where

$$C_t^d = \left[\int_0^1 \left(C_t^d(j)\right)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

is a CES index of domestically produced brands, and $C_t^d(j)$ refers to the consumption of the good produced by domestic producer j. An analogous aggregator is assumed for the bundle C_t^f of foreign varieties $C_t^f(j)$, where $j \in [0,1]$ indexes foreign producers. It follows that the corresponding price indexes are now given by:

$$P_t = \left[\chi^\eta \left(P_t^d\right)^{1-\eta} + (1-\chi)^\eta \left(P_t^f\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

and

$$P_t^i = \left[\int_0^1 P_t^i(j)^{1-\epsilon} dj\right]^{\frac{1}{1-\epsilon}}, \quad i = d, f.$$

Trade in intermediate inputs is introduced in Leith and Malley (2003) by assuming that imported intermediate goods are substitutes for the domestic labour input as reflected in the production function:

$$Y_t(j) = \left(\alpha_N N_t(j)^{\frac{\rho-1}{\rho}} + \alpha_M M_t^f(j)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}(1-\alpha)} \overline{K}^\alpha, \qquad (3)$$

where $N_t(j)$ is the amount of labour employed by firm j and $M_t^f(j)$ is the input of imported intermediate goods (a composite analogous to C_t^f above) that domestic firm j uses in its production. Consequently, the total demand for the output of domestic firm j is given by $Y_t(j) = \left(\frac{P(j)_t}{P_t^d}\right)^{-\epsilon}(C_t^d + M_t^{f*} + C_t^{f*})$, where M_t^{f*} and C_t^{f*} are the bundles of domestic varieties which are used by foreigners as the imported intermediate input and consumption good, respectively.

In terms of NKPC equation (1) that was considered in the closed economy context above, the open economy production function (3) introduces two changes. Most importantly, it implies a new measure of marginal costs, which now depend on the domestic wage rate relative to the price of imported intermediate goods, the price of domestic intermediate goods relative to the price of imported ones and the domestic output gap (equation 5). The second difference concerns the aggregation parameter ζ. It was shown that in the closed economy model, ζ depends on the labour share $1-\alpha$, adjusted for the steady state mark-up μ, that is $\zeta = \frac{1-\alpha}{1+\frac{\alpha}{(\mu-1)}}$. The fact that the open economy production function (3) contains imported intermediate goods as an additional variable input implies that the interpretation of the parameter $1-\alpha$ is now different. As a result, the aggregation parameter ζ depends now not only on the labour share but also on the share of imported intermediate goods in GDP, see Leith and Malley (2003): $1-\alpha = \mu \frac{s+i^s}{1+i^s}$, where $\mu = \frac{\epsilon}{\epsilon-1}$ is the steady state mark-up, $s = \frac{WN}{PY}$ is the steady state labour share, and $i^s = \frac{P^f M^f}{PY}$ is the steady state share of intermediate inputs in GDP. Since this share has been constantly rising in our sample, we allowed this steady state ratio to be time-varying. This, in turn, has introduced time-variation in the aggregation parameter ζ and $\tilde{\lambda}$ (as well as α).

To present the resulting open economy NKPC model more succinctly, it is useful to introduce a new parameter ψ_t, defined as $\psi_t = \frac{1}{1-\alpha_t}$.[4] The NKPC model for the open economy is then given by:

$$
\begin{aligned}
\pi_t &= \gamma_b \, \pi_{t-1} + \gamma_f \, \mathbb{E}_t \, \pi_{t+1} + \tilde{\lambda}_t \, \widehat{mc}_t^{avg}, \qquad (4) \\
\gamma_b &\equiv \frac{\omega}{\phi}, \quad \gamma_f \equiv \frac{\beta\theta}{\phi}, \\
\tilde{\lambda} &\equiv \frac{(1-\omega)(1-\theta)(1-\beta\theta)\zeta_t}{\phi}, \\
\phi &\equiv \theta + \omega[1-\theta(1-\beta)], \\
\zeta_t &\equiv \frac{1-\alpha_t}{1+\frac{\alpha_t}{\mu-1}} = \frac{1}{\psi_t \mu - 1},
\end{aligned}
$$

where the real marginal cost term is:

$$
\begin{aligned}
\widehat{mc}_t^{avg} &= \widehat{s}_t - (\psi_t - 1)\left(\frac{i_t^s}{1+(1-\psi_t)i_t^s}\right)\widehat{y}_t - \qquad (5) \\
&- \left((1-\rho)\frac{i_t^s}{s_t + i_t^s} + \rho\left(\frac{i_t^s}{1+(1-\psi_t)i_t^s}\right)\frac{s_t}{s_t+i_t^s}\right)(\widehat{w}_t - \widehat{p}_t^f) + \\
&+ \left(\frac{i_t^s}{1+(1-\psi_t)i_t^s}\right)(\widehat{p}_t^d - \widehat{p}_t^f),
\end{aligned}
$$

and where $s_t = \frac{W_t N_t}{P_t^d Y_t}$ is the (time-varying) steady state labour share, and $i_t^s = \frac{P_t^f M_t^f}{P_t^d Y_t}$ is the (time-varying) steady state share of intermediate goods in value added. In accordance with its definition, the time-varying parameter ψ_t is

