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An Analysis of the Domestic Inflation Rate Dynamics and the Phillips Curve

Ivo Krznar

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**An Analysis of the Domestic Inflation
Rate Dynamics and the Phillips Curve**

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Abstract

This paper estimates the New Keynesian Phillips Curve in order to describe the structural characteristics of the Croatian economy explaining the dynamics of the domestic inflation rate. The results of the estimation of numerous specifications of the Phillips Curve show that a hybrid version of the New Keynesian Phillips Curve provides a better explanation of the dynamics of the domestic inflation rate than other forms of the model. The main determinants of trends in the domestic inflation rate are past and expected inflation and the real marginal cost of production, which in addition to the labour share, also includes foreign imported prices. The values of the estimated parameters of the hybrid New Keynesian Curve show that the expected inflation rate plays a much more significant role in determining current prices than past inflation. In addition, the estimated parameter of the frequency of price change is low, with enterprises changing prices on average every eight quarters.

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Keywords:

the New Keynesian Phillips Curve, inflation rate, open economy, real marginal cost of production, GMM estimator

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1 Introduction

This paper analyses the domestic inflation rate in the light of the Phillips Curve derived from the structural new Keynesian model. Two forms of the model are analysed: a closed-economy model as in Gali and Gertler (1999) and an open-economy model as in Balakrishnan and López-Salido (2002). The paper aims to describe the structural characteristics of the Croatian economy accounting for inflation rate dynamics in the period from 1998 to mid-2010. The structural parameters describing these characteristics are the functions of parameters of the reduced form of the New Keynesian Phillips Curve (NKPC).

In contrast with the Old Phillips Curve, the NKPC explains inflation rate dynamics by emphasising expectations of future inflation rates in addition to the past inflation rate. Furthermore, instead of economic activity indicators (for example, the GDP gap or unemployment rate) the NKPC emphasises the real marginal cost of production (marginal cost) as one of the main determinants of the inflation rate. Three determinants of the inflation rate result exclusively from the structure from which the NKPC is derived, that is, from the optimal behaviour of enterprises operating under conditions of monopolistic competition and nominal rigidities such as sticky prices.

Along the lines of similar studies, this paper analyses two main issues. The first is to what extent the openness of the Croatian economy, given a large share of intermediate goods and raw materials imported by Croatian enterprises and their prices, affects the domestic inflation rate. The second is to what extent the past inflation rate, relative to the expected inflation rate, affects the dynamics of the domestic inflation rate.

The analysis of the inflation rate according to the new Keynesian model is preceded by an estimation of an old, *ad hoc* Phillips Curve. The results of the OLS estimation of the Old Phillips Curve suggest that an economic activity indicator, e.g. the GDP gap, cannot by itself explain the dynamics of the domestic inflation rate. In other words, the Old Phillips Curve does not exist. However, the estimated *ad hoc* model of the Phillips Curve, which includes foreign imported prices, shows a strong positive correlation between the domestic and foreign inflation rates, proving that foreign factors play an important role in explaining the dynamics of domestic prices. This empirical fact was taken into account in the analysis of the inflation rate when considering the structural model.

Most analyses of the NKPC relate to developed, closed economies wherein the labour share is a good indicator of marginal cost, which is closely linked with the inflation rate. The labour share as a measure of marginal cost derives from the assumption of the Cobb-Douglas production function. The problem with the labour share as a measure of real marginal cost in a small and open economy like that of Croatia is that it includes only a part of the total cost of production, excluding the cost of the raw materials and capital goods that enterprises in such a small and open economy import from abroad. The central section of the paper shows that real marginal cost developments in an open economy, when the production function is changed to account for imported intermediate goods, result from two different factors: the labour share, as the only factor determining real marginal cost in a closed economy, and the ratio of imported product prices to nominal wages. Based on two different real

marginal costs, estimations were made of the closed-economy NKPC and the open-economy NKPC in order to examine whether the New Keynesian Phillips Curve, which also includes the costs of imported production inputs, explains domestic inflation better than a model that includes labour as the only production factor (or assumes the Cobb-Douglas production function). The results of the GMM estimation of the two mentioned models show that the labour share as the only factor of marginal cost cannot explain the dynamics of the domestic inflation rate: the results of the estimated models support the existence of an open-economy NKPC. This result is consistent with previous research on the dynamics of the domestic inflation rate by Krznar and Kunovac (2010), who emphasise foreign prices as the key determinant of the domestic inflation rate.

In addition to the relevance of foreign prices, also analysed is the relative importance of past inflation in relation to expected inflation, as these are two key determinants of the current inflation rate. The results of the estimated open-economy NKPC refute the original version of the NKPC which, in addition to real marginal cost, explains inflation dynamics exclusively by the expected inflation rate. This conclusion points to the persistence of the domestic inflation rate, that is, to the significance of past inflation rate trends in explaining the current inflation rate. However, expected inflation turned out to be much more important for the dynamics of the current inflation rate than the past inflation rate dynamics: the estimated coefficient for the past inflation rate is almost half as large as the estimated parameter for expected inflation. Therefore, the hybrid version of an open-economy NKPC provides the best possible explanation for the behaviour of the domestic inflation rate.

The NKPC is based on microeconomic foundations. Consequently, the parameters of the reduced model (with past inflation, expected inflation and marginal cost) have a structural economic interpretation. The conclusion that expected inflation has a relatively more important role than past inflation thus derives from a low estimated share of enterprises that cannot change prices. In addition, the estimated Calvo parameter, which describes the degree of price rigidity or stickiness, ranges from 0.87 to 0.92 in the estimated original NKPC and from 0.87 to 0.89 in the estimated hybrid version of the NKPC. Such parameter values show that, once set, prices in Croatia on average remain unchanged for 8 (the hybrid version of the NKPC) to 12 quarters (the original NKPC). The high degree of price stickiness in Croatia differs from the estimated value of the same parameter in similar papers on the inflation rate dynamics in open and closed economies. In an open economy with a high foreign price volatility, prices are expected to change faster on average. The analyses of markup and the analyses of missing factors that have a significant impact on marginal cost (Gali and Gertler, 1999) are definitely a valuable attempt to investigate further the structural characteristics that might increase the frequency of price change.

The remaining part of the paper is organised as follows: the next section provides an overview of domestic and foreign, theoretical and empirical literature on the research on the inflation rate dynamics in the light of the Phillips Curve. In the third section, the Old Phillips Curve is estimated in order to demonstrate that in Croatia it does not exist. The achieved result prompts the NKPC estimation presented in the fourth section, which contains the derivation and estimation of the original and hybrid version of the NKPC, as well as a comparison of the quality of the two models regarding the *strength* of the explanation of inflation rate trends, based on the calculation of the measure of fundamental inflation. Furthermore, a comparison of an original and hybrid version of the NKPC provides for an analysis of the relative meaning of the labour share and foreign prices for the inflation rate dynamics. Finally, the sensitiveness of the results of the model estimation relative to the measure of foreign prices is analysed. The last section presents the conclusions of the paper and guidelines for future research on domestic inflation dynamics.

2 A literature overview

2.1 Foreign research

This section gives an overview of the historical development of the Phillips Curve, commenced by a Phillips paper from 1958.¹ This is followed by two critiques of Phillips analysis. The first contributed to the development of the *accelerationist Phillips curve*, according to which inflation accelerates when unemployment is less than the natural rate (Friedman, 1968 and Phelps, 1967). The second critique, related to the estimation of the Phillips curve and treatment of expectations in the model (Sargent, 1971 and Lucas, 1976), enhanced the development of the modern New Keynesian Phillips Curve. A brief overview of the historical development of the Phillips Curve is necessary in order to emphasise the value added of this paper in comparison with the previous research on the domestic inflation rate summarised in the following section. In addition, an overview of foreign research will indirectly point to all the problems related to the analyses of the Phillips Curve in Croatia so far.

Phillips shows in his paper that there is a strong negative relation between the unemployment rate, as an economic activity indicator, and the rate of change of wages in Great Britain (the original Phillips Curve).² Based on the Phillips idea on the interconnection between unemployment and wage changes in Great Britain, Samuelson and Solow (1960) show a strong link between the unemployment rate and the inflation rate (which is equal to the markup on the rate of change of wages) in the US. Theoretical reviews, primarily those related to the lack of expectations modelling in the model (Friedman, 1968 and Phelps, 1967) and the problems related to the “break” of the link between the inflation and unemployment rates in the period of high inflation and low unemployment during the oil shock of the 1970s (which is in contrast with the conclusions presented in the Phillips Curve) led to a modification of the original Phillips idea.

Friedman and Phelps emphasise the importance of real wage expectations (which are proportional to inflation rate expectations) in the wage bargaining process between employers and trade unions. The trade-off between the inflation rate π_t and the unemployment rate U_t in the original Phillips Curve

$$\pi_t = \alpha U_t \quad (1)$$

is thus replaced by the Phillips Curve that includes an expected inflation rate π_t^e :

$$\pi_t = \alpha (U_t - U^*) + \pi_t^e \quad (2)$$

where the inflation rate is in a negative correlation with the deviation of the unemployment rate from the natural rate U^* and in a positive correlation with expected inflation. The inflation expectation in the model is adaptive and related to the inflation rate that the subjects in the model expect to occur in period t (rather than inflation which is expected in period t , and which will occur in $t + 1$). Expected inflation depends on inflation trends in the previous periods

$$\pi_t^e = E_{t-1}(\pi_t) = \pi_{t-1}. \quad (3)$$

Therefore, this Phillips Curve does not contain a long-term trade-off between the inflation rate and the unemployment rate: the Phillips Curve is vertical on $U_t = U^*$. However, because there are expectations, the same trade-off can be used in a short term: price increases will accelerate if economic policy makers attempt to hold the unemployment rate below its natural rate. Given the adaptive expectations, the most often estimated model in empirical work on inflation dynamics was the model with the inflation rate as a function of lagged

¹ For a more detailed overview see Romer (1996) and Rudd and Whelan (2006).

² This conclusion suggested that expansionary fiscal or monetary policy should take into account a trade-off between (wage) inflation and the unemployment rate.

values of inflation and the unemployment rate or GDP gap.³ The lagged inflation values were an indicator of the expected inflation rate (the Old Phillips Curve), and the GDP gap was an indicator of economic activity or aggregate demand.

Sargent (1971) and Lucas (1976) criticize expectations modelling which is not in line with rational behaviour of economic entities. Rational expectations are central to microeconomics in that they attempt to explain the behaviour of any agent. In addition, Lucas (1976) criticises the estimation of the *ad hoc* model of the Phillips Curve and its parameters, which lack a structural, economic interpretation and are subject to changes when economic policy changes. Due to critiques regarding the lack of microeconomic foundations and rational expectations, in the late 90s Gali and Gertler (1999) derived an NKPC based on the *New Keynesian Model*.⁴ The Old Phillips Curve is a reduced version of the link between the inflation rate and the business cycle so that its parameters do not have a structural interpretation. The NKPC, on the other hand, is a solution to the mentioned structural dynamic stochastic model based on microeconomic foundations. Therefore the parameters of the model have a structural theoretical interpretation and are not subject to the Lucas critique. Many authors have shown that the NKPC can provide an explanation for the inflation rate dynamics in the US (see Gali and Gertler, 1999, Sbordone, 2002, Nason and Smith, 2008), EU (see Gali, Gertler and López-Salido, 2001, McAdam and Willman, 2003) and in many other countries (see Gali and López-Salido, 2001, for the NKPC in Spain, Balakrishnan and López-Salido, 2002, for Great Britain, Ribon, 2004, for Israel, Menyhert, 2008, for Hungary, Céspedes, Ochoa and Soto, 2005, for Chile, Ramos-Francia and Torres Garcia, 2006, for Mexico and Dabušinskas and Kulikov, 2007, for Estonia, Latvia and Lithuania).

The NKPC relates inflation to expected inflation and marginal cost. Marginal cost replaces the GDP gap precisely due to microeconomics-based decisions of enterprises that, in a monopolistic market, decide on price changes in order to maximise profit. In doing this, they take into account the *costs* they are faced with when changing prices. While this might lead to the conclusion that the GDP gap was included *ad hoc* in the previous versions of the Phillips curve, Rotemberg and Woodford (1996) and Gali and Gertler (1999) show under which conditions marginal cost and the GDP gap are directly linked.⁵ Rotemberg (1982) and Calvo (1983) present microeconomic foundations explaining why the Phillips Curve includes expected inflation. Rotemberg (1982) and Roberts (1995) show that expected inflation in the Phillips Curve results from the optimal reaction of enterprises during price setting as regards the costs they are faced with when changing prices. Calvo (1983) shows that expected inflation will occur in the Phillips Curve if some enterprises cannot change prices.⁶

The cost of changing prices or inability to change prices forms the basis of the New Keynesian Model as prices become *sticky* because of these elements. Without price rigidity of some kind, it is difficult to account for unemployed production factors or periods of economic activity below the *potential* level. Under the assumption of sticky prices, markets are unable to achieve an equilibrium immediately, so that total production can be below or above the economic activity level that would exist in the situation of perfect price flexibility. It is precisely due to sticky prices that room for monetary policy is created, at least in the short term. Probably the most popular formulation of sticky prices relates to the Calvo price-setting model (1983), which we build upon in this paper. In the Calvo model, prices are sticky because there are enterprises that cannot change prices in an optimal way. Other enterprises, those which can change prices, do it in a *forward-looking* manner, that is, depending of their expectations of the future average market price and future aggregate demand.

