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Unanticipated Inflation, Unemployment Persistence and the New Keynesian Phillips Curve

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Abstract

This paper puts forward an analytically tractable dynamic stochastic general equilibrium model, with both labor and product market frictions. Frictions in the labor market arise from the power of labor market insiders to periodically pre-set nominal wages, without full current infor- mation. Product market frictions arise from monopolistic competition and staggered pricing. The model results in a dynamic expectations-augmented New Keynesian Phillips Curve (DEANKPC) that transcends the main limitations of the benchmark and hybrid NKPCs based on staggered pricing, as: (i) it is expressed in terms of unanticipated inflation since current inflation depends on prior expectations about its level; (ii) unemployment (output) and inflation persistence are endogenous; and (iii) the divine coincidence between the stabilization of inflation and employment (output) does not apply, rendering a Taylor-type interest rate rule optimal. We evaluate the dy- namic properties of the model and the empirical validity of the DEANKPC, in comparison with those of the benchmark NK model, through a simulation exercise and an empirical application for the Euro Area.

Keywords: Unemployment persistence, unanticipated inflation, wage setting, staggered pricing, mon- etary policy.

JEL Classification: E3, E4, E5

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1 Introduction

Understanding the nature of short-term inflation dynamics and their interaction with the business cycle is a central issue in macroeconomics. Modern theoretical modeling of inflation dynamics has been developed within the framework of "dynamic stochastic general equilibrium" (DSGE hereafter) models, which have become the dominant approach to the study of aggregate fluctuations.[1] A major building block of DSGE models is the benchmark "new Keynesian Phillips Curve" (NKPC hereafter), a model derived from the assumptions of monopolistic competition and Calvo (1983) staggered pricing in the market for goods and services.[2] The model suggests that inflation depends on deviations of unemployment (output) from its natural rate and expected future inflation. It thus differs from the original "expectations augmented Phillips Curve" (EAPC hereafter), in that current inflation does not depend on prior expectations about current inflation itself, but on current expectations about future inflation.

Despite the widespread utilization of the NKPC in macroeconomics and especially in monetary policy analysis, the model has important limitations and shortcomings. First of all, the empirical performance of the NKPC has been found to be unsatisfactory, as it implies much faster adjustment of inflation and unemployment to both nominal and real shocks than actually observed in the data. Therefore, in empirical applications, an augmented with ad hoc lagged inflation terms version of the NKPC is utilized, in order to achieve a better correspondence of the model with the actual dynamics of inflation.[3] Because of the ad hoc nature of these additions, this has led to proposals for theoretical alternatives to the NKPC, such as the sticky information model of Mankiw and Reis (2002).[4]

A second shortcoming of the NKPC is the so called "divine coincidence" between the stabilization of inflation and the stabilization of unemployment (output) at its natural rate, first emphasized by Blanchard and Gali (2007). In models based on the NKPC, eliminating fluctuations in inflation has the effect of eliminating fluctuations in real variables as well. There is no tradeoff between the stabilization of inflation and the stabilization of real variables around their natural rates. In fact,

[1]See among others, Blanchard (2009, 2016); Chari and Kehoe (2006); Chari et al. (2009); Lucas (2009), Mankiw (2006); Woodford (2009) for macroeconomists being for or against the DSGE class of macroeconomic models.

[2]Alternative microfoundations to the Calvo (1983) model are provided through the Rotemberg (1982a,b) model of convex costs of price adjustment. See Roberts (1995) for the derivation of the NKPC under Rotemberg (1982a,b) pricing. Yun (1996) is usually credited for the original derivation of the benchmark "new Keynesian" Phillips curve under Calvo (1983) staggered pricing. For most macroeconomic purposes, Rotember and Calvo pricing are observationally equivalent.

[3]Two interesting studies that compare the empirical performance of the *standard* NKPC with that of the *hybrid* one (that incorporates ad hoc lagged inflation terms) are that of Brissimis and Magginas (2008) and Roeger and Herz (2012).

[4]The original tests of the benchmark NKPC are in Gali and Gertler (1999). These suggested a statistically significant impact from lagged inflation, leading to a rejection of the benchmark model in favor of a hybrid model with ad hoc lagged inflation terms. Additional tests in the same direction can be found in papers published in a special issue of the Journal of Monetary Economics in 2005. See King and Plosser (2005). In these, Gali et al. (2005); Sbordone (2005) and others reaffirm the significance of lagged inflation terms. See also the work of Rudd and Whelan (2007) for a consign review of the arguments in favor of the augmented NKPC with lagged inflation terms.

in order to address the divine coincidence problem, Blanchard and Gali (2007) proposed that the "new keynesian" model with staggered pricing should be augmented with some form of exogenous real wage rigidity, that would break the link between the stabilization of inflation and the stabilization of output and employment. However, the introduction of such real wage rigidity is also ad hoc, as it is not consistent with the microfoundations of the model.

In the present paper we propose an analytically tractable DSGE model, with both labor and product market frictions, that transcends the main limitations of the standard NKPC model. In our model, frictions in the labor market arise from the power of labor market insiders to periodically pre-set nominal wages, without full current information. Product market frictions arise from monopolistic competition and staggered pricing. The model allows for persistent deviations of unemployment and output from their natural rates, even in the absence of persistent shocks. In addition, the model can explain the high persistence of inflation, as a result of attempts by central banks to stabilize persistent deviations of unemployment and output from their natural rate.[5]

The main distinguishing characteristic of the model put forward in this paper is a "dynamic expectations-augmented new Keynesian Phillips Curve (DEANKPC)" that encompasses the characteristics of both the EAPC and the NKPC. The DEANKPC is expressed in terms of unanticipated inflation allowing current inflation to depend on both prior expectations for current inflation and current expectations for future inflation. The most important feature of this Phillips curve is that does not suffer from the two shortcomings of the *benchmark* and *hybrid* NKPCs. The DEANPC accounts for the unemployment (and thus inflation) persistence following nominal and real shocks (in contrast with the *standard* NKPC). In our model, this unemployment (inflation) persistence is endogenous, arising from the wage-setting behavior of the labor market insiders, and is not based on ad hoc lagged inflation terms as in the case of the *hybrid* NKPC. Finally, the divine coincidence between the stabilization of inflation and employment (output) does not apply in our model because real shocks endogenously induce a short run tradeoff between inflation and unemployment, rendering a Taylor-type interest rate rule optimal.

We evaluate the dynamic properties of our model through a simulation exercise. Responding to real and nominal shocks, our model exhibits richer inflation dynamics than the standard new Keynesian model, depending highly on the degree of the price stickiness in the economy. Moreover, we are performing a comparative assessment of the empirical performance of the DEANKPC, along with that of the *standard* and *hybrid* NKPCs using data for the Euro Area for the period 1999Q1-2022Q3.

[5]Inflation persistence is a crucial factor in the analysis of inflation dynamics. Bobeica and Jarocinski (2019) underlined that although most models had predicted a strong disinflation in the US and euro-area in the immediate wake of the Great Recession, inflation failed to fall as much as expected given the depth of the recession. An important reason for this failure of the models was that they did not capture the inflation persistence in the US and Euro-area inflation dynamics. A key aspect of our model is that it can explain the high persistence of inflation.

Building on the work of Brissimis and Magginas (2008) and Zhang et al. (2009), we proxy inflation expectations by using ECB's inflation forecasts, obtained from the *Survey of Professional Forecasters (SPF)*. The DEANKPC is empirically verified, and its explanatory power is at least as good as that of the *benchmark* and *hybrid* versions of the NKPC.