[4]Here the subscript t is meant to indicate that in the empirical implementation of the model we allow these parameters to be time-varying.

calibrated as[5] $\psi_t = \frac{1}{\mu}\frac{(1+i_t^s)}{s_t+i_t^s}$, where $\mu = \frac{\epsilon}{\epsilon-1}$ is the steady state mark-up. As before, $\widehat{x}_t$ denotes the log-deviation of $X_t = W_t, P_t^f, P_t^d, Y_t$, where $Y_t = Y_t^d - \frac{P_t^f}{P_t^d}M_t^f$ is real value added or GDP (difference between real output and real intermediate good inputs).

2.3. Oil price and marginal cost

In order to model the supply channel of oil price shocks in the framework of NKPC explicitly, we consider introducing oil (or energy more generally) as a separate factor of production. In general, it seems to be customary to model the contribution of energy to the process of production by bundling energy with capital (ECB, 2006). In our case, this approach can be adopted easily by altering the production function for differentiated goods $Y_t(j)$. For example, using a CES aggregator to combine energy and capital, we get:

$$\begin{aligned} Y_t(j) &= N_t(j)^{1-\alpha} Z_t(j)^{\alpha}, \\ Z_t(j) &= \left(\alpha_K K_t(j)^{\frac{\rho-1}{\rho}} + \alpha_E E_t(j)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \end{aligned} \tag{6}$$

where E_t denotes the energy input, entering the CES capital-energy bundle Z_t.

Naturally, in such a setup, marginal costs become a function of energy prices. However, if real marginal costs are to be expressed in terms of the labour share, as is common in the NKPC literature, then it can be shown that $\widehat{mc}_t^{avg} = \widehat{s}_t$ still holds, i.e., (log-deviations of) average real marginal costs can still be measured by (log-deviations of) the labour share. Since this result follows from the fact that the Cobb-Douglas specification is used to combine labour and the capital-energy bundle in (6), we might want to relax the unitary elasticity between the two inputs by assuming a CES aggregator instead. However, since capital is usually assumed to be given in the NKPC literature, we prefer to consider a simpler setup and assume that goods $Y_t(j)$ are produced by a CES technology in two variable inputs, labour and energy:

$$Y_t(j) = \left(\alpha_N N_t(j)^{\frac{\rho-1}{\rho}} + \alpha_E E_t(j)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}. \tag{7}$$

Under these assumptions, log-deviations in real marginal costs can be expressed as:

$$\widehat{mc}_t^{avg} = \widehat{s}_t - (1-\mu s)(\rho-1)(\widehat{p}_t^E - \widehat{w}_t), \tag{8}$$

[5]Note that this expression in Leith and Malley (2003) contains an error: the mark-up parameter μ is in the nominator of ψ_t.

where $\mu = \frac{\epsilon}{\epsilon - 1}$ is the steady state mark-up, s is the steady state labour share, and $(\widehat{p}_t^E - \widehat{w}_t)$ is the log-deviation of the price of energy relative to wages.[6]

Given the assumption that both $N_t(j)$ and $E_t(j)$ are variable inputs in (7), all producers face the same marginal costs. Since that implies $mc_t(j) = mc_t^{avg}$, the aggregator factor ζ in (1) is unity, and the NKPC becomes:

$$
\begin{aligned}
\pi_t &= \gamma_b \, \pi_{t-1} + \gamma_f \, \mathbb{E}_t \, \pi_{t+1} + \lambda \, \widehat{mc}_t^{avg}, \qquad (9)\\
\gamma_b &\equiv \frac{\omega}{\phi}, \quad \gamma_f \equiv \frac{\beta\theta}{\phi},\\
\lambda &\equiv \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\phi},\\
\phi &\equiv \theta + \omega[1 - \theta(1-\beta)],
\end{aligned}
$$

where $\widehat{mc}_t^{avg}$ is given by (8). In the discussion below, we will refer to this setup as the energy augmented NKPC, and it will be the last variant of the structural NKPC we investigate in the empirical section of the paper.

2.4. Some concerns

Having introduced the theoretical background of the paper, it is natural to ask whether this framework is appropriate for modelling inflation in the Baltic states in 1995–2005. One particularly relevant aspect of our analysis is the fact that we are dealing with transition economies, and thus the structural changes that they experienced during the sample period may raise additional difficulties for the application of the above NKPC models. Specifically, we would like to draw attention to the following three potential concerns. First, our sample partly includes the period of disinflation, a one-off event which may be qualitatively different from the usual, business-cycle-related fluctuations in inflation that the NKPC theory is meant to tackle. Another potential problem is related to the presumption that the structural price setting parameters can be treated as constants throughout the estimation period. In fact, there are quite substantial differences between inflation rates at the beginning and the end of all three country samples (see Figure 2 in Section 3), hence the stability of structural parameters, for example that of the Calvo price setting parameter θ, may be questionable. The third potential drawback of the analysis is related to the dynamics of the labour income share that in the present context serves

[6] In its structure, this setup is essentially equivalent to that employed by Galí and López-Salido (2001) and Balakrishnan and López-Salido (2002). In particular, they consider two factors of production, labour (N) and imported intermediate goods (M), and a CES technology to extend the closed economy NKPC model for the open economy case. Hence, the only difference between their model and the one we consider is different labeling of the non-labour input.

the role of a proxy for real marginal cost and is meant to capture the cyclical fluctuation in mark-ups. In contrast to this interpretation, the observed behaviour of the labour income share could largely be reflecting the structural changes that took place in the labour markets and production sectors of the Baltic economies during their transition.