3 The Phillips Curve showed that in economic boom labour demand should grow. This would lead to wage increases that would, under the assumption of a constant markup and labour as the only production factor, be reflected in price increases. In other words, GDP growth should be in a positive correlation with price increases.

4 It should be stressed that there is a large difference between the Friedman-Phelps critique of expectations and the critiques derived from the revolution of rational expectations following the Lucas-Sargent critique of adaptive expectations. The Friedman-Phelps critique was related to the absence of adaptive current inflation expectations in the previous period. On the other hand, the New Keynesian Model with rational expectations results in a Phillips Curve that includes future inflation expectations.

5 In addition, notwithstanding the theoretical link between marginal cost and the GDP gap, there was insufficient empirical evidence of the existence of the New Keynesian Phillips Curve with the GDP gap. Gali and Gertler (1999) estimate the New Phillips Curve that explains inflation rate on the basis of inflation rate expectations and the GDP gap. The estimated link between the GDP gap and the inflation rate is negative as in the Old Phillips Curve, rather than positive as in the New Keynesian Model (Section 4.1 provides an explanation for this riddle and empirical evidence for this link in the Croatian economy). Once the GDP gap is replaced by marginal cost, the link between inflation and marginal cost becomes positive, in accordance with theory.

6 For alternative methods of modelling price rigidity, see Akerlof and Yellen (1985), Fischer (1977) and Taylor (1980).

However, the original NKPC could not explain inflation persistence. Fuhrer and Moore (1995) and Fuhrer (1997) stress the necessity to include lagged past inflation into the NKPC. Rudd and Whelan (2006) even show that the NKPC provides a good explanation of inflation only because of the inclusion of the past inflation rate. This Phillips Curve that in addition to marginal cost and inflation expectations also includes the past inflation rate is known as the Hybrid New Keynesian Phillips Curve. Gali and Gertler (1999) propose microeconomic foundations that account for the existence of lagged inflation in the Phillips Curve by extending the Calvo model. They demonstrate that the Hybrid New Keynesian Phillips Curve is a consequence of optimal decisions of two types of enterprises that can change prices (and there is also the third type of enterprises, those incapable of changing prices).⁷ Enterprises of the first type are forward-looking as in the Calvo model. The second type of enterprises includes those that change prices following a simple backward-looking rule of thumb, that is, depending on the past values of the inflation rate. The share of enterprises which are forward-looking or backward-looking, in addition to the price change frequency and the discount factor, are precisely the structural parameters estimated in the NKPC estimation. The structural parameters of the NKPC enable a structural economic interpretation of *ad hoc* links between the variables that were estimated in the Old Phillips Curve and accordingly had no structural interpretation. On a technical level, given the rational expectations of the agents in the model, they are used as conditional moments in the estimation of the NKPC by the generalised method of moments, used in most empirical research of short-term inflation rate trends.⁸

2.2 Domestic inflation research papers

In the last ten years, foreign research on inflation dynamics has been based exclusively on the NKPC estimation as solution to the structural New Keynesian model. In contrast, Croatian research on the Phillips Curve and the inflation rate in general has been based either on the estimation of the original, Old Phillips Curve, or on the estimation of an *ad hoc* reduced-form model that includes the variables identified by the NKPC as the main determinants of the inflation rate.

Družić, Tica and Mamić (2006) test the existence of the original Phillips Curve, i.e., the link between the inflation rate and the unemployment rate, as well as the existence of the same relationship including the expected inflation rate (the Phillips Curve with adaptive expectations included). As there are no links between these variables, they conclude that two versions of the Phillips Curve do not exist in Croatia. However, they single out the external variables to be taken into account in analysing the determinants of the domestic inflation rate. There are several problems in their analysis. As shown in the previous section, they include critiques related to expectations modelling and the non-existence of a structural model suggesting the existence of a relationship between inflation (or the rate of change of wages) and the unemployment rate. Technical problems include an *ad hoc* assumption of inflation expectation, the impossibility of linking the *ad hoc* assumed final model to its estimated version, and the inclusion into the model of some elements which are not even present in the reduced version of the model (an autoregressive term).

Šergo and Tomčić (2003) analyse the original version of the Phillips Curve, i.e., the relationship between the inflation rate and unemployment rate.⁹ They conclude that this link does not exist. Although in the *ad hoc* reduced-form model, without a constant, the link between the inflation rate and unemployment becomes significant, and the measure of representation increases, it is clear that the estimator of the parameter describing the correlation between these two variables is biased (so that hypotheses tests and *p*-values are meaningless), and that R^2 is meaningless precisely due to the omission of the constant from the model and the endogeneity of the regressor.

7 Alternative determinants of inflation persistence include price indexation (Christiano, Eichenbaum and Evans, 2005), limited information absorption capacity (Amato and Shin, 2003) or the coordination problem (Driscoll and Holden, 2003).

8 See Rudd and Whelan (2005 a) and Lindé (2005) for the critique of the use of the generalised method of moments in the NKPC estimation and response to the critique in Gali, Gertler and López-Salido (2005).

9 The paper does not explain whether this analysis relates to the quarterly or annual inflation rate, or why the natural unemployment rate amounts to 4% (!).

Grčić and Pivac (2005) estimate the link between the wage growth rate and the unemployment rate, taking into consideration both adaptive and rational expectations (although the derivation of the Phillips Curve with rational expectations is rather questionable). It is not clear why numerical estimation methods are used for the nonlinear Phillips Curve, and it is even less clear from where (which theory) the different versions of the Phillips Curve are derived. As the statistical significance of the parameter estimator is not calculated, no conclusion can be made as to whether there is a link between wage changes and unemployment or not.

Botrić and Cota (2006) analyse the short-term determinants of inflation by estimating the VAR model, whereas Broz and Vizek (2009) and Malešević Perović (2009) analyse the main factors of inflation in both a short and a long run, based on the estimate of the (vector) error correction (V)EC model. Malešević Perović (2009) emphasises wages and the kuna/euro exchange rate as the main determinants of the domestic inflation rate. Due to technical problems of the SVAR model estimation in Botrić and Cota (2006)¹⁰ and difficulties in the EC model estimation¹¹ in Broz and Vizek (2007), the conclusions of their analyses of inflation determinants are, to say the least, questionable.

These analyses neglect the main conclusions of the modern theory serving as a basis for the NKPC. The modern Phillips Curve (the Hybrid New Keynesian Phillips Curve) clearly shows the relationship between the inflation rate, past inflation rate, expected future inflation rate and measure of marginal cost. The Phillips Curve derives from a structural model with rational expectations, which is not subject to the Lucas critique. Since the agents in the model have rational expectations, the model is estimated using the solution to the structural model as a conditional moment. Therefore, if the generalised method of moments (GMM) is applied to the estimation of structural parameters, the estimator of the parameters' vector will be a consistent and asymptotically normally distributed estimator of structural parameters. Consequently, the usefulness of the analyses of previous Phillips Curve versions and the estimation of its parameters without structural interpretation becomes questionable. It is also questionable, if not wrong, to use methods for the estimation of model parameters (e.g. the OLS) that result in asymptotic characteristics not expected from parameter estimators (primarily inconsistency).

This paper, or at least its subject, is the closest to a paper by Martina Basarac (2009), who tests the existence of the NKPC in Croatia. However, instead of estimating the structural theoretical model, Basarac (2009) applies the theory from which the NKPC derives (she does not analyse the hybrid version of the Phillips Curve) in order to estimate a reduced form of the VEC model, whose structure does not correspond with the theoretical model. Basarac (2009) uses the theoretical model to identify potential inflation rate determinants in an analysis of the cointegration among consumer prices, consumer price expectations¹² and unit labour cost. In other words, instead of estimating the structural model and its parameters, Basarac (2009) estimates the reduced model parameters, which are not directly linked with the theory (the theory does not account for the long-term link between these variables in levels), themselves have no interpretation and are subject to the Lucas critique.

Basarac (2009) applies the unit labour cost as a measure of marginal cost without considering additional factors that might influence the production cost of Croatian enterprises. The estimated NKPC with the share of labour in GDP (unit labour cost) as a measure of marginal cost has proved to be a good indicator in explaining inflation trends in relatively closed economies, as the US or some EU countries. However, research on inflation in open economies (Balakrishnan and López-Salido, 2002, for Great Britain, Bardsen, Jansen and

10 It is not clear what the relationship is between the structural model in Botrić and Cota (2006) and the one in Dibooglu and Kutan (2005), given that the long-term effects of structural shocks on endogenous variables in Botrić and Cota (2006) differ from those in Dibooglu and Kutan, 2005 (the vector of the endogenous variables is different than the one in Dibooglu and Kutan, 2005, although both models have the same structure, and the authors claim that this is one and the same model and that the long-term effects of shocks on the endogenous variables are the same). Therefore, it is not clear how the reaction functions are estimated. Furthermore, the reaction functions used to identify the determinants of inflation have no confidence intervals based which it could be concluded which reactions are significantly different from 0 and which are not.

11 The results of the model estimation do not comprise standard errors of the estimator of the parameters so that it cannot be concluded whether the links estimated by the model are statistically significant or not. While the estimated price model derives from the Cobb-Douglas version of prices as a linear combination of imported prices and the unit labour cost, the relationship between the price model, excess funds model, excess demand model and final inflation model (which includes the markup previously achieved based on the estimated price model) is not clear.

12 The author uses the Gali-Gertler model, which served as a basis for the derivation of the New Keynesian Phillips Curve. However, while it is completely clear that the subjects in the model have rational expectations, the author uses adaptive expectations. It should be borne in mind that the Gali-Gertler model with adaptive expectations would not result in the New Keynesian Curve as its solution.

Nymoer, 2004, for the European countries, Freystatter, 2003, for Finland, Rubene and Guarda, 2004, for Luxemburg, Sondergaard, 2003, for Germany, France and Spain, Gali and López-Salido, 2001, for Spain) shows that the link between inflation and the labour share is insignificant. This is because the labour share as a measure of marginal costs directly assumes that labour is the only production factor or that the production function has the Cobb-Douglas form. This excludes the cost of the acquisition of capital goods, intermediate goods or raw materials, accounting for considerable production costs of enterprises in an open economy, such as Croatia, which mostly imports them.

In view of technical problems and the questionable use of the estimation method for the reduced form model based on a theory which is over fifty years old, the conclusions on the existence of the Phillips Curve provided by most of these analyses are, to say the least, dubious. Therefore, further in this paper we estimate the Phillips Curve, which is based on the structural New Keynesian model, with the aim of identifying the structural characteristics of the Croatian economy that explain domestic inflation in the short run. The estimated parameters have a *structural* interpretation and are therefore not subject to the Lucas critique. The estimation of the Phillips Curve by the generalised method of moments (GMM) is based not on an approximation but on the use of rational expectations, which are one of the main elements of the model. The Old Phillips Curve is estimated before the NKPC in order to examine the (questionable) conclusions regarding its non-existence from the previously mentioned papers. This is followed by an analysis of the possible causes for the non-existence of the link between inflation and the GDP. The analysis points to a strong link between inflation and world prices. This fact is later incorporated in the structural model in order for world prices to appear in the Phillips Curve, in addition to the measure of economic activity, an important determinant of the dynamics of domestic prices.

3 Old Phillips Curve

The Old Phillips Curve links inflation to the cyclical component of economic activity, i.e. of excess aggregate demand, such as the GDP gap. The general form of the Old Phillips Curve is given as follows:¹³

$$\pi_t = \alpha_0 x_{t-1} + \alpha_1 \pi_{t-1} + \varepsilon_t \quad (4)$$

where π_t is the quarterly inflation rate, x_t the GDP gap, ε_t a spherical random error assumed to be *i.i.d.* with zero expectation and constant variance.¹⁴

The Old Phillips Curve is estimated by means of quarterly data for the period from the first quarter of 1998 to the second quarter of 2010. The inflation rate is defined as the percentage change of a seasonally adjusted consumer price index relative to the same index in the previous quarter. Due to the high volatility of quarterly inflation rates, the irregular component is excluded from the CPI so that the quarterly inflation rate is smoothed (Figure 1).¹⁵ For the same reason, the variables applied in the further analysis represent only their trend-cycle components. Inflation dynamics were in the same way, and for the same reason, analysed in Céspedes, Ochoa and Soto (2005) and in Gali and López-Salido (2001). Alternatively, annual growth rates can be used, which are smoothed, given that quarterly growth rates are averaged. However, the theory itself (see below) shows that it is correct to use quarterly growth rates.

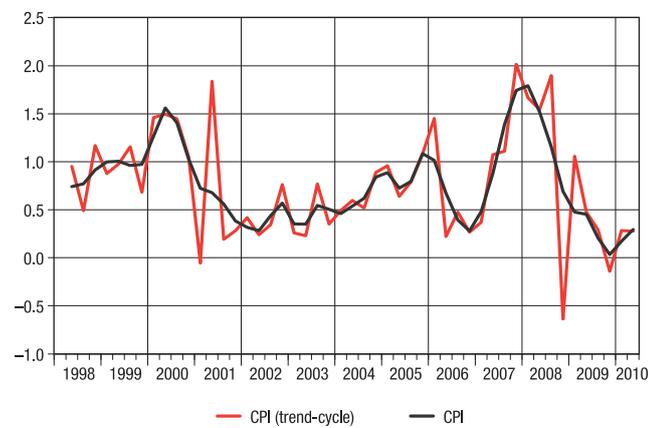
The GDP gap is defined as the (log) difference between the seasonally adjusted GDP and its trend

¹³ For the sake of comparison with the New Keynesian Phillips Curve only one lag of inflation is applied.