Compared to the benchmark NKPC, our model is based on additional distortions, both arising in the labor market, but analyzed explicitly. First, we assume that nominal wages are set in advance, on the basis of the prior expectations of wage setters about current variables, and remain fixed for one period. We thus embed into the benchmark "New Keynesian" model the one period nominal wage contracts of Gray (1976); Fischer (1977a). This introduces an additional nominal distortion, due to the fact that current shocks to productivity and aggregate demand are not known when nominal wages are determined. Thus, unanticipated current inflation reduces real wages and causes employment to increase, like in the "original" models of the "expectations augmented Phillips curve" (EAPC). The model produces a trade off between current unanticipated inflation and output and employment. In addition to inflation, all unanticipated shocks which cause a divergence between current real wages and productivity cause deviations of output and employment from their "natural rates", due to their effects on unit labor costs.

Second, we embody in our model a real labor market distortion, in the spirit of the "insider-outsider" models of wage determination of Lindbeck and Snower (1986); Blanchard and Summers (1986); Gottfries and Horn (1987) and Gottfries (1992). According to this approach, there is an asymmetry in the wage setting process between "insiders", who already have jobs, and "outsiders", who are seeking employment. "Outsiders" are disenfranchised from the labor market, as wages are set by "insiders", who seek to maximize the real wage consistent with their own employment. "Insiders" are not concerned with the employment of "outsiders". This suggests an additional reason as to why the natural rate of unemployment is inefficiently high, but, more significantly, because of the assumption that in each period the number of insiders is positively related to employment in the previous period, the model implies that deviations of unemployment rate and output from their natural rates display endogenous persistence.[6]

We first introduce these two distortions with a model of monopolistic competition with fully flexible prices. Because of the nominal distortion, we derive a "Dynamic Expectations Augmented Phillips Curve" (DEAPC), based only on predetermined nominal wage contracts and not staggered pricing. This is very similar to the original "expectations augmented Phillips curve", the only difference being that deviations of current inflation from one period ahead expectations depend on both current and past deviations of unemployment and output from their natural rates. Thus, our expectations

[6] An overview of the theoretical and empirical literature on the unemployment persistence can be found in Cross (1988) and Oâ Shaughnessy (2011). Moreover, Bakas and Makhlouf (2020) provide important empirical evidence for the role of insider-outsider theory as a key source of unemployment persistence.

augmented Phillips curve is dynamic.

We then extend the model, with the additional nominal distortion implied by staggered pricing in the market for goods and services. We derive a generalized "Dynamic Expectations Augmented New Keynesian Phillips Curve" (DEANKPC), which encompasses both the EAPC and the NKPC. Both are special cases of the more general model with both one period predetermined nominal wage contracts set by labor market insiders and staggered pricing. We demonstrate that the more general DEANKPC does not suffer from any of the two major weaknesses of the benchmark NKPC. Past inflation affects current inflation, because of the labour market induced persistence of deviations of unemployment and output from their natural rates, while expectations of future inflation affect current inflation through staggered pricing. Inflation stabilization does not result in the stabilization of output and employment, because real shocks endogenously induce a short run tradeoff between inflation and unemployment.

We analyze the model assuming a Taylor (1993) rule for monetary policy, and prove that inflation displays the same degree of persistence as deviations of unemployment and output from their natural rates.[7] In addition, we prove that the divine coincidence does not hold in this model. We also demonstrate that equilibrium inflation persists even when monetary policy is chosen in an optimal fashion.

Finally, we evaluate the dynamic properties of the theoretical model though a simulation exercise, comparing its dynamics with those of the benchmark NKPC model. Moreover, in order to examine the empirical validity of the DEANKPC, we perform an empirical application for the Euro Area.

The rest of the paper is as follows: In section 2 we discuss the optimal behavior of households and its implications for consumption and money demand. In section 3 we discuss the optimal pricing and production of monopolistically competitive firms, under the assumption of flexible prices. In section 4 we discuss wage setting and employment in a model of the labor market characterized by nominal distortions, in the form of predetermined one period nominal wage contracts, and real distortions, because of the distinction between insiders and outsiders in the labor market. We derive a dynamic expectational Phillips curve, based on these two distortions. This suggests that current inflation is determined by expected inflation based on past information, and current and past deviations of unemployment (output) from its natural rate. In section 5 we relax the assumption of fully flexible prices and introduce staggered pricing. In section 6 we derive a dynamic expectations-augmented new Keynesian Phillips curve (DEANKPC), which combines predetermined one period nominal wage contracts with staggered pricing. In section 7 we analyze the general version of our dynamic stochastic general equilibrium model under the assumption of a Taylor rule for monetary policy. In section 8 we

[7] In the Appendix, we demonstrate that the persistence of unemployment results in persistent equilibrium inflation, independently of whether one assumes staggered pricing or not. The reason is the clash in the objectives between wage setters and the monetary authorities and the endogenous persistence of unemployment.

show that this result goes through even under the assumption of optimal monetary policy. In section 9 we present dynamic simulations of the model and examine its dynamic properties under both flexible prices and staggered pricing. We also examine its dynamic properties with and without unemployment persistence. In section 10 we present a comparative empirical evaluation of the benchmark, the hybrid and the DEANKPC. The last section summarizes our conclusions.

2 Households and Optimal Consumption and Money Demand

We assume that the economy consists of a continuum of identical households i, where $i \in [0,1]$. Each household member is constrained to supply one unit of indivisible labor, and unemployment impacts all households in the same manner.[8]

The representative household chooses (aggregate) consumption and real money balances in order to maximize,

$$E_t \sum_{s=0}^{\infty} \left(\frac{1}{1+\rho}\right)^s \left(\frac{1}{1-\theta}\left(V^C_{t+s} C^{1-\theta}_{t+s} + V^M_{t+s}\left(\frac{M}{P}\right)^{1-\theta}_{t+s}\right)\right) \tag{1}$$

where ρ denotes the pure rate of time preference, θ is the inverse of the elasticity of intertemporal substitution, C is consumption and M/P real money balances. V^C and V^M denote exogenous stochastic shocks in the utility from consumption and real money balances respectively.

Consumption consists of differentiated goods and services indexed by a continuous index j, where $j \in [0,1]$. The consumption bundle is thus given by,

$$C_t = \left(\int_{j=0}^{1} C(j)_t^{\frac{\varepsilon-1}{\varepsilon}} dj\right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{2}$$

where ε is also a parameter of the preferences of the representative household, and more precicely, the elasticity of substitution between goods. We assume that $\varepsilon > 1$.

Utility is maximized subject to the sequence of expected budget constraints,

$$E_t \left(F_{t+s+1} = (1+i_{t+s}) \left(\begin{array}{l} F_{t+s} - \frac{i_{t+s}}{1+i_{t+s}} M_{t+s} + P_{t+s}\left(Y_{t+s} - T_{t+s}\right) \\ - \int_{j=0}^{1} P(j)_{t+s} C(j)_{t+s} dj \end{array} \right) \right) \tag{3}$$

where $F_t = B_t + M_t$, denotes the financial assets held by the representative household, i the nominal interest rate, B one period nominal bonds, M nominal money balances, Y real non interest income and T real taxes net of transfers. $P(j)$ is the price of good j.

The household must also satisfy the transversality condition,

[8] These assumptions can be justified in terms of models of indivisible labor, as in Hansen (1985) and Rogerson (1988).

$$\lim_{T\to\infty} E_t F_{t+T} \geq 0 \tag{4}$$

The household must decide on the distribution of its consumption expenditure among the various goods and the intertemporal allocation of its total consumption expenditure and money demand. The first problem requires the maximization of the consumption bundle (2) for any level of monetary expenditure. One can easily deduce that this implies,

$$C(j)_t = \left(\frac{P(j)_t}{P_t}\right)^{-\varepsilon} C(t) \tag{5}$$

for any good j in the interval $[0, 1]$, where P is the average price level, defined as,

$$P_t = \left(\int_{j=0}^{1} P(j)_t{}^{1-\varepsilon} dj\right)^{\frac{1}{1-\varepsilon}} \tag{6}$$

(5) defines the demand for good j as a function of its relative price and the level of aggregate demand C.