As will be explained in greater detail in the next section, we estimate the NKPC models using demeaned inflation series. This implies that we assume a constant steady state inflation rate, which is equal to the sample average inflation rate. In addition, no particular adjustment is made to account for disinflation in the beginning of the sample, and as a result, high inflation episodes are treated as periods of significant deviations of inflation from its constant steady state.[7] At first glance, the nature of the inflation series we work with (see Figure 2 in Section 3) might seem to suggest that detrending would be preferable. Admittedly, given that the theoretical model is very stylized and its derivation involves linearization around a zero-inflation steady state, some ad-hoc empirical fixes may seem necessary. We decided not to do so, however, on the grounds that such an empirical fix would be quite arbitrary and not easy to square with the underlying model. First, the fact that the model is intrinsically forward looking renders detrending less attractive. Second, independent detrending of inflation and the labour share (as a proxy for real marginal cost) is hardly acceptable in the context of a model that deals specifically with the structural relationship between these two variables. Finally, detrending the inflation and labour share series would have eliminated the medium-term co-movement between these variables that is clearly noticeable in the data for Estonia and, to a lesser extent, Latvia. However, it is this tendency for the two variables to co-move that has been emphasized by Galí and Gertler (1999) and Galí et al. (2001) as evidence supporting NKPC theory. For these reasons, we have decided to work with demeaned rather than detrended inflation and labour share series in this paper.[8]

The second rather related issue is whether it is reasonable to assume, as we do in the next section, that structural price setting parameters θ and ω were stable during the entire sample period 1995–2005. Indeed, if some characteristics of price setting behaviour, such as the frequency of price changes for example, are not independent of the level of inflation, then parameter constancy might not be a sound assumption because in our samples inflation varies quite considerably. Whether this creates stability problems for our estimation depends

[7]We treat the dynamics of the forcing variable, the labour income share, in the same way, see the discussion below.

[8]Only the relative wage and price series ($\widehat{w}_t - \widehat{p}_t^f$, $\widehat{p}_t^d - \widehat{p}_t^f$, and $\widehat{p}_t^E - \widehat{w}_t$) entering expressions for real marginal costs in the open economy models were quadratically detrended. See equations (5) and (8) and Section 3 for details.

on the sensitivity of the underlying price setting parameters to the inflation rate. Unfortunately, the shortness of our data series prevents us from testing the stability of structural parameters directly. As an alternative, we can obtain some indirect insights into the nature of the link between inflation and the frequency of price changes from a calibration exercise reported by Golosov and Lucas (2003). According to their Figure 6, 22 percent of firms change prices every month when the quarterly inflation is 0.9 percent.[9] When quarterly inflation rate is 8 percent, which is about the level of inflation that prevailed in the Baltics in 1995, the share of firms changing prices is about 30 percent. According to these figures, quarterly θ declines from 0.47 to 0.34 as quarterly inflation increases from 0.9 to 8 percent. If correct, such sensitivity of θ to inflation is sufficiently high to cast doubt on our assumption that the Calvo price setting parameters have been constant throughout the estimation period.[10] We acknowledge the potential seriousness of this problem but leave its more careful statistical and economic assessment for future research, when more data become available.

Finally, concerns can also be raised in relation to our use of the labour share of income as a proxy (or a constituent of it in the case of open economy specifications) for real marginal costs. In the context of the above NKPC models, fluctuations in real marginal costs imply deviations of actual price mark-ups from the desired ones, prompting firms to adjust prices to restore the desired mark-ups. Consequently, the use of the labour income share as a proxy for real marginal costs must be supported by a belief that the observed variation in the labour income share indeed reflects deviations in mark-ups and not something else, for example, structural changes in the economy. Although the latter possibility cannot be excluded in the case of the Baltic states in the period 1995–2005, our present empirical implementation of the NKPC models leaves it out.[11] As in the case of inflation series, we use demeaned labour income shares, implicitly assuming that a constant steady state labour income share is equal to the sample average share. This implies that all deviations of the labour share of income from its sample mean are interpreted as temporary discrepancies between the desired and actual mark-ups. Although we do not investigate the possibility that the dynamics of labour income shares mirror

[9] This particular combination of data points corresponds to the evidence provided by Bils and Klenow (2004). Note that 0.9 percent quarterly (or about 3.6 percent annual) inflation is approximately the rate of inflation characteristic to the Baltics at the end of the sample period.