¹⁴ See the estimation of the Old Phillips Curve in the US and EU in Gali and Gertler (1999) and Gali, Gertler and López-Salido (2001), or the same estimation for Great Britain in Balakrishnan and López-Salido (2002).

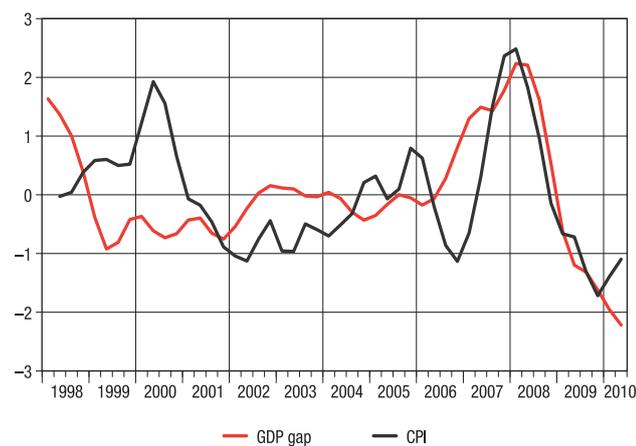
¹⁵ Each time series can be divided into four components: trend, cycle, seasonal and irregular component. The trend-cycle component of the consumer price index (excluding the seasonal and irregular components) was estimated by the X12 method (for details of the estimation, see Dagum, 1996).

Figure 1 Consumer price index (CPI), quarterly growth rates, trend-cycle component and original series



Sources: CBS and author's calculation.

Figure 2 Consumer price index (CPI), the quarterly growth rate and GDP gap, standardised data



Source: Author's calculation.

extracted from the HP-filter. The results of the OLS estimation (HAC variances of OLS parameter estimators, robust to autocorrelation and heteroskedasticity of errors, are given in the bracket) of the Old Phillips Curve show that inflation can nowadays be explained solely by the inflation rate in the previous quarter, and not by the GDP gap¹⁶

$$\pi_t = 0.012 x_{t-1} + 0.96 \pi_{t-1} + \varepsilon_t. \quad (5)$$

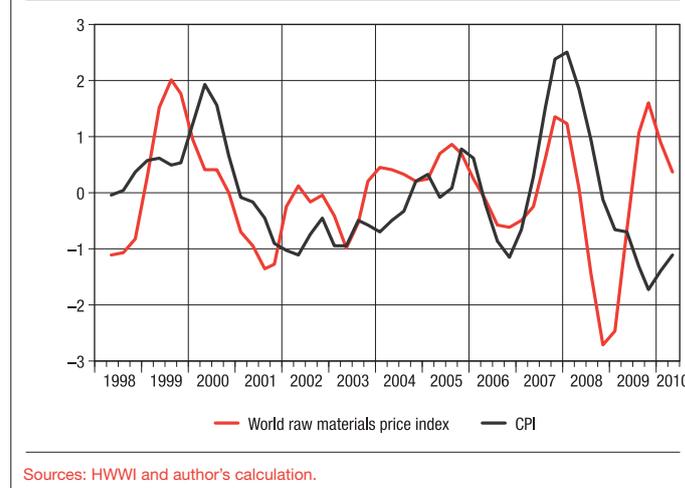
(0.026) (0.048)

The same conclusion is indicated by the weak correlation between the GDP gap and the inflation rate (Figure 2).

The inclusion of the GDP gap is directly based on the assumption that inflation can be explained by domestic factors such as domestic demand. It has already been mentioned that the analyses of open economies emphasise imported, intermediate goods and their prices as an important determinant of domestic prices (Figure 3), not only due to the considerable cost they generate in domestic goods production, but also, and

16 The conclusion does not change if additional lags of the inflation rate are included in the equation.

Figure 3 Consumer price index (CPI) and the world raw materials price index, quarterly growth rates, standardised data



primarily, because of the high volatility of their prices. In order to verify whether the same conclusion holds for the Croatian economy, the rate of change of the World Raw Materials Price Index π_t^w was included into the Old Phillips Curve, in addition to the GDP gap. The World Raw Materials Price Index is calculated based on the prices of 30 main raw materials traded on the world market,¹⁷ and it is expressed in kuna.¹⁸ Krznar and Kunovac (2010) use the World Raw Materials Price Index to show that the variation of the domestic inflation rate can primarily be explained by the variation of the change in this Index.

Figure 3 shows a high correlation between the rates of growth of world and domestic prices. Likewise, the results of the OLS estimation (HAC variances of OLS parameter estimators, robust to autocorrelation and heteroskedasticity of errors, are given in brackets) of the Old Phillips Curve, when the effect of the cost of imported prices (world raw material prices) is controlled for, show that the domestic inflation rate can be explained both by the past and by the world inflation rate (but not by the GDP gap), which is consistent with the conclusions reached by Krznar and Kunovac (2010)

$$\pi_t = 0.04 x_{t-1} + 0.89 \pi_{t-1} + 0.00015 \pi_t^w + \varepsilon_t. \quad (6)$$

(0.021) (0.036) (0.000038)

This conclusion emphasises that in the analysis of the Phillips Curve, i.e. of the inflation rate dynamics, the imported cost component should definitely be taken into account.

The result does not change significantly if additional lags of inflation are included in the model, except that the estimated parameters with lagged inflation values point to inflation persistence (parameters with inflation values lagged up to three periods backwards are significantly different from zero)

$$\pi_t = 0.033 x_{t-1} + 1.65 \pi_{t-1} - 1.44 \pi_{t-2} + 0.83 \pi_{t-3} - 0.12 \pi_{t-4} + 0.00013 \pi_t^w + \varepsilon_t. \quad (7)$$

(0.021) (0.136) (0.229) (0.270) (0.187) (0.000037)

Figure 2 shows why the GDP gap does not explain the inflation rate behaviour (on average). During the second half of 1999 and the first half of 2000 prices grew and the business cycle was relatively stable. Furthermore, from early 2002 until late 2005 inflation increased continuously during the slight recovery of the business cycle. The link between the business cycle and the domestic inflation rate becomes evident as late as in the

17 These include 4 cereals having a 3% weight in the index, 6 oilseeds (3% weight), 4 beverage raw materials (4%), 14 industrial raw materials (23%) and 2 energy raw materials (68%).

18 In euro terms, and on a monthly basis, the Index is calculated by the Hamburg Institute of International Economics HWWI). In addition to trends in the Raw Materials Price Index in euro terms, also to be taken into consideration is the dynamics of the kuna/euro exchange rate since both components affect import decisions. As the kuna/euro exchange rate volatility is relatively low, the results of the analysis should remain the same irrespective of whether the Raw Material Index is measured in a foreign or domestic currency (For details of the analysis see Section 4.2).

period from the beginning of 2007 to the end of 2009. Figure 3 shows that inflation from 1999 to the end of 2008 is closely correlated with world raw material prices. However, it should be stressed that a rapid decrease in domestic prices in 2009 probably resulted from a rapid decrease in the GDP gap, i.e. domestic demand, because world prices grew at significantly accelerated rates in that period.

The described estimated models are *ad hoc* reduced forms of the models without microeconomic foundations. The estimated parameters therefore have no structural interpretation and are subject to the Lucas critique. A structural inflation model whose solution is the NKPC to be estimated is derived in the next section. First, the closed economy Phillips Curve will be discussed, and then imported intermediate goods will be included into the model in order to take into account the strong link between domestic and world inflation rates.

4 New Keynesian Phillips Curve

In response to numerous critiques, primarily to that related to the lack of structure the Phillips Curve is derived from, the New Keynesian Model was developed upon microeconomic foundations. Economic agents in this model have rational expectations. This model aimed to justify the role of monetary policy and the effects it produces on economic activity, at least in the short-term. The model's prime ingredient pertains to sticky prices.

Presented below is the Basic New Keynesian Model with original Calvo sticky prices.¹⁹ The estimated NKPC is the solution (reduced form) of the model. The parameters of the reduced form of the NKPC are the function of structural parameters of the New Keynesian Model, which do not change because of economic policy changes. This, original NKPC explains inflation by marginal cost developments and expected inflation. This is followed by the presentation of the Galí and Gertler model (1999), which in addition to enterprises that are *forward-looking* (as in the Calvo model) comprises enterprises that are *backward-looking*. *Forward-looking behaviour* refers to the situation when prices are changed in relation to expected market conditions. *Backward-looking behaviour* is related to a simple rule of thumb of setting current prices based on past price developments. The solution of this model is a hybrid NKPC, which explains the inflation rate by marginal cost developments, the expected and past inflation rates. The Galí-Gertler model includes imported intermediate products in the same manner as in Galí and López-Salido (2001) or in Balakrishnan and López-Salido (2002). Imported goods will change marginal cost into a function, not only of the labour share in GDP, but also of the prices of imported intermediate goods (relative to wages). Finally, a measure of fundamental inflation will show which of all the estimated NKPCs provides the best explanation for inflation trends in Croatia.

4.1 Closed economy New Keynesian Phillips Curve

The NKPC is derived from a simple New Keynesian Model comprising two types of economic subjects: households and enterprises. The household problem is standard²⁰: households maximise the discounted sum of expected utilities, taking into account budgetary limits. The utility derives from leisure $(1 - L_t)$ where L_t denotes the amount of labour and consumption of aggregate goods C_t which represents a basket of differentiated goods C_{it} . Households purchase differentiated goods from various enterprises. Aggregate goods are represented by the *Dixit-Stiglitz* index of constant elasticity of substitution between differentiated goods:

¹⁹ The role of monetary policy cannot be justified without sticky prices.

²⁰ As the solution of the household problem is reflected in the intertemporal substitution of consumption, i.e. in the IS curve with rational expectations, which is not directly linked with the Phillips Curve, the whole household problem with its solution has been omitted. The Basic New Keynesian Model consists of three equations: the IS Curve with expectations, which is the solution to the household problem and connects production and interest rates, the New Keynesian Phillips Curve, which is the solution to the enterprise problem and connects production and prices; and the Taylor monetary policy rule, which *closes* the model.

$$C_t = \left[\int_0^1 (C_{it}^{\frac{\varepsilon-1}{\varepsilon}}) di \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad (8)$$

where ε is the elasticity of substitution between differentiated goods. Future, expected utilities of households are discounted by the subjective discount factor $\beta < 1$, which means that households assign a lower weight to utilities in the distant future than to those closer to the present time.

Enterprises are *ex ante* different because they produce different goods Y_{it} . As a result, they have some market power, that is, they operate in an environment of monopolistic competition. In order to produce a good Y_{it} , enterprises purchase labour L_t from households in exchange for wages W_t . The production technology is linear:

$$Y_{it} = Z_t L_t \quad (9)$$

where Z_t is the productivity shock.

Since enterprises operate in an environment of monopolistic competition, each of them can influence the price of its product. However, it is assumed that there are two (*ex post*) types of enterprise, as in Calvo (1983): those that can and those that cannot change prices. This assumption results in sticky prices. Each enterprise can change prices with probability $(1-\theta)$ so that by setting the price P_{it} it maximises profit taking into account the constraint of the frequency of price changes and the demand²¹ for its differentiated products Y_{it} :

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\varepsilon} Y_t \quad (10)$$

P_t denotes the price index for all market products:²²

$$P_t = \left[\int_0^1 (P_{it}^{1-\varepsilon}) di \right]^{\frac{1}{1-\varepsilon}}. \quad (11)$$

In an equilibrium this reads $C_{it} = Y_{it}$ and $\int_0^1 C_{it} = \int_0^1 Y_{it}$. Total production therefore equals:

$$Y_t = \left[\int_0^1 (Y_{it}^{\frac{\varepsilon-1}{\varepsilon}}) di \right]^{\frac{\varepsilon}{\varepsilon-1}}. \quad (12)$$

Since each enterprise can, in any period, with some probability, change prices, only a certain number of enterprises (equal to $1-\theta$) can make an optimal decision regarding prices. All other enterprises (their number is θ) cannot change prices. The probability that an enterprise will change prices is independent of the period of time that has passed since the last change in prices by the same enterprise and of the *state of the world* in every period. The expected period between two price changes by an enterprise is therefore $D = (1-\theta) \sum_{j=0}^{\infty} j\theta^{j-1} = 1/(1-\theta)$.

Enterprise i , which can change prices in period t , will decide on its price P_{it} in order to maximise the discounted sum of expected profits:

$$\max_{P_{it}} E_t \left[\sum_{j=0}^{\infty} \theta^j Q_{t+j} (P_{it} Y_{it+j} - TC(Y_{it+j})) \right]$$

where $TC(Y_{it+j})$ is the total production cost in nominal terms Y_{it+j} , which depends on the price of production

21 The demand for a specific good is the solution to the household expenditure minimisation problem where households decide on the purchase and quantity of each differentiated good by minimising the total cost of purchasing all differentiated goods taking into account that the total consumption is given by the *Dixit-Stiglitz* aggregator. This aggregator has been applied ever since the incorporation of the idea of monopolistic competition into macroeconomic models as the constant elasticity of substitution function form (CES function) to aggregate differentiated products into an aggregated product.

22 The price index is such that it minimises the household cost function.

factors purchased in a perfect competition market. In addition to labour, offered with perfect elasticity by households to enterprises in exchange for wages, none of the other production factors is introduced for the time being. Section 4.2 assumes that each good Y_{it} is produced by means of labour and imported intermediate goods. E_t denotes a mathematical operator of conditional expectation with respect to all the information available to the enterprise until period t , i.e., enterprises form rational expectations. The discount factor depends on probability θ that an enterprise will not be able to change prices in the following periods²³ and on the marginal rate of substitution of consumption in period t for consumption in period $t + j$:²⁴ $Q_{t+j} = \beta^j (C_{t+j}/C_t)^{-\eta}$ where η is the household relative risk aversion parameter.