In addition, when the household follows this optimal allocation policy, we also have that,

$$\int_{j=0}^{1} P(j)_t C(j)_t dj = P_t C_t \tag{7}$$

(7) suggests that total consumption expenditure can be written as the product of the aggregate consumption index and the aggregate price index. Substituting (7) in the sequence of expected budget constraints (3), we get,

$$E_t \left(F_{t+s+1} = (1 + i_{t+s}) \left(\begin{array}{l} F_{t+s} - \frac{i_{t+s}}{1+i_{t+s}} M_{t+s} \\ +P_{t+s} \left(Y_{t+s} - T_{t+s} - C_{t+s}\right) \end{array} \right) \right) \tag{8}$$

The solution to the intertemporal problem of the household can thus be derived from the first order conditions for a maximum of (1), subject to (8). We then get,

$$V_t^C C_t^{-\theta} = \lambda_t (1 + i_t) P_t \tag{9}$$

$$V_t^M \left(\frac{M}{P}\right)_t^{-\theta} = \lambda_t i_t P_t \tag{10}$$

$$E_t \lambda_{t+1} = E_t \left(\frac{1+\rho}{1+i_{t+1}}\right) \lambda_t \tag{11}$$

where λ_t is the Lagrange multiplier in period t.

(9)-(11) have the standard interpretations. (9) suggests that at the optimum the household equates the marginal utility of consumption to the value of savings. (10) suggests that the household equates the marginal utility of real money balances to the opportunity cost of holding money. (11) suggests that at the optimum, the real interest rate, adjusted for the expected increase in the marginal utility of consumption, is equal to the pure rate of time preference.

From (9), (10) and (11), eliminating λ, implies that,

$$\left(\frac{M}{P}\right)_t = C_t\left(\frac{V_t^C}{V_t^M}\frac{i_t}{1+i_t}\right)^{-\frac{1}{\theta}} \tag{12}$$

$$E_t\left(\frac{V_{t+1}^C(C_{t+1})^{-\theta}}{P_{t+1}}\right) = \left(\frac{1+\rho}{1+i_t}\right)\left(\frac{V_t^C(C_t)^{-\theta}}{P_t}\right) \tag{13}$$

(12) is the money demand function, which is proportional to consumption and a negative function of the nominal interest rate, and (13) is the familiar Euler equation for consumption.

Log-linearizing (12) and (13),

$$m_t - p_t = c_t - \frac{1}{\theta}\ln\left(\frac{i_t}{1+i_t}\right) + \frac{1}{\theta}\left(v_t^M - v_t^C\right) \tag{14}$$

$$c_t = E_t c_{t+1} - \frac{1}{\theta}\left(i_t - E_t\pi_{t+1} - \rho\right) + \frac{1}{\theta}(v_t^C - E_t v_{t+1}^C) \tag{15}$$

where lowercase letters denote natural logarithms, and $\pi_t = p_t - p_{t-1}$ is the rate of inflation.[9]

We now turn to the behavior of firms in product markets.

3 Firms and Optimal Pricing and Production

We assume that output is produced by a set of firms denoted by a continuous index j defined in the interval [0,1]. Each firm produces a differentiated product under conditions of monopolistic competition. All firms have access to the same production technology, denoted by the production function,

$$Y(j)_t = A_t L(j)_t{}^{1-\alpha} \tag{16}$$

where $A_t > 0$ and $0 < \alpha < 1$ are exogenous technological parameters, common to all firms. $L(j)_t$ is employment of labor by firm j in period t. The parameter α is constant, while A_t, exogenous

[9] Technically, since the logarithm of the expectation of a product (or ratio) of two random variables is not equal to the sum (or difference) of the expectations of the logarithms of the relevant random variables, (15) must also contain second order terms, depending on the covariance matrix of consumption, inflation and shocks to preferences for consumption and money. Assuming that all exogenous shocks are independent stationary stochastic processes, these second order terms are constant and can be ignored.

productivity, is assumed to follow an exogenous stochastic process.

The optimal price of each firm, if it can choose its price in every period, is given by the maximization of its profits, under the constraint of the production function (16) and the demand function for its product (5). Each firm takes the average price P, the nominal wage $W(j)$ and the level of aggregate demand C as given.

The per period profits of firm j are given by,

$$P(j)_t Y(j)_t - W(j)_t L(j)_t \tag{17}$$

From the first order conditions for a maximum of (17), under the constraints (16) and (5), the optimal price is determined as,

$$P(j)_t = \frac{\varepsilon}{\varepsilon - 1}\left(\frac{W(j)_t (L(j)_t)^{\alpha}}{(1-\alpha)A_t}\right) \tag{18}$$

The optimal price is a fixed markup on the firm's marginal cost, which equals the expression in brackets.

The marginal cost of production is the wage divided by the marginal product of labor. Since the marginal product of labor is decreasing with the level of employment, the marginal cost of production is an increasing function of employment and output.

The markup depends positively on the elasticity of substitution between goods in the preferences of consumers, which determines the price elasticity of demand of their product, and therefore the profit margin of the firm. In the case of perfect competition, the elasticity of substitution tends to infinity, and the price tends to marginal cost. In the case of monopolistic competition with $\varepsilon > 1$, as we have assumed, the optimal price is higher than the marginal cost of labor.[10]

As all firms have the same production function and the same demand function for their product, they will all choose the same price if they face the same nominal wage W. Consequently, the price level will be defined as,

$$P_t = \frac{\varepsilon}{\varepsilon - 1}\left(\frac{W_t L_t^{\alpha}}{(1-\alpha)A_t}\right) \tag{19}$$

If firms face different wages $W(j)$, then they will choose different prices, and (19) denotes the average price as a function of the average of marginal unit labor costs. In either case, the price level is a fixed markup on marginal labor costs. It thus depends positively on nominal wages and employment, and negatively on exogenous productivity shocks.

Taking the logarithm of the production function (16) for the representative firm, and equation

[10] This model of monopolistic competition, with a constant elasticity of demand, is due to Dixit and Stiglitz (1977)

(19) for the optimal price, we get,

$$y_t = a_t + (1-\alpha)l_t \tag{20}$$

$$p_t = \mu + w_t - a_t + \alpha l_t \tag{21}$$

where, $a_t = \ln A_t$ and $\mu = \ln\left(\frac{\varepsilon}{\varepsilon-1}\right) - \ln(1-\alpha)$. a is the logarithm of the exogenous productivity shock, and the constant μ is the logarithm of the markup on marginal cost, minus the logarithm of the coefficient of decreasing returns to the employment of labor.

From (21), the higher the level of employment, the higher the price level relative to nominal wages, as higher employment implies lower marginal productivity of labor. Since employment is positively related to output from the production function (20), higher output also implies higher prices relative to nominal wages. This can be seen by using (20) to substitute for employment in (21). One finds that,

$$p_t = \mu + w_t - \frac{1}{1-\alpha}a_t + \frac{\alpha}{1-\alpha}y_t \tag{22}$$

From (22), for given exogenous productivity a_t, firms will only produce more if prices rise relative to wages. The reason is that an increase in output results in higher unit labor costs, because of the diminishing marginal productivity of labor.

We next turn our attention to the labor market and the determination of nominal wages.

4 Wage Setting and Employment in a Insider Outsider Model

Nominal wages are set in a decentralized manner, by "insiders" in each firm. Wages are set at the beginning of each period, before variables, such as current productivity, current aggregate demand and the current price level are known. Nominal wages remain constant for one period, and they are renegotiated at the beginning of the following period.[11]

Thus, this model is characterized by nominal wage stickiness of the Gray (1976), Fischer (1977b) variety. Prices are determined ex post by firms, given the contract wage, aggregate demand, the price level and exogenous productivity a_t.