[10] Assume, for a moment, that the point estimate of θ is "neutral" 0.5. For this point estimate to be statistically significant at conventional significance levels, its standard error must be about 0.25 or lower. Judging from this point of view, the variation in θ implied by the Golosov and Lucas (2003) results constitutes at least half of the above standard error and thus is quite substantial.

[11] The Baltic labour income share series are plotted in Figure 2 in Section 3.

developments other than those accounted for by the NKPC framework, we deem the issue relevant and plan to address it in future research.

Interestingly, in a recent paper, Lawless and Whelan (2006) raise doubts about the way inflation is linked to the behaviour of the labour income share in empirical implementations of the NKPC models of Galí and Gertler (1999) and Galí et al. (2001). In particular, Lawless and Whelan (2006) argue that the model cannot explain the observed combination of declining inflation and labour shares in the euro area. After examining the factors underlying the decline in the labour shares using sectoral data, they conclude that the main drivers of the labour share dynamics are related to technological and labour market developments, which are not considered in the standard NKPC framework. Hence, given that transition entails both massive changes in the sectoral structure of the affected economies as well as rapid technological change, the findings of Lawless and Whelan (2006) may apply in the case of the Baltic economies as well. As mentioned above, we plan to investigate this possibility in the future.

We now turn to a description of the data and econometric methodology employed in the current analysis.

3. Data and econometric methodology

Quarterly macroeconomic series for Estonia, Latvia and Lithuania have been sourced from the Eurostat database. Prior to estimation, all series are adjusted for seasonality using the filter $(1 - \mathbb{L}^4)$, where $\mathbb{L}$ denotes the lag operator. All empirical results presented in Section 4 are based on seasonally adjusted inflation and marginal costs series, since the theory of the NKPC is not designed to explain seasonal variations in inflation rates.

Inflation is constructed by taking logarithmic differences of the GDP deflator series, where the latter is computed as the ratio of nominal to real GDP series for each of the three Baltic economies.[12]

The average real marginal cost variable mc_t^{avg} in the closed economy model of Galí et al. (2001) is measured using the labour income share according to equation (2). The labour income share is defined as a ratio of compensation of employees to GDP excluding indirect taxes. Though it would be necessary to additionally adjust the labour income share using data on the proportion of

[12] A number of other inflation measures is available for the three Baltic economies, including the CPI based inflation and its various sub-aggregates. However, the NKPC theory in Section 2 is explicitly based on the production side of the economy, making the GDP deflator based inflation series most appropriate for an application of this theory.

self-employed in total employment figures, the lack of appropriate series for Latvia prevents us from doing so. In order to keep cross-country results comparable, this adjustment is not done for Estonia and Lithuania. However, it is unlikely that empirical results will be substantially affected by this adjustment.

The output gap series needed in the open economy model of Leith and Malley (2003) are constructed from the real GDP series by means of the Hodrick-Prescott filter. The latter is used to approximate potential output of the target economies, after which a logarithmic difference of the actual and estimated potential output is computed. Results from Vahter (2006) suggest that differences between a variety of methodologies for estimating the output gap are likely to be minor in the Estonian case. The study by Jakaitiene (2006) shows a relatively large variation of the output gap estimates in Lithuania across different statistical methodologies in mid-1990s, but the differences become minor during the later periods. While there are no similar studies for Latvia, there is a high degree of confidence that the adopted method of estimating the output gap produces reasonable results for all three Baltic countries.

The empirical implementation of the Leith and Malley (2003) model also requires data on wages and domestic prices relative to foreign prices, refer to equation (5). These are calculated as quadratically de-trended logarithmic differences of nominal wages and the import price deflator, and GDP deflator and the import price deflator respectively for Estonia, Latvia and Lithuania. In addition, i_t^s and s_t variables in equation (5) are an adjusted share of real imports to real GDP and the labour income share respectively, both are quadratically smoothed. Since detailed data on the imports of intermediate goods is not available for the full length of our sample, a simple adjustment of i_t^s is done by assuming that 50% of total imports are used as intermediate factors in production in each of the three Baltic economies.

In the energy augmented NKPC model of subsection 2.3 the proxy for an energy price $\hat{p}_t^E$ is given by the international oil price in US dollars, which is then converted into local currencies using the corresponding US dollar exchange rate.

Figure 1 displays three average real marginal costs measures corresponding to the closed economy model of Galí et al. (2001), the open economy model of Leith and Malley (2003) and the energy augmented NKPC model of subsection 2.3 for each of the three Baltic countries. All marginal costs series exhibit similar long-run dynamics driven by the labour income share, but there are noticeable differences in the short-run fluctuations that are explained by the open economy and energy adjustments as detailed in equations (4) and (9).

Figure 2 depicts the logarithm of labour income share and the inflation series for Estonia, Latvia and Lithuania. Note that the two series move together

Figure 1: $\{mc_t^{avg} : 1 \leq t \leq T\}$ series for Estonia, Latvia and Lithuania (top to bottom).