Following the substitution for Y_{it+j} from (12) and the division with P_{it+j} the maximisation problem of enterprises can be written down as follows:

$$\max_{P_t} E_t \left[\sum_{j=0}^{\infty} \theta^j Q_{t+j} \left(\left(\frac{P_t}{P_{t+j}} \right)^{1-\varepsilon} Y_{t+j} - \frac{1}{P_{t+j}} TC \left(\left(\frac{P_t}{P_{t+j}} \right)^{-\varepsilon} Y_{t+j} \right) \right) \right].$$

Enterprises that can change prices are perfectly symmetrical, which means that they are *ex post* equal in the sense that they set the same price $P_t^* = P_t^*$. If the price of labour is considered as given, the solution of the profit maximisation problem with regard to price P_t is as follows:

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \left[\sum_{j=0}^{\infty} \theta^j Q_{t+j} (Y_{t+j} P_{t+j}^{\varepsilon-1} MC_{t+j}) \right]}{E_t \left[\sum_{j=0}^{\infty} \theta^j Q_{t+j} (Y_{t+j} P_{t+j}^{\varepsilon-1}) \right]} \quad (13)$$

where MC_t is the nominal marginal cost of production, and P_t^* the optimal price. The solution of the maximisation problem is reflected in the rule of optimal setting of the price as markup $\left(\frac{\varepsilon}{\varepsilon - 1} \right)$ on the weighted average of the present and future discounted marginal costs, which is a direct consequence of the assumption of sticky prices. Without the limitation of the price change frequency the optimal price would be equal to $P_t^* = MC_t \frac{\varepsilon}{\varepsilon - 1}$ (this is why $\frac{\varepsilon}{\varepsilon - 1}$ is called markup)²⁵ and it does not depend on the expectations of future marginal costs.

It can easily be demonstrated that the aggregate price index (11) for two types of enterprises (those that can and those that cannot change prices) is equal to the weighted average of the price $(1 - \theta)$ of enterprises that can change prices in period t and the price θ of enterprises that cannot change prices and adopt the price index from the previous period as prices in period t

$$P_t = [(1 - \theta)P_t^{*(1-\varepsilon)} + \theta P_{t-1}^{(1-\varepsilon)}]^{\frac{1}{1-\varepsilon}}. \quad (14)$$

The constraint of the price change frequency, i.e., the difference between enterprises in their ability to change prices is the very reason for the existence of sticky prices.

The optimal price (13) and the price index (14) are the solution to the model. In order for the system to be solved with two nonlinear equations, this equation system will be log-linearised by the Taylor expansion around the steady state with inflation equal to 0 to obtain two linear equations that are *easier to work with*

$$p_t = (1 - \theta)p_t^* + \theta p_{t-1} \quad (15)$$

$$p_t^* = (1 - \theta\beta)E_t \left[\sum_{j=0}^{\infty} (\theta\beta)^j mc_{t+j} \right]. \quad (16)$$

Small letters denote the variables as log-deviations from their steady state.²⁶

²³ The probability that the price will remain fixed for k periods in the future is equal to θ^k . The expected profit of period k is therefore weighted by this probability.

²⁴ As households own enterprises, each profit unit is evaluated with regard to its contribution to utility (deriving from consumption).

²⁵ This means that the steady state condition of the real marginal cost MC/P corresponds to the inverse of the markup.

The linearised solution to the optimal price is in fact the solution of the first-order stochastic difference equation

$$p_t^* = (1 - \theta\beta)mc_t + \theta\beta E_t[p_{t+1}^*]. \quad (17)$$

Therefore, in setting new prices, enterprises form an expectation of the future optimal price with the present marginal cost. The combination of two linearised equations leads to the New Keynesian Phillips Curve, which explains inflation rate dynamics by the expected inflation rate and the marginal cost to price ratio, the so-called real marginal cost

$$\pi_t = p_t - p_{t-1} = \beta E_t[\pi_{t+1}] + \frac{(1 - \theta)(1 - \theta\beta)}{\theta}(mc_t - p_t). \quad (18)$$

Real marginal cost measures the relationship between nominal marginal cost and the price. Only an increase in this ratio, and not nominal marginal cost itself, will contribute to inflation pressures because enterprises that can change the price will actually change it if this increase occurs.

Equation (18) shows that the link between the current inflation rate and the expected inflation rate depends on the value of the subjective discount factor and on the price change frequency, i.e., the share of enterprises that can change prices. An increase in the discount factor raises the impact of inflation expectations on the current inflation rate and reduces the weight of marginal cost. In order to explain the impact of the increase in the discount factor on the relationship between the inflation rate and inflation expectations and on the relationship between the inflation rate and marginal cost, it should be noted that solving the NKPC will result in

$$\pi_t = \frac{(1 - \theta)(1 - \theta\beta)}{\theta} \sum_{j=0}^{\infty} \beta^j E_t[(mc_{t+j} - p_{t+j})]. \quad (19)$$

As enterprise owners use β in discounting future marginal costs to their present value in order to determine the optimal price, an increase in the discount factor raises the impact of inflation expectations (which measures the sum of expected future marginal costs) in explaining the inflation rate dynamics. At the same time, an increase in the discount factor reduces the correlation between current marginal cost and inflation. The same impact will be produced if the share of enterprises which can change prices increases because these enterprises change the price in an optimal (*forward-looking*) way.

Such an interpretation of the parameters of the model may be the first significant difference in relation to the Old Phillips Curve, whose parameters do not have structural interpretation. Thanks to the microeconomic theory from which the NKPC is derived, the parameters have structural interpretation and are not subject to economic policy changes. Furthermore, in contrast with the Old Phillips Curve, the NKPC contains rational expectations ($E_t[\pi_{t+1}]$) instead of $E_{t-1}[\pi_t]$, which have most often been assumed to read, given the adaptive expectations, as follows $E_{t-1}[\pi_t] = \pi_{t-1}$. This is the main reason why the Old Phillips Curve includes lagged inflation values, and the NKPC the expected future inflation rate. However, since inflation data (at least in the US) point to strong inflation persistence, it is precisely because of the lack of past rates that the original NKPC has been severely criticised. In order to *reconcile* data and the NKPC, a method of including lagged inflation values into the NKPC had to be devised. This will be dealt with in the section on the hybrid NKPC.

The second criticism of the NKPC was related to the measure of marginal cost. The GDP gap was originally used as the measure of marginal cost. While it is easy to find the conditions under which real marginal cost equals the GDP gap (see Rotemberg and Woodford, 1996)

$$(mc_t - p_t) = \kappa x_t \quad (20)$$

26 There is no markup in the equation (16). This result is due to the application of the log-deviation of the marginal cost from its steady state (which is equal to the negative value of the logarithm of the markup). If the value of the marginal cost was applied instead of the log-deviation, the markup should be included into the equation (16). For details see Gali (2008).

the estimation of such an NKPC

$$\pi_t = \beta E_t[\pi_{t+1}] + \frac{(1-\theta)(1-\theta\beta)}{\theta} \kappa x_t \quad (21)$$

encounters two major problems (κ is the elasticity of production with respect to marginal cost). The NKPC with the GDP gap

$$\pi_t = \alpha_1 \pi_{t+1} + \alpha_2 x_t + \varepsilon_t \quad (22)$$

shows that inflation is in a positive correlation with the GDP gap, i.e. that a change in inflation ($\pi_t - \pi_{t-1}$) is negatively linked with the GDP gap (if we assume that $\alpha_1 = \beta = 1$ and shift equation (22) one period backwards because we do not notice expected inflation)

$$\pi_t - \pi_{t-1} = -\alpha_2 x_{t-1} + \varepsilon_t \quad (23)$$

However, Gali and Gertler (1999) show that the estimation of such a NKPC by means of OLSs points to a positive link between a change in inflation and the GDP gap. This result is in contrast with the new theory, and in line with the conclusions drawn from the Old Phillips Curve!²⁷

If the same equation is estimated for Croatia (at the sample from the first quarter 1998 to the second quarter of 2010), the conclusion in terms of the existence of the NKPC with the GDP gap is even worse

$$\pi_t = -0.005 x_t + 0.98 \pi_{t+1} \quad (24)$$

(0.028) (0.047)

The estimated parameter with the GDP gap is negative (as shown by the Old Phillips Curve) and insignificant. None of this is in accordance with the new Keynesian theory. The data therefore reject the hypothesis that the Phillips Curve exists, and even if it does “exist”, it is the old Phillips Curve.²⁸

The error in model (22) is the error of (rational) expectations: $\varepsilon_t = \pi_t - E[\pi_{t+1}]$. Therefore the replacement of $E_t(\pi_{t+1})$ with *ex post* realised, “future” inflation rate π_{t+1} (performed in the estimation of equation (24)) results in an inconsistent OLS estimator of the NKPC parameter with π_{t+1} because π_{t+1} is correlated with ε_t . Given the rational expectations and the non-correlation of the error with information available until period t , lagged variables may be used as instruments for $E_t(\pi_{t+1})$ in the NKPC estimation. An IV estimator or a general GMM estimator, which is used in further NKPC estimations, will in that case be a consistent estimator of the model’s parameters. In order to verify whether this result of the negative and non-significant parameter with the GDP gap is a consequence of this parameter’s inconsistent OLS estimator, the GMM estimation of this equation uses the following instruments: 4 lags of inflation, 4 lags of PPI inflation (PPI – producer price index), 4 lags of the GDP gap and 4 lags of the wage growth rate.²⁹ The results of the estimated equation did not change considerably

$$\pi_t = -0.006 x_t + 0.99 E_t(\pi_{t+1}) \quad (25)$$

(0.028) (0.055)

The parameter with the GDP gap remains negative and insignificant.

Gali and Gertler (1999) offer a solution for the questionable sign of correlation between the GDP gap and inflation rate using the *correct* measure of marginal cost. Under the assumption that enterprises use labour in their production, as in the previously shown model, the optimal decision regarding the problem of the

27 The NKPC shows that inflation movement should precede the movement of the GDP gap. However, the data for the US show exactly the opposite: the correlation between the current GDP gap and the future inflation rate is positive, and the correlation between the current GDP gap and the past inflation rate is negative (Fuhrer and Moore, 1995). This explains the negative sign in estimated equation (22) and the positive sign in equation (23).

28 The existence of the Phillips Curve should be taken with caution because in a hypothesis test the hypothesis can never be accepted.

29 With the exception of GDP gap data, all other data are published by the Central Bureau of Statistics. The wage variable is the nominal gross wage in the private sector.

enterprise, which minimises the cost, results in real marginal cost which is equal to the ratio of the real wage to the marginal product of labour:

$$\frac{MC_t}{P_t} = \frac{\frac{W_t}{P_t}}{\frac{\partial Y_t}{\partial L_t}}. \quad (26)$$

If the production technology is like that in (9), marginal cost equals the labour share in GDP, i.e., the real unit labour cost (the share of the wage bill in total, nominal production):

$$\frac{MC_t}{P_t} = S_t = \frac{W_t L_t}{P_t Y_t}. \quad (27)$$

If this equation is linearised around the steady state of each variable

$$(mc_t - p_t) = s_t \quad (28)$$

the NKPC becomes:

$$\pi_t = \beta E_t[\pi_{t+1}] + \lambda s_t \quad (29)$$

where the reduced form parameter λ is the function of structural parameters

$$\lambda = \frac{(1 - \theta)(1 - \theta\beta)}{\theta} \quad (30)$$

which is in an inverse relationship with the degree of price stickiness: if the share of enterprises that can change prices drops, inflation becomes less sensitive to changes in marginal cost. The NKPC shows that enterprises that are able to change prices set the price taking into account their expectations of future inflation, i.e. future marginal costs.

In order to estimate the NKPC, equation (29) can be written down as a restriction

$$E_t[\pi_t - \lambda s_t - \beta \pi_{t+1}] = 0. \quad (31)$$

This restriction can be used as a conditional moment in the GMM estimation of NKPC parameters. As this is a scalar conditional moment, NKPC parameters will be unidentified. However, due to rational expectations, anticipation error π_{t+1} is not correlated with information until period t , so that m moments can be constructed based on m instruments

$$m_t(\beta, \lambda) = [\beta \pi_{t+1} + \lambda s_t - \pi_t] \mathbf{z}_t \quad (32)$$

or m conditional moments based on these moments

$$E_t[m_t(\beta, \lambda)] = E_t[(\pi_t - \lambda s_t - \beta \pi_{t+1}) \mathbf{z}_t] = 0 \quad (33)$$

where \mathbf{z}_t is a m dimensional vector of instruments from the information set until time t which are therefore orthogonal to π_{t+1} . As long as the number of instruments equals or exceeds the number of parameters to be estimated, the estimator of the parameters will be (over) identified. In the event that the vectors of parameters are over-identified, conditional moments (33) will be used in the GMM estimation of NKPC's unknown parameters. The GMM estimator of parameters is, in contrast with the OLS, a consistent estimator of parameters.