Following Blanchard and Summers (1986), we assume that the number of "insiders" in each firm, who at the beginning of each period determine the contract wage, consists of an exogenous number of "core insiders", and those who were employed by the firm in the previous period. The objective of

[11] The labor market model in this section was first introduced by Alogoskoufis (2018) in the context of a analysis of optimal monetary policy in a perfectly competitive product market model with flexible prices.

insiders is to set the maximum nominal wage which, given their rational expectations about aggregate demand, the price level and exogenous productivity, will minimize expected deviations of employment from the target level of "insiders". This target level is a weighted average of all those who were employed in period $t-1$, and the exogenous set of "core" employees of each firm. Thus, this model is characterized by a state dependent pool of insiders, as in Blanchard and Summers (1986). The employment target of insiders in period t is determined by,

$$\bar{n}(j)_t = \delta l(j)_{t-1} + (1-\delta)\bar{n}(j) \tag{23}$$

where $l(j)_{t-1}$ is the logarithm of the number of those who were actually employed in the previous period, and $\bar{n}(j)$ is the logarithm of the number of "core" employees of firm j, assumed exogenous. δ is the weight of those recently employed relative to "core" employees, in the employment target of insiders. This formulation is the one proposed by Blanchard and Summers (1986).

The expectations on the basis of which wages are set depend on information available until the end of period $t-1$, but not on information about aggregate demand, prices and exogenous productivity in period t. On the basis of the above, we assume that the objective of wage setters is to choose the path of maximum wages that would minimize deviations of the expected employment path, from the expected path of the employment target of current "insiders".

This can be modeled as a maximin problem. Insiders are assumed to choose the expected employment path that minimizes deviations from their target, and select the maximum wage path that satisfies their optimal employment path, subject to the optimal pricing decisions of firms. Thus, the frist stage of the problem can be formalized as choosing the path of current and expected future wages which minimizes the following quadratic intertemporal loss function,

$$\min E_{t-1} \sum_{s=0}^{\infty} \beta^s \frac{1}{2} \left(l(j)_{t+s} - \bar{n}(j)_{t+s} \right)^2 \tag{24}$$

This is mininized subject to the sequence of optimal prices (21) and employment targets $\bar{n}(j)_t$, as defined in (23). $\beta = 1/(1+\rho) < 1$ is the discount factor, with ρ being the pure rate of time preference. As can be seen from (24), "outsiders", i.e the unemployed, have no influence on the wage setting process.

We shall assume that the total number of "core" employees in the economy is always strictly smaller than the labor force. This assumption ensures that the natural rate of unemployment is strictly positive. We thus assume that,

$$\int_{i=0}^{1} \bar{n}(j) dj = \bar{n} < n \tag{25}$$

where n is the log of the labor force.

From the first order conditions for a minimum of (24), wages are set at the maximum level which ensures that expected (log) employment by each firm satisfies,

$$E_{t-1}l(j)_t = \frac{\beta\delta}{1+\beta\delta^2}E_{t-1}l(j)_{t+1} + \frac{\delta}{1+\beta\delta^2}l(j)_{t-1} + \frac{(1-\beta\delta)(1-\delta)}{1+\beta\delta^2}\bar{n}(j) \tag{26}$$

The implied contract wage can be derived by using the log linear version of the optimal pricing condition (18), to substitute for employment in (26).

Integrating over j, *expected aggregate employment* must then satisfy,

$$E_{t-1}l_t = \frac{\beta\delta}{1+\beta\delta^2}E_{t-1}l_{t+1} + \frac{\delta}{1+\beta\delta^2}l_{t-1} + \frac{(1-\beta\delta)(1-\delta)}{1+\beta\delta^2}\bar{n} \tag{27}$$

(27) is the same as (26) without the i index.

Wage contracts that satisfy (27) encompass Gray-Fischer wage contracts and Blanchard-Summers wage contracts as special cases.

With the standard Gray-Fischer contracts, $\delta = 0$, as past employment does not exert any separate influence on the wage setting process. Only "core" employees would matter in Gray-Fischer type contracts. Setting $\delta = 0$ in (23), nominal wages in Gray-Fischer contracts would be set at the maximum level which ensures that,

$$E_{t-1}l_t = \bar{n}$$

On the other hand, with Blanchard-Summers contracts, there is no consideration of the effects of current contracts on expected employment beyond period t. This is equivalent to setting $\beta = 0$ in (27), i.e with myopic behavior. Setting $\beta = 0$ in (27) implies that nominal wages would be set in order to ensure that,

$$E_{t-1}l_t = \delta l_{t-1} + (1-\delta)\bar{n}$$

This is identical to equation (3.2) in Blanchard and Summers (1986). Nominal wages with Blanchard-Summers contracts would be set at the maximum level which ensures that expected employment equals a weighted average of "core" employees, and those recently employed, without consideration for the effects on future employment.

In our more general dynamic model, wages are set at the maximum level which ensures that expected employment in period t is given by (27), which also depends on expected employment in period $t+1$. This is because expected employment at t will affect the number of insiders who will negotiate wages for period $t+1$. Thus, in our model, current labor market "insiders" are forward looking, in that they set nominal wages in order to achieve an employment target which depends on "core" employees, those previously employed, but also on those expected to be employed in the future, as expected future employment will affect the future number of "insiders" and thus future wage setting behavior.

As a result, this dynamic model is more general than the standard Gray-Fischer and Blanchard-Summers models.

4.1 Wage Determination, Unemployment Persistence and the Phillips Curve

To solve (27) for expected employment, define the forward expectations operator F, as,

$$F^s l_t = E_{t-1} l_{t+s} \tag{28}$$

We can then rewrite (27) as,

$$\left((1+\beta\delta^2)F^0 - \beta\delta F - \delta F^{-1}\right) l_t = (1-\beta\delta)(1-\delta)\bar{n} \tag{29}$$

(29) can be rearranged as,

$$-\beta\delta F^{-1}\left(F^2 - \frac{1+\beta\delta^2}{\beta\delta}F + \frac{1}{\beta}\right) l_t = (1-\beta\delta)(1-\delta)\bar{n} \tag{30}$$

It is straightforward to show that if $0 < \beta < 1$ and $0 < \delta < 1$, the characteristic equation of the quadratic in the forward shift operator (in brackets) has two distinct real roots, which lie on either side of unity. The two roots satisfy,

$$\lambda_1 + \lambda_2 = \frac{1+\beta\delta^2}{\beta\delta}, \lambda_1\lambda_2 = \frac{1}{\beta} \tag{31}$$

Using (31) we can rewrite (30), as,

$$(F-\lambda_1)(F-\lambda_2)l_t = -\frac{(1-\beta\delta)(1-\delta)}{\beta\delta}\bar{n} \tag{32}$$

Assuming λ_1 is the smaller root, we can solve (32) as,

$$E_{t-1}l_t = \lambda_1 l_{t-1} + (1-\lambda_1)\bar{n} \tag{33}$$

(33), which is the rational expectations solution of (27), determines the path of expected employment aimed at by the wage setting behavior of "insiders".

It is straightforward to show that λ_1, the coefficient that determines the persistence of expected unemployment, is equal to δ, the relative weight of recent employees in the wage setting process. From (31), which defines the two roots, it follows that since $\lambda_2 = 1/\beta\lambda_1$, it follows that,

$$\lambda_1 + \frac{1}{\beta\lambda_1} = \frac{1+\beta\delta^2}{\beta\delta} = \delta + \frac{1}{\beta\delta} \tag{34}$$

Thus, the degree of persistence of employment λ_1 is equal to the weight of recent employees relative to "core" employees in the wage setting process δ, exactly as suggested by Blanchard and Summers (1986).

The expected employment equation (33) can be transformed into an expected unemployment equation in a straightforward manner. Subtracting (33) from the log of the labor force n, after some rearrangement, we get,

$$E_{t-1}u_t = \delta u_{t-1} + (1-\delta)\bar{u} \tag{35}$$

where, $u_t \simeq n - l_t$ is the current unemployment rate, and $\bar{u} \simeq n - \bar{n} > 0$ is the natural rate of unemployment. The natural rate of unemployment in this model is defined in terms of the difference between the labor force and the number of core "employees". This is the equilibrium rate towards which the economy would converge in the absence of shocks. Note that In (35) we have also made used of the fact that $\lambda_1 = \delta$.