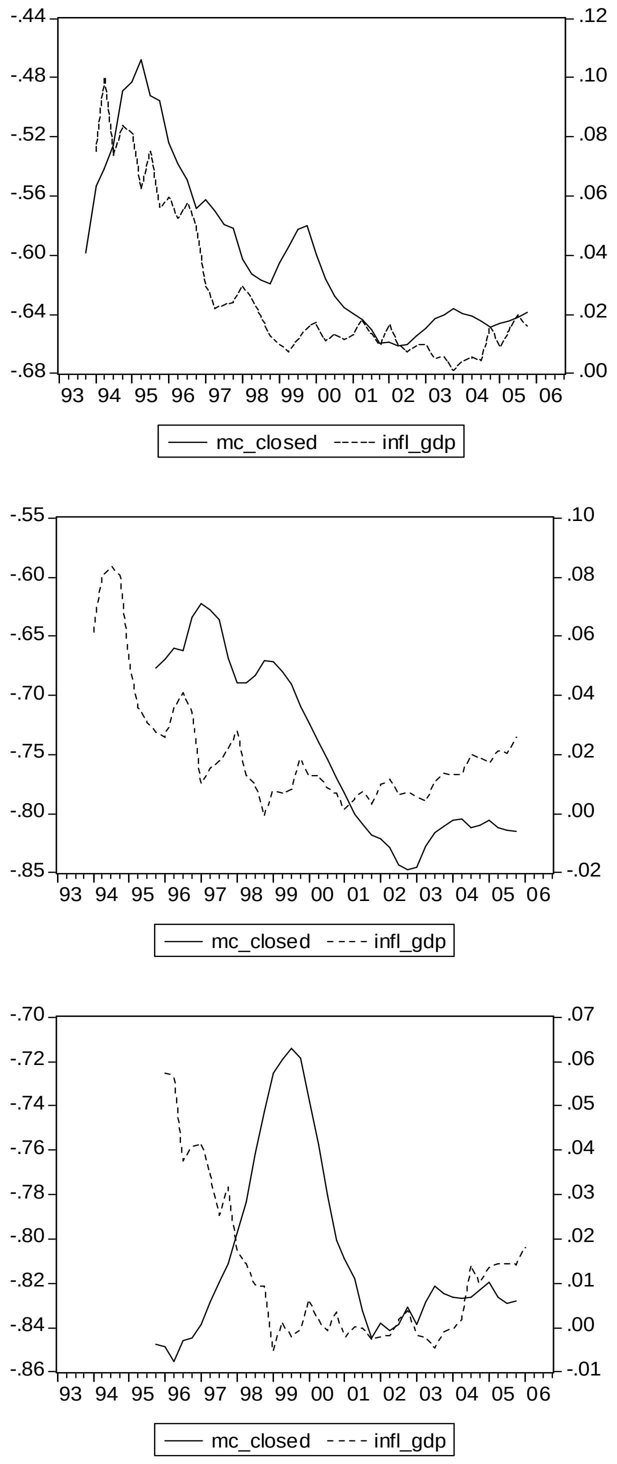

Figure 2: Inflation and logarithmic labour share series for Estonia, Latvia and Lithuania (top to bottom).

in Estonia and Latvia, whereas the long-term dynamics of the labour income share in Lithuania is markedly different. Galí et al. (2001) find that the labour income share and inflation in many OECD countries co-move over a period of 30 years, including periods of high inflation during the oil price shocks of 1970s. However, the underlying theory of the NKPC is about a short- to medium-term response of inflation to the average real marginal costs in an environment of sticky prices; thus, it is important to focus on the effects of the short- to medium-term response of the inflation to the labour income share. Again, looking at Figure 2, the dynamics of the labour income share and inflation in Lithuania in the second half of the nineties appears to be the opposite. However, during the last five years the labour income share and inflation in Lithuania move together in accordance with the NKPC theory.

The estimation of the NKPC model (1) and its variants is carried out using the GMM estimator. For an introductory exposition of the GMM estimator refer to Hamilton (1994). Let the column vector $\boldsymbol{x}_t$ consist of variables that are assumed to be uncorrelated with the expectation error $\epsilon_t := \pi_{t+1} - \mathbb{E}_t\,\pi_{t+1}$. Then the conditional expecation term $\mathbb{E}_t\,\pi_{t+1}$ in equation (1) can be substituted for $\pi_{t+1} - \epsilon_t$, implying the following moment restriction:

$$\mathbb{E}_{\boldsymbol{x}_t} \gamma_f\,\pi_{t+1} - \pi_t + \gamma_b\,\pi_{t-1} + \tilde{\lambda}\,mc_t^{avg} \;= 0\,. \tag{10}$$