The equivalent of conditional moments (33) in the sample (which according to the law of large numbers converges to expectation (33)) reads as follows:

$$m_n(\beta, \lambda) = \frac{1}{T} \sum_{t=1}^T m_t(\beta, \lambda) \quad (34)$$

where T is the size of the sample. If $W_n(\beta, \lambda)$ is defined as the estimated covariance matrix $m_n(\beta, \lambda)$, which

represents the matrix of the weights of conditional moments, the GMM method estimates unknown parameters (β, λ) by minimising a distance measure between conditional moments

$$d(m_n(\beta, \lambda)) = m_n'(\beta, \lambda) W_n(\beta, \lambda) m_n(\beta, \lambda) \quad (35)$$

with regard to unknown parameters. In the case of over-identification of model parameters the GMM attempts to bring conditional moments as close to zero as possible. As the distance measure depends on the parameters, the minimisation is achieved by simultaneously updating $m_n'(\beta, \lambda)$ and $W_n(\beta, \lambda)$. The weight matrix is estimated by the Newey-West procedure, i.e., by the estimate of the spectrum at zero frequency using the Bartlett (Newey-West) kernel and the Newey-West optimal bandwidth parameter.

We continue with an estimation of the reduced form NKPC (29): only two parameters λ, β are estimated, i.e. those with an *interpretation* of the link between the independent variables and the dependent variable. This is followed by an estimation of the structural NKPC equation (18) i.e. an estimation of the parameters with theoretical, structural interpretation: θ, β . Data used in the estimation of the NKPC relate to the period from the first quarter in 1998 to the second quarter in 2010. As in the section on the Old Phillips Curve, inflation rate data are data on the quarterly rate of change in the trend-cycle component of the consumer price index. The only difference from the previously used data is that the inflation rate has to be calculated in accordance with the theory from which the NKPC is derived. The NKPC is the non-linear form of an equation linearised in such a manner that all variables in the NKPC represent a deviation from the steady state. Therefore, the calculation of the inflation rate excludes the HP-trend which is, as in most analyses, assumed to be equal to the steady state. Real marginal cost is calculated as the share of the nominal gross wage bill of the private sector (excluding the agricultural sector) in nominal gross value added, which excludes the public sector. Real marginal cost is also calculated based on the trend-cycle variables of wages, employment and GDP. All the variables are in logarithm and detrended in line with the theory. The instruments in the estimation of the NKPC include 4 lags of inflation, 4 lags of PPI inflation, 4 lags of the labour share and 4 lags of the wage growth rate.

The results of the estimated NKPC are not significantly different from the Phillips Curve that comprises the GDP gap instead of the labour share

$$\pi_t = -0.007 s_t + 0.91 E_t(\pi_{t+1}). \quad (36)$$

(0.01) (0.089)

The estimated coefficient for β is significantly different from 0, it is lower than 1 and its value does not deviate too much from the values found in the literature. The parameter of the link between the labour share and the inflation rate (Figure 4), as the correct measure of real marginal cost, is negative and insignificant,



which is in complete disagreement with theoretical predictions. Given the *incorrect* conclusion of the estimated reduced form NKPC, it would be useless to estimate the structural model. The next section therefore deals with solving the problem of the wrong sign of the link between marginal cost and the inflation rate. The mentioned conclusion could suggest that the production function does not comprise all relevant production factors contributing to changes in the production cost. The following section assumes that a good is produced by means of labour and imported intermediate goods. It is shown that marginal cost thus changes and becomes a function not only of the labour share but of imported prices (relative to wages) as well. It is also shown that this solves the questionable sign of the link between marginal cost and the inflation rate from this section.

4.2 Open economy New Keynesian Phillips Curve

So far no link has been found between the measure of real marginal cost used in closed economy models (the labour share or the GDP gap) and the inflation rate. The Croatian economy being open, the price of imported intermediate goods and the exchange rate of the kuna versus the euro or US dollar can affect domestic prices. Krznar and Kunovac (2010) show that world raw material prices are the main determinant of the domestic inflation rate. The existence of the link between inflation and the rate of change in world prices was confirmed in section 3. Therefore, we will now focus on the measure of marginal cost and the problem of additional variables related to the openness of the economy in order to tackle the problem of the link between the inflation rate and marginal cost from the previous chapter.

In an environment where enterprises purchase not only labour but also intermediate imported products, the labour share will no longer be a correct measure of marginal costs. The specification of marginal cost will depend on the form of the production function. In order to link imported intermediate goods to inflation, an alternative production function applied in open economy models will be assumed. This production function aggregates the input of labour L_t and the input of intermediate goods M_t in the CES form of the production function (as in Galí and López-Salido, 2001, Balakrishnan and López-Salido, 2002 and Batini, Brian and Stephen, 2005)

$$Y_t = \left[\alpha_L (Z_t L_t)^{\frac{\sigma-1}{\sigma}} + \alpha_M (M_t)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad (37)$$

where σ is the elasticity of substitution between labour and imported intermediate goods, and α_L and α_M the *shares* of each input in total production.³⁰ The minimisation cost problem of the enterprise leads to an intra-temporal substitution of the two inputs

$$\frac{L_t}{M_t} = \left(\frac{\alpha_L P_t^M}{\alpha_M W_t} \right)^\sigma \quad (38)$$

where P_t^M is the price of an imported intermediate good (expressed in the domestic currency). It can be demonstrated that real marginal cost in that case equals:³¹

$$\frac{MC_t}{P_t} = \frac{W_t}{P_t M_t L_t} = \frac{W_t L_t}{Y_t} \frac{S_t}{\frac{\partial Y_t}{\partial L_t} \frac{L_t}{Y_t} 1 - \alpha_M \left(\frac{Y_t}{M_t} \right)^{\frac{1-\sigma}{\sigma}}}. \quad (39)$$

The inclusion of (39) in (38) and the log-linearisation of real marginal cost around the steady state result in real marginal cost (deviation from the steady state) as the weighted average of the labour share and the ratio of imported intermediate goods prices to wages

³⁰ It used to be assumed that the elasticity of production in relation to labour was constant, which indirectly leads to an assumption that the labour share in production is constant. In the CES production function the labour share is no longer fixed and it depends on the price of labour relative to the price of an imported intermediate good.

³¹ For details of the derivation, see Balakrishnan and López-Salido (2002).

$$(mc_t - p_t) = s_t + \phi(p_t^M - w_t) \quad (40)$$

where parameter ϕ determines the elasticity of real marginal cost to relative prices

$$\phi = \frac{1 - \mu s}{\mu s}(\sigma - 1). \quad (41)$$

Parameters μ and s represent, respectively, the markup and the labour share in the steady state. An increase in the elasticity of substitution σ increases the impact of the relative price (relative to the labour share) as a determinant of the inflation rate.

An open economy model of the NKPC suggests that the main determinants of the inflation rate include the expected inflation rate, the labour share and the ratio of imported intermediate goods prices to wages

$$\pi_t = \beta E_t[\pi_{t+1}] + \lambda[s_t + \phi(p_t^M - w_t)]. \quad (42)$$

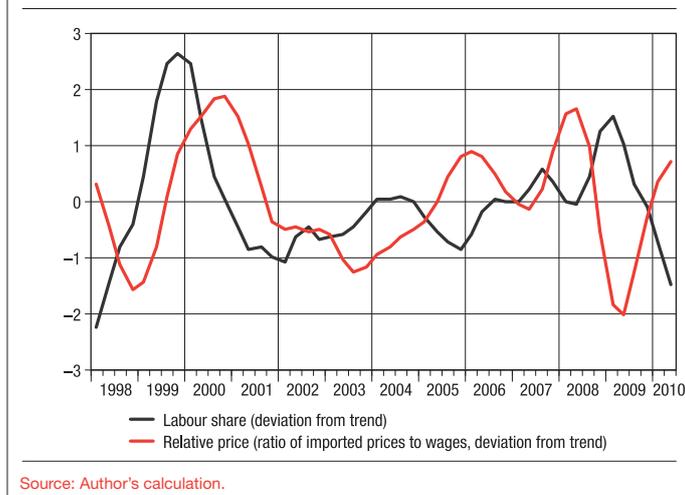
Prior to the estimation of the NKPC, which now includes a new measure of real marginal cost, parameters σ , μ , s need to be calibrated since they cannot be estimated. It has to be noted that under condition $\sigma < 1$ an increase in relative prices leads to a decrease in marginal cost. A simple regression of inflation on relative prices leads to a positive link between these two variables. This shows that $\sigma > 1$. Therefore the value of the parameter of elasticity of substitution σ is assumed to be higher than 1, i.e. $\sigma = 1.5$ (as in Gali and López-Salido, 2001).³² The labour share in the steady state was considered to be an average of the labour share (Figure 5) calculated in the previously described manner: $s = 0.45$. The value of the markup in the steady state was arbitrarily taken to be 10% (as in Gali *et al.*, 2001, Rumlér, 2007 and Leith and Malley, 2007), which is in accordance with the calibrated markup value ranging from 20% to 70% on an annual level (see Domowitz *et al.*, 1988, Morrison, 1994, or Olive, 2002).



In order to analyse the contribution from the inclusion of imported intermediate goods in the production function, that is, the contribution of their cost to explaining inflation, a reduced form of the open-economy NKPC (42) was estimated by the GMM with the following instruments: 4 lags of inflation, 4 lags of PPI inflation, 4 lags of real marginal cost (as the weighted sum of the labour share and relative prices) and 4 lags of the wage growth rate. Data used in the estimation of the open-economy NKPC are the same as those used in the closed economy NKPC. Imported intermediate goods prices were obtained from a time series of the World

32 The results of the NKPC estimation proved to be robust to minor changes in the value of parameters σ .

Figure 8 Labour share and the relative price ratio (imported prices to wages), deviation from trend, standardised data



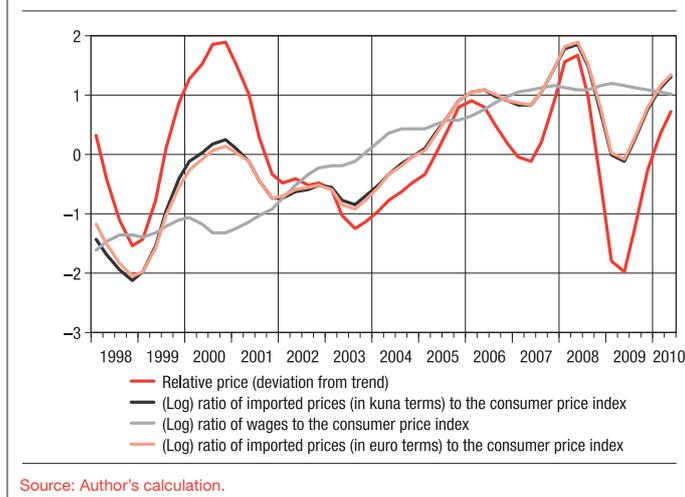
dynamics is mainly a consequence of trends in the relative price (the ratio of the import price to wages), primarily due to its volatility, regardless of its carrying a lower weight in the calculation of real marginal cost ($\phi=0.51$) than the labour share.³³

In order to analyse in detail which of the two prices (imported prices versus wages) determine the dynamics of relative prices, it should be noted that relative prices can be written as the (log) difference between the ratio of imported prices to the consumer price index and the ratio of nominal wages to the consumer price index

$$p_t^M - w_t = (p_t^M - p_t) - (w_t - p_t). \quad (44)$$

This decomposition of the relative price (Figure 9) shows that its behaviour since 1998 can primarily be explained by import price trends, expressed either in kuna or euro terms. Such a result confirms that the pass through effect from changes in the kuna/euro exchange rate on domestic prices is negligible.

Figure 9 Decomposition of the relative price, deviation from trend, standardised data



33 The volatility (measured by the variance) of the relative price is 28 times higher than the volatility of the labour share.

Once it was established that there was a link between the economic activity indicator (in our case open economy real marginal cost) and the inflation rate, the structural parameters of the NKPC were estimated

$$\pi_t = \beta E_t[\pi_{t+1}] + \lambda[s_t + \phi(p_t^M - w_t)] \quad (45)$$

where

$$\lambda = \frac{(1 - \theta)(1 - \theta\beta)}{\theta}. \quad (46)$$

Conditional moments, to be used in the GMM estimation of parameters, related to the share of enterprises that cannot change price θ (and to the price change frequency $D=1/(1-\theta)$) and subjective discount factor β are as follows:³⁴

$$E_t \left\{ \left[\pi_t \frac{(1 - \theta)(1 - \beta\theta)}{\theta} [s_t + \phi(p_t^M - w_t)] - \beta\pi_{t+1} \right] \mathbf{z}_t \right\} = 0 \quad (47)$$

where \mathbf{z}_t are the same instruments as the ones used in the estimation of the reduced form NKPC (4 lags of inflation, 4 lags of PPI inflation, 4 lags of real marginal cost as the weighted sum of the labour share and relative prices and 4 lags of the wage growth rate).³⁵ In order to check the robustness of the estimated parameters based on conditional moments (47), the second specification of the model (45) (restricted model) includes a constraint that the discount factor is to equal 1 (as in Gali and Getler, 1999). Since the GMM estimator in a small sample is often very sensitive to conditional moments applied in the estimation (Fuhrer, 1997), an alternative set of conditional moments in the NKPC was also used, representing the normalisation of conditional moments (47)

$$E_t \{ [\theta\pi_t - (1 - \theta)(1 - \beta\theta)[s_t + \phi(p_t^M - w_t)] - \theta\beta\pi_{t+1}] \mathbf{z}_t \} = 0. \quad (48)$$

The estimated parameters (with Newey-West standard errors in brackets) θ, β are given in Table 1. Also calculated were the implied values of parameters of the reduced form λ , which represents a link between marginal cost and the inflation rate (based on equation (46)) and $D=1/(1-\theta)$, which measures the average number of quarters with constant prices. The estimated parameters relate to two specifications of the NKPC which differ in respect of the conditional moments (model (48) versus model (47)) used in the estimation of the NKPC and in respect of parameter β (the unrestricted model versus the restricted model). The standard errors of parameters λ, D , which are a nonlinear function of the standard errors of structural parameters and their covariance, are calculated by the delta method. The last column in the table shows the results of the Hansen J -test (p -values in brackets) on the over-identified restrictions which test the exogeneity of instruments.