Actual employment, is determined from the pricing and employment decisions of firms, after information about aggregate demand and productivity shocks has been revealed.

From the optimal pricing equation (21), in order to achieve the employment target (33), insiders will set the nominal wage at,

$$w_t = E_{t-1}p_t - \mu + E_{t-1}a_t - \alpha\left(\delta l_{t-1} + (1-\delta)\bar{n}\right) \tag{36}$$

In (36) we have also made used of the fact that $\lambda_1 = \delta$.

Substituting the wage determination equation (35) in the optimal pricing equation of firms (21), the (log) price level will be determined by,

$$p_t = E_{t-1}p_t - (a_t - E_{t-1}a_t) + \alpha\left(l_t - \delta l_{t-1} - (1-\delta)\bar{n}\right) \tag{37}$$

Thus, prices will differ from the expectations of wage setters to the extent that there are unanticipated shocks to exogenous productivity and unanticipated shocks to aggregate demand, which cause firms to determine employment at a different level than the one expected by wage setters.

It is straightforward to transform (37) into an expectations augmented Phillips curve. Subtracting p_{t-1} from both sides, and adding and subtracting the log of the labor force multiplied by α on the right hand side, we get,we get that,

$$\pi_t = E_{t-1}\pi_t - (a_t - E_{t-1}a_t) - \alpha\left((u_t - \bar{u}) - \delta(u_{t-1} - \bar{u})\right) \tag{38}$$

where $\pi_t = p_t - p_{t-1}$ is the inflation rate, $u_t \simeq n - l_t$ is the unemployment rate, where n is the log of the labor force, and $\bar{u} \simeq n - \bar{n}$, is the natural unemployment rate.

(38) is the expectations augmented Phillips curve in this model. It is a dynamic version of a traditional "expectations augmented Phillips curve" (EAPC), in the sense that inflation depends on prior inflationary expectations, but also on both current and past deviations of unemployment from its natural rate. According to (38), current inflation differs from prior expectations of inflation to the extent that there are unanticipated shocks to exogenous productivity and unanticipated shocks to aggregate demand, which cause the unemployment rate to differ from the target unemployment rate of wage setters. The dynamics arise because of the assumption that the target unemployment rate of wage setters is a weighted average of the past and the natural unemployment rate, due to the objectives of labor market insiders.

4.2 The Relation between Output and Unemployment Persistence

It is also clear from this model that only unanticipated shocks to exogenous productivity and aggregate demand cause unemployment to deviate from its expected path, as determined by the behavior of wage setters, and summarized in (35).

Note that if (35) holds, and wage setters have rational expectations, the unemployment rate follows,

$$u_t = \delta u_{t-1} + (1-\delta)\bar{u} + \zeta_t^u \tag{39}$$

where ζ_t^u is a white noise process, encompassing unanticipated productivity and demand shocks.

Hence, deviations of current unemployment from its natural rate will display persistence equal to δ, the weight of past employees on the wage setting process. In fact, deviations of unemployment from its natural rate will follow an AR(1) process of the form,

$$(u_t - \bar{u}) = \delta(u_{t-1} - \bar{u}) + \zeta_t^u \tag{40}$$

The persistence of employment and unemployment, will also be translated into persistent output fluctuations.

Adding and subtracting $(1-\alpha)(n - \bar{n})$, to the aggregate production function (20), we get that,

$$y_t = \bar{y}_t - (1-\alpha)(u_t - \bar{u}) \tag{41}$$

where,

$$\bar{y}_t = (1-\alpha)\bar{n} + a_t \tag{42}$$

is the log of the natural rate of output.

(41) is an Okun (1962) type of relation, which suggests that fluctuations of output around its natural rate will be negatively related to fluctuations of the unemployment rate around its own natural rate. Since deviations of employment and unemployment from their natural rates display persistence, so will fluctuations in output. The propagation mechanism is the state dependence of the employment target of insiders in the labor market. Hence, deviations of output from its own natural rate will follow,

$$(y_t - \bar{y}_t) = \delta(y_{t-1} - \bar{y}_{t-1}) - (1-\alpha)\zeta_t^u \tag{43}$$

Deviations of output from its natural rate will follow an AR(1) process as well, with the same degree of persistence δ as unemployment.

5 The Implications of Staggered Pricing

Up to now we have assumed predetermined wages and flexible prices. We shall now introduce price stickiness as a additional nominal distortion. A number of alternative "new keynesian" models of gradual price adjustment under monopolistic competition have been developed in the literature. We shall concentrate on one of them, the Calvo (1983) model, which is based on staggered pricing.[12]

All firms are assumed to be able to automatically index their prices to the steady state inflation rate. However, following Calvo (1983), we shall assume that the probability of adjusting prices freely, at a rate different than steady state inflation, is equal to $1-\gamma$, which is constant and independent of the length of time that has elapsed since the last such price adjustment by the firm. Thus, in each period, a proportion $1-\gamma$ of all firms adjust their prices freely, and the remaining proportion γ are constrained to index their prices only to the rate of steady state inflation.[13]

[12] An observationally equivalent model, is the Rotemberg (1982a), Rotemberg (1982b) model of quadratic costs of adjusting prices, which is observationally equivalent to the Calvo (1983) model. The concept of staggered price and wage adjustment was first introduced to macroeconomics by Akerlof (1969). Versions of staggered nominal wage contracts were used to study the role of monetary policy under rational expectations by Fischer (1977a), and Taylor (1979), Taylor (1980). These contracts were fixed term contracts. Calvo (1983) generalized the Taylor fixed term contracts to contracts with a stochastic duration.

[13] In most standard models of staggered pricing, it is assumed that the firms that are constrained cannot adjust their

Under these assumptions, in period t, the expected future duration of any price contract is given by,

$$(1-\gamma)\sum\nolimits_{s=0}^{\infty} s\gamma^{s} = \frac{\gamma}{1-\gamma} \tag{44}$$

From the definition of the price level in (6), and the fact that all firms that freely reset their prices in period t set the same price, it follows that,

$$\hat{P}_t = \left(\gamma\left(\hat{P}_{t-1}\right)^{1-\varepsilon} + (1-\gamma)\left(\bar{P}_t\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \tag{45}$$

where $\hat{P}$ is the price level relative to the steady state price level, and $\bar{P}$ is the price set by the firms that freely reset their prices in the current period relative to the steady state price level.

From (45) one can show that the dynamic adjustment of the price level relative to the steady state price level is determined by,

$$\left(\frac{\hat{P}_t}{\hat{P}_{t-1}}\right)^{1-\varepsilon} = \gamma + (1-\gamma)\left(\frac{\bar{P}_t}{\hat{P}_{t-1}}\right)^{1-\varepsilon} \tag{46}$$

In the steady state with inflation equal to π^* we have that $\hat{P}_t = \bar{P}_t = 1$ and the price level evolves as,

$$P_t = (1+\pi^*)P_{t-1} \tag{47}$$

A loglinear approximation of (46) around the steady state price level yields,

$$\hat{p}_t - \hat{p}_{t-1} \simeq (1-\gamma)\left(\bar{p}_t - \hat{p}_{t-1}\right) \tag{48}$$

From (48) it follows that inflation exceeds its steady state rate if firms that set prices in the current period set them at a higher level than the average price of the previous period adjusted for steady state inflation.