This moment restriction is the basis for GMM estimation of model (1). Define $\boldsymbol{g}_t(\gamma_f, \gamma_b, \tilde{\lambda}) := (\gamma_f\,\pi_{t+1} - \pi_t + \gamma_b\,\pi_{t-1} + \tilde{\lambda}\,mc_t^{avg})\boldsymbol{x}_t$. Then the sample counterpart of (10) is given by $\boldsymbol{g}_T(\gamma_f, \gamma_b, \tilde{\lambda}) := \frac{1}{T}\sum_{t=1}^{T}\boldsymbol{g}_t(\gamma_f, \gamma_b, \tilde{\lambda})$, where T is the sample size. Let $\boldsymbol{S}_T(\gamma_f, \gamma_b, \tilde{\lambda})$ be a positive definite estimate of the variance-covariance matrix of $\boldsymbol{g}_t(\gamma_{0f}, \gamma_{0b}, \tilde{\lambda}_0)$, where γ_{0f}, γ_{0b} and $\tilde{\lambda}_0$ are population parameters of the NKPC model. GMM estimation of the NKPC model proceeds by minimizing the following criterion function with respect to γ_f, γ_b and $\tilde{\lambda}$:

$$Q_T(\gamma_f, \gamma_b, \tilde{\lambda}) = \boldsymbol{g}_T^{\mathrm{t}}(\gamma_f, \gamma_b, \tilde{\lambda})\,\boldsymbol{S}_T^{-1}(\gamma_f, \gamma_b, \tilde{\lambda})\,\boldsymbol{g}_T(\gamma_f, \gamma_b, \tilde{\lambda})\,.$$

In general, all elements of the criterion function $Q_T(\gamma_f, \gamma_b, \tilde{\lambda})$ depend on the parameters, and minimization is carried out by simultaneous updating of $\boldsymbol{g}_T(\gamma_f, \gamma_b, \tilde{\lambda})$ and $\boldsymbol{S}_T(\gamma_f, \gamma_b, \tilde{\lambda})$. This corresponds to the "continuous-updating GMM estimator" in the terminology of Hansen et al. (1996). The weighting matrix $\boldsymbol{S}_T(\gamma_f, \gamma_b, \tilde{\lambda})$ in the empirical NKPC models of Section 4. is estimated using the Newey and West (1987) method and the Bartlett kernel, with the bandwidth proportional to $\sqrt{T}$.

The coefficients γ_f, γ_b and $\tilde{\lambda}$ in equation (1) are complicated non-linear functions of the structural parameters θ, ω, β, α and ϵ of the NKPC model. Since the empirical aim of this paper is to estimate and compare structural parameters of the model in the three Baltic economies, minimization of the GMM criterion function $Q_T(\gamma_f, \gamma_b, \tilde{\lambda})$ is carried out in terms of the structural parameters by mapping them into the reduced-form coefficients γ_f, γ_b and $\tilde{\lambda}$ according to (1), (4) and (9). As noted in Ma (2002), the GMM criterion function for the hybrid NKPC model might have several local minima in the space of the structural parameters. In order to avoid corresponding identification issues, in the empirical NKPC models of Section 4 the discount rate β is set to 0.98, the demand elasticity parameter ϵ to 6, leading to the assumed average mark-up of 20%, the CES elasticity of production factors substitution ρ to 0.5, and the technology coefficient α is set to fit the sample average labour share $\bar{S}_T$ according to $\hat{\alpha}_T = 1 - \frac{\epsilon}{1-\epsilon}\bar{S}_T$, leaving only two freely varying structural parameters θ and ω. The latter are further restricted during the estimation to lie in the unit interval, as required by the theory.

The selection of instruments $\boldsymbol{x}_t$ for the GMM estimation of model (1) and its variants has been influenced by Nason and Smith (2005). Apart from the usual rank and order conditions for instrumentation in the GMM estimator of the NKPC model, they present results about the minimal sets of instruments needed to identify parameters of the model under a set of plausible assumptions on the average real marginal cost process $\{mc_t^{avg} : 1 \leq t \leq T\}$. These results are taken into account when selecting instrumentation for empirical NKPC models in Section 4.

Nason and Smith (2005) have remarked that the identification of γ_f, γ_b and $\tilde{\lambda}$ in the NKPC model hinges on sufficient dynamics being present in $\{mc_t^{avg} : 1 \leq t \leq T\}$, and is not dependent on large instrument sets. According to their results, only two out of three reduced-form parameters of the NKPC model are identified by the GMM estimator when the average real marginal cost process $\{mc_t^{avg} : 1 \leq t \leq T\}$ follows a simple random walk. Hence, Nason and Smith (2005) recommend reducing the number of estimated parameters to a minimum in empirical applications of the NKPC model.

In addition, by removing seasonality in the data as mentioned at the start of this section, there is no need for a long augmentation in $\boldsymbol{x}_t$ to account for possible seasonal dynamics in the model residuals. Hence the choice of instruments is guided by parsimony and results in Nason and Smith (2005). A limited sensitivity analysis of the estimated models with respect to instrument selection has also been conducted — the results are available from the authors on request.

4. Empirical results

The GMM estimation of the NKPC models is based on equations (1), (4) and (9), where the average marginal cost measures are computed according to Gali, Gertler and Lopez-Salido (2001) for the closed economy case, Leith and Malley (2003) for the open economy case and equation (8) for the energy augmented NKPC model. The empirical aim of this study is to identify and compare structural parameters of the NKPC model in the three Baltic economies; that is, the coefficient of price stickiness θ, the proportion of the backward-looking price setters ω, the discount rate β, the technology parameters α and ρ and the demand parameter ϵ. As discussed in Section 3, only θ and ω are estimated, other structural parameters are kept fixed at theoretically plausible levels or fitted to sample averages. These fixed parameters are reported in the tables below, their corresponding standard errors are missing. Reduced-form parameter estimates of γ_b, γ_f and $\tilde{\lambda}$ are also reported in the tables, their standard errors are computed using the delta method.