As for the estimation of reduced form parameters (β i λ), the results of the estimated unrestricted structural models are very similar to the results of the estimated reduced form model (43): both parameters are statistically different from zero, and even the estimated values of the parameters are the same. However, in relation to the reduced form, the estimated structural model shows that the share of enterprises that cannot change prices (equal to θ), in every quarter, is very high, on average about 90% in all model specifications. This means that enterprises change prices approximately every two to two and a half years. In the restricted model the results are significantly different. The price change frequency in that model specification decreases from three years to approximately two years (since the share of enterprises that can change prices is slightly higher), which is still considerably higher than in similar analyses of price change frequencies in the US, EU (Gali *et al.*), Israel (Ribon, 2004), Spain (Gali and López-Salido, 2001), Estonia, Latvia and Lithuania (Dabušinskis and Kulikov, 2007), the G-7 countries (Leith and Malley, 2007) and Mexico (Ramos-Francia

³⁴ Conditional moments are directly derived from the open economy NKPC.

³⁵ The results of the estimation are robust relative to the number of lags of instruments. The problem with the estimation of the NKPC is a well-known problem of the GMM estimator in small samples: the results of the estimation are sensitive to the choice of the bandwidth parameter of the Bartlett kernel used in the covariance estimation as the spectrum at zero frequency. This is the very reason why the bandwidth parameter was chosen in an *automatic*, optimal way.

Table 1 Estimated parameters of various specifications of the structural NKPC

	Parameters				Test
	θ	β	λ	D	J – statistics (p-value)
<i>Unrestricted model</i>					
Model (47)	0.92 (0.0089)	0.93 (0.031)	0.0126 (0.0013)	12.5 (1.6)	6.49 (0.98)
Model (48)	0.90 (0.0144)	0.94 (0.044)	0.0171 (0.0019)	10 (1.4)	13.07 (0.73)
<i>Restricted model ($\beta = 1$)</i>					
Model (47)	0.88 (0.0033)	1	0.0164 (0.0009)	8.3 (0.2)	6.62 (0.98)
Model (48)	0.87 (0.0061)	1	0.0194 (0.0020)	7.7 (0.4)	13.03 (0.73)

and Torres Garcia, 2006). The price change frequency in these analyses ranges from two to six quarters.

The average price change frequency appears to be low, especially since, due to high volatility of imported prices, prices in an open economy could be expected to change more often. An analysis capable of answering the question why this is not the case in a small open economy like Croatia, that is, why prices change slowly, has yet to be made in some future paper. Gali and Gertler (1999) offer two explanations for the high share of enterprises that do not change prices, that is, for slow changes in prices. Firstly, it is assumed that the markup is constant in the situation of flexible prices. If it were countercyclical, as claimed in the literature (see Bils, 1987, Warner and Barsky, 1995, Chevalier and Scharfstein, 1995 and Sbordone, 2002), the estimation of parameter θ would be lower. Secondly, if any variable in the production/cost function is disregarded, the average of the labour share and the ratio of the import price to wages is not a good indicator of the real marginal cost. In that case the parameter of the link between the real marginal cost and the inflation rate (λ) is biased downwards, and the parameter of the share of enterprises that cannot change prices (θ) is biased upwards (due to an inverse relationship between λ and θ). In addition, the absence of variables (e.g. lags of inflation) that might explain inflation persistence may lead to estimator bias.

The following section will deal with introducing lags into the NKPC, i.e., with the hybrid version of the NKPC, in order to verify whether the past inflation rate contributes to the explanation of the inflation rate dynamics in Croatia. Numerous analyses have shown that without lagged inflation values, the inflation rate envisaged by the NKPC model is not at all in line with the realised inflation rate (the fit of such a model is very low). With respect to the NKPC in the US, Rudd and Whelan (2006) conclude that almost the whole explanation for the fit derives from the inclusion of lagged inflation values into the NKPC. However, it should also be stressed that critiques demonstrating the (un)importance of the expectation of future costs by excluding these costs and then verifying the quality of the model without this element are practically useless. Rudd and Whelan (2005b) conclude that the quality of the model does not decrease even if future marginal costs are excluded from the model, which points to a dominant role of past inflation in the explanation of current inflation rate trends. This conclusion is in contrast with that reached by Gali and Gertler (1999). However, marginal cost cannot be removed from the NKPC without a detailed analysis of the consequences this exclusion might have on the structural parameters, given that reduced form parameters are a function of all structural parameters and therefore interconnected (for details see Gali *et al.*, 2005).

Nevertheless, in the next section, following on from Gali and Gertler (1999), the model from which the NKPC was derived will be extended in order for the newly-derived hybrid version of the NKPC to include lagged values of the inflation that is estimated subsequently. In order to assess the quality of the explanation of the inflation rate dynamics provided by real marginal cost and inflation expectation, the measure of fundamental inflation for the estimated original NKPC is calculated below. The fundamental inflation rate will be an informal but intuitive measure of the quality and representativeness of the already estimated NKPC model in explaining the inflation rate dynamics in Croatia. Once lagged inflation values are included in the NKPC, the calculation of fundamental inflation for each model will enable a comparison of their quality in terms of better or worse explanations of their fit.

4.2.1 Fundamental inflation

The Phillips Curve derived in the previous section

$$\pi_t = \beta E_t[\pi_{t+1}] + \lambda[s_t + \phi(p_t^M - w_t)] \quad (49)$$

is a first-order stochastic difference equation. The measure of the fundamental inflation rate π_t^* is defined as a solution to this equation, that is, as an infinite sum of future real marginal costs (if the NKPC is solved in advance)

$$\pi_t = \frac{\lambda}{\delta\beta} \sum_{j=0}^{\infty} \left(\frac{1}{\delta}\right)^j E_t[s_{t+j} + \phi(p_{t+j}^M - w_{t+j})] = \pi_t^* \quad (50)$$

where $\delta > 1$ is an unstable root defined as:

$$\delta = \frac{1}{\beta} \quad (51)$$

so that fundamental inflation becomes

$$\pi_t^* = \lambda \sum_{j=0}^{\infty} \beta^j E_t[s_{t+j} + \phi(p_{t+j}^M - w_{t+j})]. \quad (52)$$

Consequently, inflation in the original NKPC is fully determined by the behaviour of future marginal costs. The non-existence of inflation persistence is precisely one of the major, and most criticised, conclusions of the NKPC (for details see Rudd and Whelan, 2006), which will be discussed in the following section.

In the GMM estimation of the model there is in general no standard measure of the model's representativeness, i.e., quality of explanation of the dependent variable (in our case, inflation rate trends) it provides. Fundamental inflation calculated with respect to the estimated parameters of the model is a substitute for the measure of the model's representativeness. Based on the calculation of fundamental inflation it will therefore be possible to assess the quality of explanation of inflation dynamics the NKPC provides and compare the quality of alternative models. In addition to parameter values, the calculation of the fundamental inflation rate requires the calculation of future expected real marginal costs that are not directly noticeable.³⁶ Campbell and Shiller (1987) propose an estimation method for the fundamental price equation as a discounted value of the sum of expected dividends, which is used here in the calculation of the discounted values of the sum of expected marginal costs. This method comprises an estimation of the VAR model for marginal cost and the use of this VAR model to predict the future values of marginal cost.

Let us define marginal cost as follows:

$$mc_t = [s_t + \phi(p_t^M - w_t)] \quad (53)$$

and Y_t as a vector of marginal costs and inflation

$$Y_t = [mc_t \quad mc_{t-1} \quad \dots \quad mc_{t-q} \quad \pi_t \quad \pi_{t-1} \quad \dots \quad \pi_{t-q}] \quad (54)$$

i.e., as a set of available information constituting the variables of marginal cost and inflation until period t , including their lagged values q periods backwards. As a rule, vector Y_t should include all the variables used in the IV estimation of the model, that is, all the instruments constituting this information set. However, due to a small number of data, our information set consists only of the inflation rate and marginal cost (as in Gali and Gertler, 1999, and Ramos-Francia and Torres Garcia, 2006).

In order to predict future marginal cost, the VAR(q) model, containing two variables, marginal cost and

³⁶ The calculation of the fundamental inflation rate is also used to verify if the critiques related to the very poor fit of the NKPC in the US are valid in this case too.

inflation, is estimated. This $VAR(q)$ model can be written as the $VAR(1)$ model

$$Y_t = AY_{t-1} + u_t \quad (55)$$

or

$$\begin{bmatrix} mc_t \\ mc_{t-1} \\ \dots \\ mc_{t-q+1} \\ \pi_t \\ \pi_{t-1} \\ \dots \\ \pi_{t-q+1} \end{bmatrix} = \begin{bmatrix} \alpha_1 & \alpha_2 & \dots & \alpha_q & \eta_1 & \eta_2 & \dots & \eta_q \\ 1 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \dots & 0 \\ \zeta_1 & \zeta_2 & \dots & \zeta_q & \varphi_1 & \varphi_2 & \dots & \varphi_q \\ 0 & 0 & \dots & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} mc_{t-1} \\ mc_{t-2} \\ \dots \\ mc_{t-q} \\ \pi_{t-1} \\ \pi_{t-2} \\ \dots \\ \pi_{t-q} \end{bmatrix} + \begin{bmatrix} u_t^{mc} \\ 0 \\ \dots \\ 0 \\ u_t^\pi \\ 0 \\ \dots \\ 0 \end{bmatrix} \quad (56)$$

where parameters $\alpha_1, \dots, \alpha_q$ and η_1, \dots, η_q are $VAR(q)$ model parameters for the marginal cost equation, and parameters ζ_1, \dots, ζ_q and $\varphi_1, \dots, \varphi_q$ are $VAR(q)$ model parameters for the inflation rate equation. The $VAR(1)$ model can be used to calculate expected future marginal costs k periods forwards, with regard to the information set, by means of the expectations of the $VAR(1)$ model k periods forwards

$$E[Y_{t+k}] = A^k Y_t. \quad (57)$$

Since marginal cost is the first variable in vector Y , the fundamental inflation rate can be calculated on the following basis

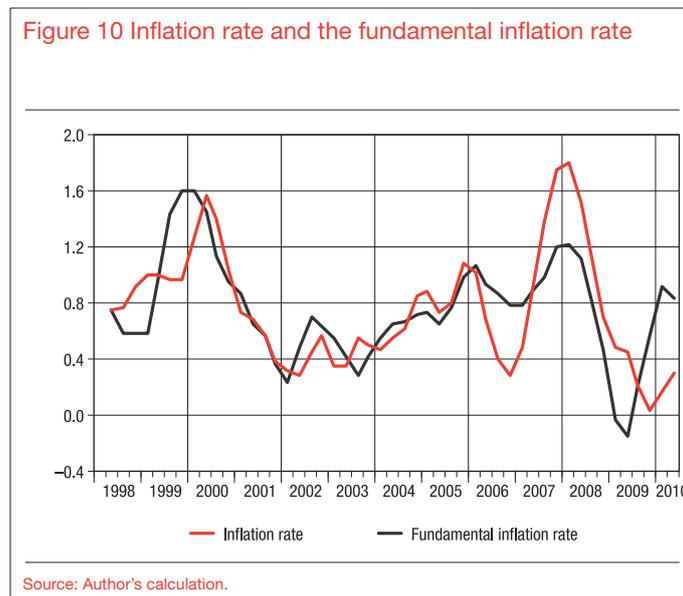
$$\pi_t^* = \lambda \sum_{j=0}^{\infty} \beta^j E_t[mc_{t+j}] = \lambda_{j=0}^{\infty} \beta^j h' A^j Y_t \quad (58)$$

where h' is a vector with one in the first place and zeros elsewhere. This formula can be simplified by the calculation of the infinite sum so that fundamental inflation in the case of the original NKPC reads

$$\pi_t^* = \lambda h' (I - \beta A)^{-1} Y_t \quad (59)$$

where I is the unit matrix.

The calculation of the fundamental inflation rate uses estimated values of parameters of the unrestricted model: $\lambda=0.0171$; $\beta=0.94$ and parameters of the estimated $VAR(2)$ model with marginal cost and inflation.



The result is almost the same if estimated parameters of remaining model specifications are used. The measure of the model's quality in explaining inflation is *RMSE*, i.e., the average difference between the fundamental and the realised inflation rate and R^2 as the percentage of inflation rate variation explained by the variation of the fundamental inflation rate. Figure 10 shows the realised and the calculated fundamental inflation rate,³⁷ with *RMSE* amounting to 0.33%, and R^2 to 0.4. The fit of the model does not seem to be as low as shown by Rudd and Whelan (2005b) for the NKPC in the US. The poor fit of the NKPC for the US is a result of there being no link between the inflation rate and the discounted value of the sum of expected marginal costs. The fit of the NKPC for Croatia is not that poor precisely because the same link in equation (52) is significantly different from zero. This conclusion emphasises the importance of the expectation of future business conditions in a situation where enterprises change domestic prices.