5.1 Optimal Pricing with Staggered Price Adjustment

In order to analyze the adjustment of inflation, one has to examine how firms that can freely adjust prices in the current period decide on their optimal price, taking into account the fact that for a period

prices at all. Yun (1996) is probably the first analysis of a "new keynesian" dynamic stochastic general equilibrium model, such as the one in this section, under the Calvo (1983) assumption of staggered pricing. However, in the case that one does not allow for indexation to the steady state inflation rate, and the steady state inflation is positive, the model violates the natural rate property. See for example Ascari and Sbordone (2014).

in the future they may not be able to readjust their prices freely, while some of their competitors will have the option of readjusting their own prices at a rate different than core inflation.

The problem of the firm that decides on the price it is about to set in period t is to set the price that maximizes the expected present value of its profits, given that the probability of readjusting its price in any future period is equal to $1-\gamma$. Thus, all firms that readjust their prices in period t maximize,

$$E_t \sum\nolimits_{s=0}^{\infty} \gamma^s \left(I(s) \left(\bar{P}_t Y_{t+s}^t - \hat{W}_{t+s} L_{t+s}^t \right) \right) \tag{49}$$

where $I(s) = \prod_{z=0}^{s} \left(\frac{1}{1+i_{t+z}} \right)$ and $\hat{W}$ is the nominal wage divided by the steady state price level.

The maximization takes place under the constraints of their production function and the demand function for their product. These are given by,

$$Y_{t+s}^t = A_{t+s} \left(L_{t+s}^t \right)^{1-\alpha} \tag{50}$$

$$Y_{t+s}^t = \left(\frac{\bar{P}_t}{\hat{P}_{t+s}} \right)^{-\varepsilon} Y_{t+s} \tag{51}$$

where, Y_{t+s}^t and L_{t+s}^t are the volume of output and employment in period $t+s$, of the firm that has set its prices freely in period t. The higher the relative price of the firm in any period, the lower the demand for its product and thus the volume of its output and employment.

From the first order conditions for a maximum it follows that,

$$E_t \sum\nolimits_{s=0}^{\infty} \gamma^s I(s) \begin{pmatrix} (\varepsilon - 1) \left(\frac{\bar{P}_t}{\hat{P}_{t+s}} \right)^{-\varepsilon} \\ - \frac{\varepsilon}{(1-\alpha)} \left(\frac{\bar{P}_t}{\hat{P}_{t+s}} \right)^{-\frac{1-\alpha+\varepsilon}{1-\alpha}} \left(\frac{\hat{W}_{t+s}}{\hat{P}_{t+s}} \right) \left(\frac{L_{t+s}^{\alpha}}{A_{t+s}} \right) \end{pmatrix} = 0 \tag{52}$$

(52) implies that the expected present value of revenues from the optimal price is equal to the expected present value of the marginal cost of production, augmented by the price markup $\varepsilon/(\varepsilon-1)$ of the firm.

It is worth noting that, as we have already shown in equation (19), if the firm could determine its prices in every period, the price of the product in each period would be equal to the marginal cost of production augmented by the same markup. However, if the firm cannot adjust prices freely in every period, as is assumed in the Calvo (1983) model, pricing follows the dynamic pricing rule (52).

Assuming that in the steady state inflation is equal to π^*, and all prices are equal to steady state prices, (52) can be transformed into logarithmic deviations from the steady state equilibrium, using a log linear Taylor approximation. Thus, in logarithms we shall have that,

$$\bar{p}_t \simeq (1-\beta\gamma)\sum\nolimits_{s=0}^{\infty}(\beta\gamma)^s E_t\left(\hat{p}_{t+s}+\omega\left(\mu+w_{t+s}-p_{t+s}+\alpha l_{t+s}-a_{t+s}\right)\right) \tag{53}$$

where, $\beta=\frac{1}{1+\rho+\pi^*}$ and $\omega=\frac{1-\alpha}{1+\alpha(\varepsilon-1)}$. It follows that $0<\beta,\omega<1$.

Consequently, firms that freely reset their prices in period t will choose a price which corresponds to a weighted average of the current and expected future price levels, relative to the steady state price level, plus a margin μ on a weighted average of the current and expected future levels of real marginal costs. The discount factor of a future period $t+s$ depends on the probability that the firm will not be able to reset its price in the future period $t+s$, which equals γ^s, times the discount rate β^s. Furthermore, the part of pricing which depends on the expected marginal cost of the firm depends negatively on the elasticity of demand for the product of the firm, through the parameter ω.

Using the future mathematical expectations operator F, (53) can be rewritten as,

$$\bar{p}_t \simeq \frac{1-\beta\gamma}{1-\beta\gamma F}\hat{p}_t+\omega\left(\mu+\frac{1-\beta\gamma}{1-\beta\gamma F}\left(w_t-p_t+\alpha l_t-a_t\right)\right) \tag{54}$$

5.2 The "New Keynesian Phillips Curve"

Substituting (54) in the equation for the adjustment of the average price level (48) we get that,

$$\hat{p}_t=\gamma\hat{p}_{t-1}+(1-\gamma)\left(\frac{1-\beta\gamma}{1-\beta\gamma F}\hat{p}_t+\omega\left(\mu+\frac{1-\beta\gamma}{1-\beta\gamma F}\left(w_t-p_t+\alpha l_t-a_t\right)\right)\right) \tag{55}$$

Multiplying both sides of (55) by $1-\beta\gamma F$, after some rearrangements, we get that,

$$(1+\beta)\hat{p}_t-\hat{p}_{t-1}-\beta E_t\hat{p}_{t+1}=\frac{(1-\gamma)(1-\beta\gamma)}{\gamma}\omega\left(\mu+\left(w_t-p_t+\alpha l_t-a_t\right)\right) \tag{56}$$

(56) is the equation of adjustment of the price level towards the steady state price level, which is a constant markup on the marginal cost of production.

From the price adjustment equation (56), we can deduce an equation for fluctuations in inflation. Expressing (56) as an inflation equation we have that,

$$\pi_t=(1-\beta)\pi^*+\beta E_t\pi_{t+1}+\frac{(1-\gamma)(1-\beta\gamma)}{\gamma}\omega\left(\mu+\left(w_t-p_t+\alpha l_t-a_t\right)\right) \tag{57}$$

where $\pi_t=p_t-p_{t-1}$ is the rate of inflation.

(57), which is the basis of the NKPC, implies that deviations of current inflation from steady state inflation are greater than discounted expected deviations of future inflation from steady state inflation, if the current marginal cost of labor, plus the margin μ is higher than the current price level p. The reason is that firms able to set prices freely in the current period post larger price increases than (discounted) expected future inflation, in order to offset the higher current marginal cost of labor.

Note that if all firms can adjust their prices freely, and $\gamma = 0$, then the price level is always equal to the marginal cost of production augmented by the fixed markup μ, and inflation is equal to steady state inflation in all periods. Hence, the existence of a positive relation between inflation and employment, in (57) requires staggered pricing in the form of a positive γ.

6 A Dynamic Expectations-Augmented New Keynesian Phillips Curve: Combining Staggered Pricing with Periodic Nominal Wage Contracts

We can now combine staggered pricing with periodic nominal wage contracts set by insiders, as the ones introduced in section 3.

Wages in period t are set in the beginning of the period, based on information available until the end of $t-1$, in order to ensure that expected employment is equal to the target of labor market insiders, i.e, that,

$$E_{t-1}l_t = \delta l_{t-1} + (1-\delta)\bar{n} \tag{58}$$

Hence, from (57), the nominal wage in period t satisfies,

$$\begin{aligned} w_t = \tfrac{\gamma}{(1-\gamma)(1-\beta\gamma)\omega}\left(E_{t-1}(\pi_t - \pi^*) - \beta(E_{t-1}\pi_{t+1} - \pi*)\right) + \\ + E_{t-1}p_t - \mu + E_{t-1}a_t - \alpha\left(\delta l_{t-1} + (1-\delta)\bar{n}\right) \end{aligned} \tag{59}$$

which is the equivalent of equation (36) in the case of staggered pricing. Note that if we set $\gamma = 0$, we get back to (36).