All empirical NKPC models are estimated using the data series described in Section 3. Sample sizes vary from 44 observations for Estonia, to 38 for Latvia and Lithuania. Sample start and end dates are reported in the headers, GMM estimator instrumentation for each country is described in the notes below each table.

The estimated parameters of the three NKPC models, together with their standard errors and some test statistics, are shown in Tables 1 to 3. The J-test of overidentifying restriction shows an adequate fit of all models to the data. There is a remarkable degree of similarity in estimated θ coefficients across the three Baltic countries. For the closed and open economy NKPC models, the estimated price rigidity parameter is around 0.75, implying that the expected price duration is around one year. This is lower than the average euro area coefficient, but higher than the US parameter as reported in Galí et al. (2003) for the closed economy case. On the other hand, there is larger degree of uncertainty about parameter ω, as evident from its relatively wide confidence intervals and variation acrross models in Tables 1 to 3. In general, the estimated proportion of backward lookers is highest in Estonia, amounting to 50–80%, whereas in Lithuania it falls into the interval 20–40%. Galí et al. (2003) report an estimated ω of around 30% for the euro area and the US.

A common result across almost all estimated models in Tables 1 to 3 is that coefficient γ_f corresponding to the expected inflation in the NKPC model is larger than γ_b. The estimated range of γ_f is 0.5 to 0.6, while for γ_b it is about 0.3 to 0.5. This result suggests that the inflation process in the Baltic area is driven primarily by inflation expectations. The relative importance of forward

Table 1: Empirical NKPC models for Estonia, 1994.4 to 2005.3

	Model (1)		*Model (4)*		*Model (9)*	
			Structural parameters			
θ	0.6830	(0.1716)	0.7498	(0.0516)	0.8632	(0.1251)
ω	0.7916	(0.2456)	0.5252	(0.2027)	0.7996	(0.1995)
α	0.3399		0.1661		0.3399	
			Reduced–form parameters			
γ_b	0.5408	(0.0625)	0.4145	(0.1077)	0.4849	(0.0833)
γ_f	0.4573	(0.0608)	0.5799	(0.1043)	0.5130	(0.0810)
$\tilde{\lambda}$	0.0037	(0.0083)	0.0113	(0.0044)	0.0026	(0.0045)
J-test	1.3514		1.4061		1.1141	
Skewness	-0.2230		-0.1765		-0.0717	
Kurtosis	4.2761*		4.3286*		4.2088	

Notes: Instruments include three lags of inflation, and the current and lagged value of marginal costs series. Newey and West (1987) asymptotic standard errors are shown in the parentheses next to the estimated coefficients. Structural parameters β, μ and ρ are fixed at 0.98, 1.2 and 0.5 respectively during the estimation, α is calibrated to fit the sample average. The asterisks next to the test statistics indicate significance at the 5% level. Skewness and kurtosis statistics and their standard errors are computed as in Jarque and Bera (1987).

Table 2: Empirical NKPC models for Latvia, 1996.2 to 2005.3

	Model (1)		*Model (4)*		*Model (9)*	
			Structural parameters			
θ	0.7404	(0.0910)	0.7670	(0.0403)	0.8780	(0.0401)
ω	0.5943	(0.1935)	0.4010	(0.1443)	0.3856	(0.1580)
α	0.4304		0.2941		0.4304	
			Reduced–form parameters			
γ_b	0.4483	(0.0957)	0.3452	(0.0932)	0.3068	(0.0911)
γ_f	0.5472	(0.0929)	0.6469	(0.0902)	0.6846	(0.0878)
$\tilde{\lambda}$	0.0039	(0.0032)	0.0085	(0.0011)	0.0083	(0.0054)
J-test	2.0675		0.9532		1.1072	
Skewness	-0.3311		0.0777		0.2859	
Kurtosis	3.9291		3.7271		3.7812	

Notes: Instruments include three lags of inflation, and the current and lagged value of marginal costs series. Newey and West (1987) asymptotic standard errors are shown in the parentheses next to the estimated coefficients. Structural parameters β, μ and ρ are fixed at 0.98, 1.2 and 0.5 respectively during the estimation, α is calibrated to fit the sample average. The asterisks next to the test statistics indicate significance at the 5% level. Skewness and kurtosis statistics and their standard errors are computed as in Jarque and Bera (1987).