4.3 Hybrid version of an open economy NKPC

The first section establishes that there is a certain persistence in inflation rate trends, i.e., that past inflation also *influences* changes in actual prices. The results of the (GMM) estimation of the reduced form NKPC, which includes *ad hoc* lagged inflation

$$\begin{aligned}\pi_t &= \gamma^b E_t[\pi_{t+1}] + \lambda mc_t + \gamma^f \pi_{t-1} = \\ &= \underset{(0.009)}{0.63} E_t[\pi_{t+1}] + \underset{(0.001)}{0.0097} mc_t + \underset{(0.012)}{0.42} \pi_{t-1}\end{aligned}\quad (60)$$

show that lagged inflation is positively correlated with current inflation, which is confirmed by the result from the first section.³⁸ Furthermore, this result refutes the original NKPC from the previous section as a relevant model for the explanation of the domestic inflation rate dynamics, in contrast with the model that, in addition to inflation expectation, also includes past inflation. However, the results of the estimation of the model with both components of inflation confirm that inflation expectations have a dominant role in determining current inflation trends.

This section presents the hybrid version, theoretically founded, of the NKPC that enables structural interpretation of parameters of the estimated *ad hoc* model. It is analysed whether the hybrid version of the NKPC, i.e. adding lags of inflation, contributes to the decrease in *RMSE* or increase in R^2 (as in many analyses), or whether the strong link between the current inflation rate and its lags exists only because the lags carry information on inflation expectations. This will reinforce the conclusion that the NKPC which does not include past inflation is irrelevant in the explanation of the domestic inflation rate.

In response to critiques related to the non-persistence of the NKPC that explains inflation behaviour exclusively by expected marginal cost, Galí and Gertler (1999) propose a hybrid version of the NKPC. The background theory for the hybrid version of the NKPC is very similar to the model presented in the previous section. The difference between them is that the new model also analyses enterprises that change prices applying a simple rule of thumb based on the past price. These enterprises are *backward-looking*. However, the new model, in addition to *backward-looking* enterprises, also includes both types of enterprises from the Calvo model: enterprises that cannot change prices and enterprises that change prices in an optimal way based on expectations of future marginal costs.

In other words, all enterprises that can change prices continue to do it with probability $(1-\theta)$. However, only a share of enterprises corresponding to $(1-\varpi)$ changes price P_t^f in an optimal way (*looking forward*), as in the Calvo model. The remaining proportion of enterprises ϖ sets price P_t^b , *looking backward*, according to a simple rule, based on the past price. These enterprises' newly-set price thus equals the weighted average of the newly-set price in the previous period and expected inflation, which is based on past inflation trends

37 The calculated fundamental inflation rate represents the deviation of the rate from the trend. In order to calculate a fundamental inflation rate comparable with the realised inflation rate, we added up the HP-trend of the realised inflation rate and the calculated fundamental inflation rate.

38 The instruments applied in the estimation of the model are equal to those used in the estimation of the NKPC in the previous section.

$$P_t^b = P_{t-1}^*(1 + \pi_{t-1}) \quad (61)$$

where P_t^* is the price index as the weighted price average consisting of the price of *backward-looking* and *forward-looking* enterprises

$$P_t^* = (1 - \varpi)P_t^{f(1-\varepsilon)} + \varpi P_t^{b(1-\varepsilon)}. \quad (62)$$

The simple *backward-looking* rule of thumb assumes that enterprises change prices by first checking the price from the previous period and correcting it for inflation in the previous period.

Because of *backward-looking* enterprises, the aggregate price index consists of three types of prices: prices that are changed in a *forward-looking* manner P_t^f , prices that are changed in a *backward-looking* manner P_t^b and prices that are not changed, that is, correspond to prices in previous period P_{t-1}

$$P_t = [(1 - \theta)((1 - \varpi)P_t^{f(1-\varepsilon)} + \varpi P_t^{b(1-\varepsilon)}) - \theta P_{t-1}^{(1-\varepsilon)}]^{1-\varepsilon}. \quad (63)$$

Forward-looking enterprises change prices in an optimal way, as beforehand, and their price is given as:

$$P_t^{f*} = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \left[\sum_{j=0}^{\infty} \theta^j Q_{t+j} (Y_{t+j} P_{t+j}^{\varepsilon-1} MC_{t+j}) \right]}{E_t \left[\sum_{j=0}^{\infty} \theta^j Q_{t+j} (Y_{t+j} P_{t+j}^{\varepsilon-1}) \right]}. \quad (64)$$

As previously, optimal price P_t^{f*} , price index P_t and price index P_t^b of the *backward-looking* enterprises are the solution of the model (for the details of the derivation see Gali *et al*, 2001). In order to solve the system with three nonlinear equations, this equation system is log-linearised by the Taylor expansion around the steady state with inflation equalling 0, which results in three *easier to handle* linear equations

$$p_t^b = (p_{t-1}^* + \pi_{t-1}) = (1 - \varpi)p_t^f + \varpi p_t^b + \pi_{t-1} \quad (65)$$

$$p_t = (1 - \theta)((1 - \varpi)p_t^f + \varpi p_t^b) + \theta p_{t-1} \quad (66)$$

$$p_t^{f*} = (1 - \theta\beta)E_t \left[\sum_{j=0}^{\infty} (\theta\beta)^j mc_{t+j} \right] = (1 - \theta\beta)mc_t + \theta\beta E_t[p_{t+1}^{f*}]. \quad (67)$$

Small letters, as previously, denote variables as log-deviations from their steady state.

Three linearised equations result in a hybrid version of the New Keynesian Phillips Curve, which explains inflation based on expected inflation, past inflation and real marginal cost³⁹

$$\pi_t = \lambda mc_t + \gamma^f E_t(\pi_{t+1}) + \gamma^b \pi_{t-1} \quad (68)$$

where reduced form parameters λ , γ^f , γ^b are the function of structural parameters of the degree of price stickiness θ (which is equal to the share of enterprises which can change prices in an optimal way), discount factor β and the share of *backward-looking* enterprises ϖ

$$\lambda = \frac{(1 - \varpi)(1 - \theta)(1 - \theta\beta)}{\theta + \varpi(1 - \theta(1 - \beta))} \quad (69)$$

³⁹ The hybrid version of the NKPC, due to the inclusion of past inflation, has an important consequence with regard to the role of monetary policy in efforts aimed at reduction of inflation. In the NKPC, a credible inflation reduction monetary policy can reduce inflation without cost because inflation depends exclusively on expected future marginal costs. In the hybrid version, the same policy has a weaker influence because there is inflation persistence. The disinflation process will accelerate if the share of enterprises that change prices *looking forward* increases.

$$\gamma^f = \frac{\theta\beta}{\theta + \varpi(1 - \theta(1 - \beta))} \quad (70)$$

$$\gamma^b = \frac{\varpi}{\theta + \varpi(1 - \theta(1 - \beta))}. \quad (71)$$

An increased share of enterprises incapable of changing prices (θ) definitely increases the weight of expected future inflation in determining current inflation. An increased share of enterprises which can change prices, using simple rule of thumb (ϖ), increases the weight of past inflation. Therefore an increase in both parameters reduces the impact of marginal cost on current inflation.

It should be noted that under condition $\varpi=0$ the hybrid version becomes the NKPC derived in the previous section. If restriction $\beta=1$ is introduced, it is in fact implied that $\gamma^f + \gamma^b = 1$, by which we replicated the reduced form of the hybrid version of the NKPC used prior to the structural theory presented in Galí and Gertler, 1999 (see Buiter and Jewitt, 1982, and Fuhrer and Moore, 1995).

Structural parameters θ , ϖ , β were estimated by the GMM. To achieve robust results of the NKPC estimation (68) two alternative sets of conditional moments were applied

$$E_t \{[\phi\pi_t - (1 - \varpi)(1 - \theta)(1 - \beta\theta)s_t - \theta\beta\pi_{t+1} - \phi\varpi\pi_{t-1}]z_t\} = 0 \quad (72)$$

$$E_t \{[\pi_t - (1 - \varpi)(1 - \theta)(1 - \beta\theta)\phi^{-1}s_t - \theta\beta\phi^{-1}\pi_{t+1} - \varpi\pi_{t-1}]z_t\} = 0 \quad (73)$$

where $\phi = \theta + \varpi(1 - \theta(1 - \beta))$. In addition, in order to make another verification of robustness, two sets of the model were estimated with restriction $\beta=1$. The instruments for π_{t+1} used in the estimation of the hybrid version of the NKPC are the same as those used in the estimation of the NKPC: 4 lags of inflation, 4 lags of PPI inflation, 4 lags of marginal costs and 4 lags of the wage growth rate.

Table 2 shows the results of estimation of the hybrid version of the NKPC. The first three columns show estimated structural parameters (standard errors in brackets), the following four columns show implied reduced form parameters (based on equations (69), (70), (71)), whose standard errors are calculated by the delta method, and the last column presents the Hansen J test-statistics for testing the exogeneity of instruments (p -values in brackets). The results of the estimation of the hybrid version are similar to those attained in the previous section (especially if the standard error of each parameter is taken into account). The estimated share of enterprises that cannot change prices (θ) ranges, as previously, from 0.87 to 0.89. The estimated value for discount factor β is similar to that from the estimated NKPC and to the values of the estimated discount factor in the already mentioned, similar studies. The only difference from the estimated original NKPC is that here, in addition to the importance of expected future inflation, the importance of past inflation in the situation when enterprises change prices is also emphasised. In other words, the estimated parameter of the share of enterprises using a simple rule (ϖ) is significantly different from zero (in all model specifications) and parameter γ^b is therefore significantly different from zero. In contrast, parameter γ^f is significantly different from zero

Table 2 Estimated parameters of various specifications of the hybrid version of the NKPC

	Parameters						Test	
	ϖ	θ	β	γ^b	γ^f	λ	D	J -test
<i>Unrestricted model</i>								
Model (72)	0.44 (0.025)	0.89 (0.011)	0.95 (0.039)	0.33 (0.012)	0.65 (0.013)	0.0073 (0.0013)	9 (1.0)	6.26 (0.97)
Model (73)	0.55 (0.033)	0.87 (0.016)	0.97 (0.067)	0.39 (0.009)	0.60 (0.017)	0.0060 (0.0021)	8.1 (1.0)	22.52 (0.09)
<i>Restricted model ($\beta = 1$)</i>								
Model (72)	0.44 (0.021)	0.88 (0.008)	1	0.33 (0.010)	0.66 (0.010)	0.0057 (0.0010)	8.5 (0.6)	6.23 (0.98)
Model (73)	0.55 (0.023)	0.87 (0.011)	1	0.39 (0.007)	0.61 (0.007)	0.0054 (0.0012)	7.8 (0.7)	23.83 (0.09)

primarily because the share of enterprises that optimally change prices (*forward-looking*) is significantly different from zero (in all model specifications). The fact that γ^f is much larger than γ^b , shows that, in changing prices, enterprises attach more importance to expectations than to past inflation trends.⁴⁰ Most critiques related to the weak role of expectations as the main determinant of the current inflation rate (see Rudd and Whelan, 2005a, 2005b, 2006) are thus rejected.

As concerns the robustness of estimated parameters, the estimated value of the share of enterprises using a simple backward-looking rule of thumb depends on the conditional moments applied in estimation of the hybrid version of the NKPC. The estimated value of this parameter ranges from 0.4 to 0.58 (taking into account the standard error), which shows that approximately half the enterprises that can change prices in a specific period do so based on the inflation rate in the previous period. It is precisely the high value of this parameter that contributes to higher (relative to similar analyses) values of parameter γ^b , which connects past and current inflation. Notwithstanding the higher values of ϖ and γ^b , inflation expectations are the main determinant of the inflation rate. This conclusion is robust relative to any model specification. In addition, the parameter of the restricted model which connects marginal cost and inflation (λ) is in all specifications significant and positive and it is robust to the specification of the model. In all model specifications, the implicitly estimated parameter of price stickiness (D) is in a range of about two years, which is still longer than the average period of unchanged prices in similar, already mentioned studies.⁴¹ Two possible causes for this result are given in the previous section.

The over-identified restrictions test (*J*-test) shows that all instruments used in the estimation of any model are exogenous. In order to verify the non-existence of the problem of weak instruments (for models (47) and (73) and the same conclusion is reached for the remaining specifications of the model) that might influence the bias of the GMM estimator (Stock, Wright and Yogo, 2002), a test is performed to show that all parameters with all instruments together equal zero in the regression of endogenous regressor (π_{t+1}) on all instruments. The results of the test (Table 3) confirm that the problem of weak instruments does not exist.

Table 3 Weak instruments test

	π_{t+1}	Adjusted R^2
	<i>F</i> – statistics (<i>p</i> -value)	
Model (47)	5.89 (0.000093)	0.54
Model (73)	3.94 (0.000853)	0.52

4.3.1 Fundamental inflation

In order to assess the quality of the explanation of the inflation rate dynamics by the hybrid version of the NKPC, the fundamental inflation rate was calculated by the Campbell-Shiller method in a manner similar to that used for the calculation of the fundamental inflation rate for the NKPC. However, in this case the inflation rate does not depend only on the discounted value of the sum of expected real marginal costs, but also on inflation in the previous period

$$\pi_t = \gamma^b \pi_{t-1} + \gamma^f E_t[\pi_{t+1}] + \lambda[s_t + \phi(p_t^M - w_t)]. \quad (74)$$

The hybrid version of the NKPC is therefore a second-order stochastic difference equation, whose solution, that is, the fundamental inflation rate, reads as follows:

$$\pi_t = \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma^f} \sum_{j=0}^{\infty} \left(\frac{1}{\delta_2}\right)^j E_t[s_{t+j} + \phi(p_{t+j}^M - w_{t+j})] = \pi_t^* \quad (75)$$

⁴⁰ Reduced form parameters, estimated as the function of structural parameters, are similar to those directly estimated at the beginning of this section.