Substituting (59) for the nominal wage in the NKPC (57), after some rearrangement, we get,

$$\begin{aligned} \pi_t = E_{t-1}\pi_t + \beta\left(E_t\pi_{t+1} - E_{t-1}\pi_{t+1}\right) - \tfrac{(1-\gamma)(1-\beta\gamma)\omega}{\gamma}\left(\pi_t - E_{t-1}\pi_t\right) \\ + \tfrac{(1-\gamma)(1-\beta\gamma)}{\gamma}\omega\left(\alpha\left(l_t - \delta l_{t-1} - (1-\delta)\bar{n}\right) - (a_t - E_{t-1}a_t)\right) \end{aligned} \tag{60}$$

Noting that, $l_t - \delta l_{t-1} - (1-\delta)\bar{n} \simeq -(u_t - \delta u_{t-1} - (1-\delta)\bar{u})$, (60) can be solved for current inflation, as,

$$\begin{aligned} \pi_t &= E_{t-1}\pi_t + \tfrac{\beta\gamma}{\gamma+(1-\gamma)(1-\beta\gamma)\omega}\left(E_t\pi_{t+1} - E_{t-1}\pi_{t+1}\right) + \\ &- \tfrac{(1-\gamma)(1-\beta\gamma)\omega}{\gamma+(1-\gamma)(1-\beta\gamma)\omega}\left(\alpha\left((u_t-\bar{u}) - \delta\left(u_{t-1}-\bar{u}\right)\right) + \left(a_t - E_{t-1}a_t\right)\right) \end{aligned} \tag{61}$$

(61) is a “dynamic expectations-augmented new Keynesian Phillips curve” (DEANKPC), which encompasses both the “new keynesian Phillips curve” (NKPC) and the “expectations augmented Phillips curve” (EAPC) (38) as special cases. It is *dynamic* as past inflation affects current inflation, because of the labour market induced persistence of deviations of unemployment and output from their natural rates due to wage setting. It is *expectations-augmented* as current inflation depends on prior expectations about current inflation itself. It is *new Keynesian* as current inflation depends on expectations about future inflation.

For example, by dropping the assumption of staggered pricing and setting $\gamma = 0$, (61) is transformed to,

$$\pi_t - \pi^* = \left(E_{t-1}\pi_t - \pi^*\right) - \left(a_t - E_{t-1}a_t\right) - \alpha\left((u_t-\bar{u}) - \delta\left(u_{t-1}-\bar{u}\right)\right)$$

This is the same as (38), which determines inflation only as a function of previously expected inflation, unanticipated productivity shocks and current and lagged deviations of unemployment from its natural rate.

(61) allows for both current expectations of future inflation, due to the assumption of staggered pricing, and past expectations of current inflation, due to the assumption of predetermined nominal wage contracts. It also allows for the effects of both the current and the past unemployment rate, because of the dynamics in the composition of labor market insiders.

From the Okun type relation (41), it follows that,

$$u_t - \bar{u} = -\frac{1}{1-\alpha}\left(y_t - \bar{y}_t\right) \tag{62}$$

where $\bar{y}_t$ is the natural rate of output, given by (42).

Through the use of (62), the DEANKPC (61) can also be expressed in terms of deviations of output from its natural rate as,

$$\begin{aligned} \pi_t &= E_{t-1}\pi_t + \tfrac{\beta\gamma}{\gamma+(1-\gamma)(1-\beta\gamma)\omega}\left(E_t\pi_{t+1} - E_{t-1}\pi_{t+1}\right) + \\ &+ \tfrac{(1-\gamma)(1-\beta\gamma)\omega}{\gamma+(1-\gamma)(1-\beta\gamma)\omega}\left(\tfrac{\alpha}{1-\alpha}\left((y_t-\bar{y}_t) - \delta\left(y_{t-1}-\bar{y}_{t-1}\right)\right) - \left(a_t - E_{t-1}a_t\right)\right) \end{aligned} \tag{63}$$

In what follows, we shall use this version of the DSPC. When we need to go back to the determination of unemployment, we shall use the Okun-type equation (62).

7 Inflation and Aggregate Fluctuations under a Taylor Rule

Since there is no capital and investment in this model, and no distinction between private and government consumption expenditure, product market equilibrium implies that output is equal to consumption.

$$Y_t = C_t \tag{64}$$

This product market equilibrium condition allows us to substitute output for consumption in the money demand function and the Euler equation for consumption, and derive optimal aggregate money and output demand functions.

7.1 "New Neoclassical Synthesis" IS-LM Functions

Substituting (64) in (14) and (15), we get the money and output aggregate demand functions, as,

$$m_t - p_t = y_t - \frac{1}{\theta} \ln \left(\frac{i_t}{1+i_t} \right) + \frac{1}{\theta} \left(v_t^M - v_t^C \right) \tag{65}$$

$$y_t = E_t y_{t+1} - \frac{1}{\theta} \left(i_t - E_t \pi_{t+1} - \rho \right) + \frac{1}{\theta} (v_t^C - E_t v_{t+1}^C) \tag{66}$$

(65) can be seen as the money market equilibrium condition, the equivalent of the LM curve in the traditional models of the "neoclassical synthesis", and (66) as the product market equilibrium condition, the equivalent of the IS curve. Since (65) and (66) are derived from an explicit problem of intertemporal optimization by the representative household, we shall refer to them the "new neoclassical synthesis" (NNS) LM curve and IS curves respectively.

7.2 The Natural and Equilibrium Real Interest Rate

The real interest rate is defined by the Fisher (1896) equation,[14]

$$r_t = i_t - E_t \pi_{t+1} \tag{67}$$

[14] To quote from Fisher (1896), "When prices are rising or falling, money is depreciating or appreciating relative to commodities. Our theory would therefore require high or low interest according as prices are rising or falling, provided we assume that the rate of interest in the commodity standard should not vary." (p. 58). The rate of interest in the commodity standard is the real interest rate, and rising or falling prices are expected inflation.The Fisher equation was further elaborated in Fisher (1930), where it was made even clearer that Fisher referred to expected inflation.

As with other real variables, we shall distinguish between the current and the natural real interest rate. The natural real interest rate is determined by the product market equilibrium condition, when output is at its natural rate. From (42) and (67), the natural real interest rate is thus determined by,

$$\bar{r}_t = \rho - \theta \left(a_t - E_t a_{t+1}\right) + \left(v_t^C - E_t v_{t+1}^C\right) \tag{68}$$

The natural real interest rate is equal to the pure rate of time preference, but also depends positively on deviations of current shocks to consumption from anticipated future shocks, and negatively on deviations of current productivity shocks from anticipated future shocks. Hence, the natural real interest rate is affected by real shocks, such as productivity and consumption preference shocks. Productivity shocks which cause a temporary increase in the natural level of output, lead to a reduction of the natural real rate of interest, in order to induce a corresponding increase in consumption and maintain product market equilibrium. On the other hand, real consumption preference shocks which cause a temporary increase in consumption, require an increase in the natural real rate of interest, in order to bring consumption back to the natural level of output, and maintain product market equilibrium.

Because of the existence of predetermined one period nominal wage contracts, and because of staggered pricing, the current equilibrium real interest rate deviates from its natural rate to the extent that current output deviates from its own natural rate. Solving the "new neoclassical synthesis" IS curve (66) for the real interest rate, using (42) for the natural rate of output, we get that the current real interest rate is given by,

$$r_t = i_t - E_t \pi_{t+1} = \bar{r}_t - \theta(1-\delta)(y_t - \bar{y}_t) \tag{69}$$

Deviations of the current real interest rate from its natural rate depend negatively on deviations of output from its own natural rate. Since deviations of output from its natural rate tend to persist, deviations of the real interest rate from its own natural rate will tend to persist as well.