Table 3: Empirical NKPC models for Lithuania, 1996.3 to 2005.4

	Model (1)		*Model (4)*		*Model (9)*	
			Structural parameters			
θ	0.7038	(0.0705)	0.7541	(0.0320)	0.8429	(0.0443)
ω	0.2104	(0.0937)	0.3846	(0.0964)	0.3153	(0.1371)
α	0.4655		0.2671		0.4655	
			Reduced–form parameters			
γ_b	0.2309	(0.0751)	0.3395	(0.0613)	0.2735	(0.0933)
γ_f	0.7569	(0.0726)	0.6523	(0.0593)	0.7165	(0.0901)
$\tilde{\lambda}$	0.0128	(0.0083)	0.0109	(0.0031)	0.0162	(0.0076)
J-test	1.9739		3.1145		3.1139	
Skewness	0.3985		0.2755		0.5548	
Kurtosis	3.4564		3.2535		3.5036	

Notes: Instruments include two lags of inflation, the current and lagged values of marginal costs, and a current value of the output gap series. Newey and West (1987) asymptotic standard errors are shown in the parentheses next to the estimated coefficients. Structural parameters β, μ and ρ are fixed at 0.98, 1.2 and 0.5 respectively during the estimation, α is calibrated to fit the sample average. The asterisks next to the test statistics indicate significance at the 5% level. Skewness and kurtosis statistics and their standard errors are computed as in Jarque and Bera (1987).

inflation relative to its lag is a rather common result in the empirical NKPC literature, see discussion in Walsh (2003) on page 243.

The importance of the cost factor in determining the inflation process in the three Baltic economies is reflected by parameter $\tilde{\lambda}$. It is found to be relative large and statistically significant in the open economy NKPC model (4) for all three countries, whereas in the baseline closed economy model (1) and the energy augmented model (9) the estimated $\tilde{\lambda}$ is not significant, see Tables 1 to 3. Therefore, the overall role of marginal costs in driving inflation in the three Baltic economies remains unclear. Likewise, Galí et al. (2003) report mixed evidence on the statistical significance of $\tilde{\lambda}$ for both the euro area and the US[13].

[13] In order to assess the degree to which the statistical significance of estimated $\tilde{\lambda}$ depends on the choice of estimator and mathematical properties of the model, a limited Monte Carlo study has been conducted as described below. 300 samples of $1 \leq t \leq 100$ were generated using the following system of equations:

$$\pi_t = \delta_1 \, \pi_{t-1} + \frac{\tilde{\lambda}}{\gamma_f \, (\delta_2 - 1)} mc_t^{avg} + u_{1t} \, , \qquad mc_t^{avg} = mc_{t-1}^{avg} + u_{2t} \, ,$$

where $(u_{1t}, u_{2t})^{\mathrm{t}}$ are standard independent Gaussian errors, δ_1 and δ_2 are the roots of the forward solution of equation (1), see Nason and Smith (2005). The structural parameters β, θ, ω, μ and α were chosen as estimated by Galí et al. (2003) for the euro area. It was found that both Monte Carlo and GMM estimated standard errors of $\tilde{\lambda}$ were too large relative to the point value of $\tilde{\lambda}$ implied by the structural parameters. Therefore, conditioned on this particular

Graphical model diagnostics, available from the authors on request, show that the models fail to account for the full dynamics of the inflation process, as there is some unexplained autocorrelation in the residuals. This, however, is not entirely unexpected because the NKPC models are strongly theory-driven. The standard errors reported in Tables 1 to 3 are autocorrelation and heteroscedasticity consistent, see Newey and West (1987). Despite some remaining autocorrelation, an overall fit of the estimated inflation process to the actual data is generally good.

Empirical energy augmented NKPC model estimates for Estonia, Latvia and Lithuania are displayed in the last column of Tables 1 to 3. Compared to the benchmark closed economy models, both the estimated price stickiness parameter θ and the share of backward looking price setters ω are higher across the three Baltic countries. As before, inflation dynamics in Estonia, Latvia and Lithuania is found to be dominated by inflation expectations rather than the cost factor.

5. Conclusions

The paper presents an empirical analysis of the inflation process in Estonia, Latvia and Lithuania within the framework of the NKPC model of Galí and Gertler (1999) and Galí et al. (2001). The open economy extension of Leith and Malley (2003) and a NKPC model that explicitly incorporates energy into the average marginal cost measure are also considered. The primary focus of the paper is to identify the underlying structural parameters of the model for the three Baltic countries.

Empirical NKPC model estimates point to a limited role of the cost measure in determining inflation dynamics in Estonia, Latvia and Lithuania, even though statistically significant results are reported for the open economy version of the model. The inflation process is found to depend mainly on inflation expectations and lagged inflation. The latter feeds about 30% to 50% to the current inflation dynamics. Price setting flexibility, as measured by the stickiness coefficient, is in line with the euro area results of Galí et al. (2001) and implies an average price duration of around 4 quarters. This result applies to all three Baltic countries. The estimates of the share of backward-looking price setters are less precise and vary from 80% in Estonia to 20% in Lithuania.

Additional investigation is required to determine the effects of rapid disinflation experienced by the three Baltic countries in the mid-nineties on the specification and estimation of the NKPC model.

Monte Carlo setup, statistical insignificance of estimated $\tilde{\lambda}$ in Tables 1 to 3 may not imply that the cost factor has no impact on inflation in the empirical NKPC models.

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