⁴¹ The estimated average time of price stickiness and the remaining estimated parameters of the NKPC are similar to the ones employed in the analyses of the NKPC for Chile (Céspedes, Ochoa and Soto, 2005).

where $\delta_1 \leq 1$ is a stable root, and $\delta_2 \geq 1$ unstable root defined as:

$$\delta_1 = \frac{1 - \sqrt{1 - 4\gamma^f \gamma^b}}{2\gamma^f}, \delta_2 = \frac{1 + \sqrt{1 - 4\gamma^f \gamma^b}}{2\gamma^f}. \quad (76)$$

The discounted value of the infinite sum of expected real marginal costs is calculated in the same manner as in the calculation of the fundamental inflation rate for the original NKPC using the VAR(2) model for marginal cost, $mc_t = [s_t + \phi(p_t^M - w_t)]$ and the inflation rate, and using its VAR(1) representation. The fundamental inflation rate therefore reads as follows:

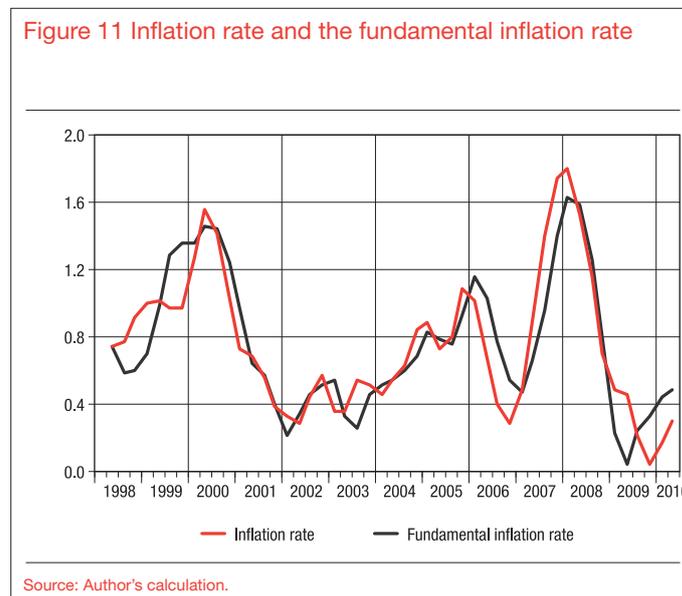
$$\begin{aligned} \pi_t^* &= \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma^f} \sum_{j=0}^{\infty} \left(\frac{1}{\delta_2}\right)^j E_t[mc_{t+j}] = \\ &= \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma^f} \sum_{j=0}^{\infty} \left(\frac{1}{\delta_2}\right)^j h' A^j Y_t = \\ &= \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma^f} h' \left(I - \frac{1}{\delta_2} A\right)^{-1} Y_t \end{aligned} \quad (77)$$

where A , Y_t , h are as previously the autoregressive matrix of the VAR(1) model, vector comprising marginal cost and the inflation rate and vector with 1 in the first place and 0 elsewhere.

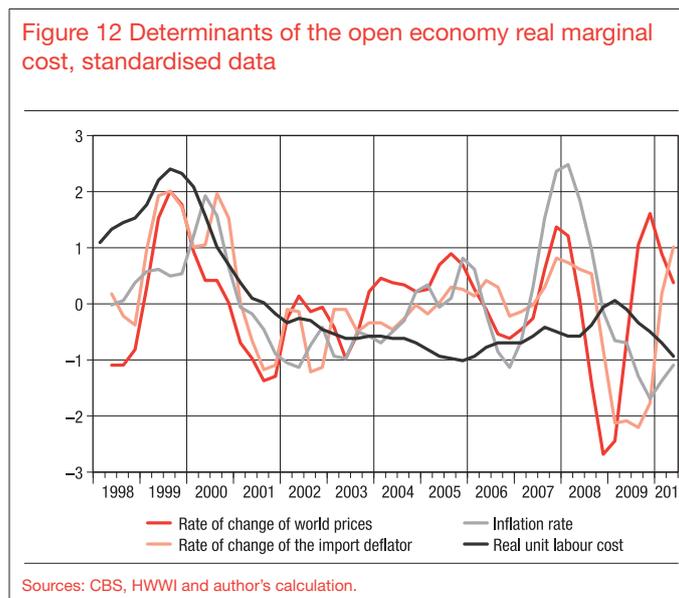
The calculation of the fundamental inflation rate for the hybrid version of the NKPC employed the parameters of the estimated VAR(2) model with marginal cost and inflation (as previously) and the estimated values of structural parameters of unrestricted model $\varpi=0.55$, $\theta=0.87$, $\beta=0.97$ based on which reduced form parameters are calculated $\gamma^f=0.39$, $\gamma^b=0.60$, $\lambda=0.0060$ and finally the roots of the characteristic equation δ_1 and δ_2 .

$RMSE$ and R^2 were used as measures of the model quality in the explanation of inflation. Figure 11 shows the realised and fundamental inflation rates, with $RMSE$ standing at 0.20%, which is by 0.13 basis points lower than $RMSE$ of the original NKPC. The other measure of model quality R^2 jumps from 0.32 to 0.78. The fit of the hybrid version of the NKPC is much better than that in the original NKPC model, which, in addition to the significance of expected inflation, also points to the importance of past inflation trends in the situation of a change in current prices. The results showing the importance of both *forward-looking* and *backward-looking behaviour* in price setting, with the component of expectations having a larger influence, correspond with the estimated parameters of the hybrid version of the NKPC.

The fundamental inflation rate in the hybrid version of the NKPC very well explains the realised inflation rate dynamics (Figure 11). However, the two inflation rates start to diverge in mid-2009, the time of the



recovery of world prices as the main determinant of marginal cost, which we used in the estimation of the hybrid version of the NKPC. This is why the model shows that the domestic inflation rate should have increased because of cost pressures stemming from a surge in imported inflation. The reason why this did not happen is probably because domestic demand was weak (the unit labour cost decreased) during the recession, which attenuated cost pressures. This is best illustrated by the rate of change of the import deflator, whose growth considerably has lagged behind that of world prices since late 2008, due to weak demand and its recovery in the domestic market (Figure 12). The moderate inflation rate growth since the beginning of 2010 is probably due to the late recovery of imported prices irrespective of the continued decrease in the unit labour cost.



4.4 Sensitivity analysis

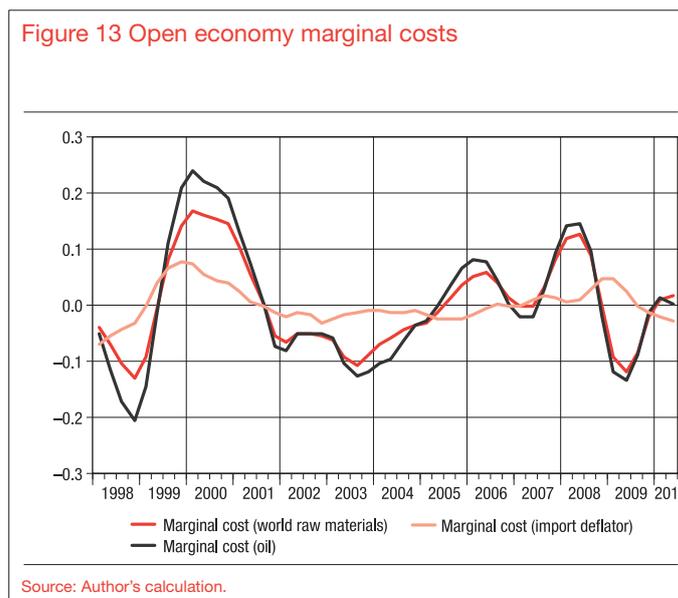
In order to check the sensitivity of estimated NKPC parameters, two additional unrestricted models of the hybrid version of the NKPC were estimated (72), using the oil price (in kuna terms) or the import deflator in the marginal cost calculation, instead of world raw material prices (basic model). The parameters of the estimated hybrid version of the NKPC with the oil price are very similar to the estimated parameters of the basic model (Table 4). This result is not surprising, since the oil price dynamics and, even more importantly, its volatility are very similar to those of world raw material prices (Figure 6), accounting for the very similar movement of the two measures of marginal costs (Figure 13) based on which they are calculated. The parameters of the hybrid version of the NKPC related to the share of enterprises that use a simple rule in changing prices (ϖ) and the discount factor (β) (and thus also reduced form parameters γ^b , γ^f) do not deviate from the values of the same parameters of the basic model.

The large difference between the two sets of parameters relates to the share of enterprises that cannot change prices θ : this parameter of the model with marginal cost that uses the import deflator is higher in the calculation than the same parameter in the basic model. It is even more important that the same parameter is less precisely estimated. Precisely due to its large variance, the average time during which prices are sticky (D) is insignificant (irrespective of its unrealistic high value). Due to the same reason, the parameter linking marginal cost and inflation rate (λ) is insignificant, which is in disagreement with theoretical conclusions and the previously estimated models of the NKPC. Although the behaviour of the import deflator is also similar to that of oil prices and world raw materials, its volatility is much lower. This is probably the reason why marginal cost calculated on the basis of the import deflator is under the prevailing influence of the unit labour cost (and therefore on the decrease since early 2009, in spite of the import deflator increasing since mid 2009, see Figure 6), which, as we have already shown, cannot explain the dynamics of the domestic inflation rate.

Table 4 Sensitivity analysis of estimated NKPC parameters with regard to marginal cost calculation

	Parameters							Test
	ϖ	θ	β	γ^b	γ^f	λ	D	$J - test$
Model with marginal cost								
Raw materials (basic model)	0.44 (0.025)	0.89 (0.011)	0.95 (0.039)	0.33 (0.012)	0.65 (0.013)	0.0073 (0.0013)	9 (1.0)	6.26 (0.97)
Oil	0.46 (0.030)	0.87 (0.016)	0.97 (0.067)	0.39 (0.009)	0.60 (0.017)	0.0060 (0.0021)	8.1 (1.0)	22.52 (0.09)
Import deflator	0.52 (0.017)	0.87 (0.011)	1	0.39 (0.007)	0.61 (0.007)	0.0054 (0.0012)	7.8 (0.7)	23.83 (0.09)

Figure 13 Open economy marginal costs



5 Conclusion

This paper is an empirical analysis of the domestic inflation rate in the light of the New Keynesian Model, that is, the New Keynesian Phillips Curve as its solution. The results of the estimation of numerous specifications of the NKPC show that the hybrid version of an open-economy NKPC provides a better explanation for the dynamics of the domestic inflation rate than other forms of the model. This result is in accordance with previous research on the dynamics of the domestic inflation rate, which emphasises the importance of foreign prices as the main determinant of domestic inflation (Krznar and Kunovac, 2010). The Old Phillips Curve *does not exist* because an indicator of the domestic economic activity like the GDP gap cannot explain the behaviour of the domestic inflation rate. The estimated original New Keynesian Curve, which does not include persistence of the inflation rate, demonstrates a strong link between open economy marginal cost and the inflation rate and between the expected and current inflation rate. However, the quality of this model with regard to the proportion of inflation rate variation explained by the model is much weaker than the estimated hybrid version of the NKPC.

The empirical results of this paper point to the conclusion that the main determinants of domestic inflation are past and expected inflation and real marginal cost which, in addition to the labour share, also includes foreign, imported prices. As the estimated value of the share of enterprises that cannot change prices is relatively small, the values of estimated parameters of the hybrid New Keynesian Curve suggest that in a situation when enterprises change prices, expected inflation rates play a more important role than past inflation.

The parameter of the price change frequency is low, with enterprises changing prices on average every eight quarters. Therefore, modelling the determinants of the variable markup and the analysis of additional factors of marginal cost (e.g. of imported consumer goods that affect a trader's marginal cost⁴²) would seem to be reasonable steps to take in any future research into the inflation rate and the high degree of price stickiness in Croatia.

42 For details see Dabušinskas and Kulikov (2007).

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paper must be well laid out, containing: number, title, units of measurement, legend, data source, and footnotes. The footnotes referring to tables, figures and charts should be indicated by lower-case letters (a,b,c...) placed right below. When the tables, figures and charts are subsequently submitted, it is necessary to mark the places in the text where they should be inserted. They should be numbered in the same sequence as in the text and should be referred to in accordance with that numeration. If the tables and charts were previously inserted in the text from other programs, these databases in the Excel format should also be submitted (charts must contain the corresponding data series).

The preferred formats for illustrations are EPS or TIFF with explanations in 8 point Helvetica (Ariel, Swiss). The scanned illustration must have 300 dpi resolution for grey scale and full colour illustration, and 600 dpi for lineart (line drawings, diagrams, charts).

Formulae must be legible. Indices and superscript must be explicable. The symbols' meaning must be given following the equation where they are used for the first time. The equations in the text referred to by the author should be marked by a serial number in brackets closer to the right margin.

Notes at the foot of the page (footnotes) should be indicated by Arabic numerals in superscript. They should be brief and written in a smaller font than the rest of the text.

References cited in the text are listed at the last page of the manuscript in the alphabetical order, according to the authors' last names. References should also include data on the publisher, city and year of publishing.

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