Shocks to inflation or productivity, which cause a temporary rise in current output relative to its natural rate, affect output through reducing the current real interest rate relative to its natural rate.[15]

7.3 Equilibrium Fluctuations with Exogenous Preference and Productivity Shocks

In what follows, we shall assume that the logarithms of the exogenous shocks to preferences and productivity follow stationary $AR(1)$ processes of the form.

[15] This is the well known "Wicksellian" mechanism, emphasized for the first time by Wicksell (1898).

$$v_t^C = \eta_C v_{t-1}^C + \varepsilon_t^C \tag{70}$$

$$v_t^M = \eta_M v_{t-1}^M + \varepsilon_t^M \tag{71}$$

$$a_t = \eta_A a_{t-1} + \varepsilon_t^A \tag{72}$$

where the autoregressive parameters satisfy, $0 < \eta_C, \eta_M, \eta_A < 1$, and ε^C, ε^M, ε^A, are white noise processes.[16]

With these assumptions, for a given nominal interest rate, fluctuations in output and inflation will be determined by the NNS IS relation (67), and the DEANKPC (64). Expressing these as deviations from natural rates, we get that,

$$y_t - \bar{y}_t = -\frac{1}{\theta(1-\delta)}\left(i_t - E_t\pi_{t+1} - \bar{r}_t\right) \tag{73}$$

$$\begin{aligned} \pi_t = E_{t-1}\pi_t + \tfrac{\beta\gamma}{\gamma+(1-\gamma)(1-\beta\gamma)\omega}\left(E_t\pi_{t+1} - E_{t-1}\pi_{t+1}\right) + \\ + \tfrac{(1-\gamma)(1-\beta\gamma)\omega}{\gamma+(1-\gamma)(1-\beta\gamma)\omega}\left(\tfrac{\alpha}{1-\alpha}\left(\left(y_t - \bar{y}_t\right) - \delta\left(y_{t-1} - \bar{y}_{t-1}\right)\right) - \varepsilon_t^A\right) \end{aligned} \tag{74}$$

The natural rates of real variables, such as output, $\bar{y}_t$, and the real interest rate $\bar{r}_t$, evolve as functions of the exogenous real shocks only. Using (70) and (72) to substitute for productivity and real consumption shocks in (42) and (68), we get that,

$$\bar{y}_t = (1-\alpha)\bar{n} + a_t \tag{75}$$

$$\bar{r}_t = \rho - \theta\left(1-\eta_A\right)a_t + \left(1-\eta_C\right)v_t^C \tag{76}$$

Thus, deviations of real output from its natural rate depend on the current nominal interest rates, expected future inflation and shocks to the natural real rate of interest, while inflation is determined through the dynamic expectations-augmented new Keynesian Phillips curve (74).

In order to solve the model one needs an assumption about the determination of the nominal interest rate. We shall assume that this is determined by the central bank, which follows a Taylor

[16] The assumption of $AR(1)$ processes could easily be generalized to $AR(n)$ processes, without affecting the nature of the results in this paper, as, eventually, it is only the unanticipated component of these shocks that affects deviations of real and nominal variables from their natural rates.

rule of the form,

$$i_t = \bar{r}_t + \pi^* + \phi_\pi (\pi_t - \pi^*) + \phi_y (y_t - \bar{y}_t) + \varepsilon_t^i \tag{77}$$

where $\phi_\pi, \phi_y > 0$ are policy parameters, and ε_t^i is a white noise monetary policy shock.

According to this rule, the central bank aims for a nominal interest rate which is equal to the natural real rate of interest, plus a target inflation rate equal to the steady state inflation rate π^*. If actual inflation is higher than the target π^*, then the central bank raises interest rates in order to reduce inflation towards its target. In addition, if output is higher than its natural rate, then the central bank increases nominal interest rates, in order to reduce aggregate demand and bring output back to its natural rate.[17]

One can use the Taylor rule (77), to substitute for the nominal interest rate in the aggregate demand equation (73), and then substitute for deviations of output from its natural rate in the dynamic expectations-augmented new Keynesian Phillips curve (74), to derive an inflation equation that depends only on inflation terms, and on real and nominal shocks. Proceeding with these substitutions one gets a transformed inflation process of the form,[18]

$$\begin{aligned} \hat{\pi}_t = & E_{t-1}\hat{\pi}_t + \kappa_1 (E_t\hat{\pi}_{t+1} - E_{t-1}\hat{\pi}_{t+1}) + \\ & -\kappa_2 \left(\kappa_3 \left(\phi_\pi (\hat{\pi}_t - \delta\hat{\pi}_{t-1}) - (E_t\hat{\pi}_{t+1} - \delta E_{t-1}\hat{\pi}_t) + \varepsilon_t^i - \delta\varepsilon_{t-1}^i\right) + \varepsilon_t^A\right) \end{aligned} \tag{78}$$

where, $\hat{\pi}_t = \pi_t - \pi^*$ is the deviation of current inflation from steady state inflation, the target of the central bank, and where the κ coefficients are defined as,

$$\begin{aligned} \kappa_1 &= \tfrac{\beta\gamma}{\gamma+(1-\gamma)(1-\beta\gamma)\omega} \\ \kappa_2 &= \tfrac{(1-\gamma)(1-\beta\gamma)\omega}{\gamma+(1-\gamma)(1-\beta\gamma)\omega} \\ \kappa_3 &= \tfrac{\alpha}{1-\alpha}\tfrac{1}{\theta(1-\delta)+\phi_y} \end{aligned} \tag{79}$$

In order to solve for inflation, we first take expectations of (78) conditional on information available up to the end of period $t-1$. This yields,

$$E_{t-1}\hat{\pi}_t = \frac{1}{\delta + \phi_\pi} E_{t-1}\hat{\pi}_{t+1} + \frac{\delta\phi_\pi}{\delta + \phi_\pi}\hat{\pi}_{t-1} + \frac{\delta}{\delta + \phi_\pi}\varepsilon_{t-1}^i \tag{80}$$

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[17]We have expressed the Taylor rule in terms of deviations of output and not unemployment from its natural rate. This does not affect the results, as through the Okun type relation (41), deviations of unemployment from its natural rate are a negative linear function of deviations of output from its own natural rate. We have also assumed that the central bank interest rate adjusts to shocks that affect the natural real rate of interest, which is not treated as a constant.

[18]Once one solves for inflation, one can also determine deviations of output from its natural rate, as well as deviations of all other nominal and real variables, such as the nominal interest rate, the unemployment rate and others.Note that under a nominal interest rate rule such as (77) the money supply becomes endogenous, and is determined through the money demand function (65).

The process (80) will be stable if and only if,

$$\frac{1+\delta\phi_\pi}{\delta+\phi_\pi} < 1 \tag{81}$$

It is straightforward to show that a necessary and sufficient condition for (81) to hold is that,

$$\phi_\pi > 1 \tag{82}$$

Condition (82), reflects the *Taylor principle.* It requires that nominal interest rates react sufficiently strongly to deviations of current inflation from target inflation, in order to affect real interest rates and aggregate demand in the desired direction. This is a necessary and sufficient condition for a stable and determinate process for expected (and actual) inflation.[19]

If (82) is satisfied, then it is straightforward to show that the expected inflation process has two roots that lie on either side of unity. The smaller root is δ and the larger root is ϕ_π. Thus, the solution for the expected inflation process (80) is given by,

$$E_{t-1}\hat{\pi}_t = \delta\hat{\pi}_{t-1} + \frac{\delta}{\phi_\pi}\varepsilon^i_{t-1} \tag{83}$$

where $\delta < 1$ is the smaller root of the characteristic polynomial of (81).

From (83) it follows that,

$$\begin{aligned} E_{t-1}\hat{\pi}_{t+1} &= \delta E_{t-1}\hat{\pi}_t \\ E_t\hat{\pi}_{t+1} &= \delta\hat{\pi}_t + \tfrac{\delta}{\phi_\pi}\varepsilon^i_t \end{aligned} \tag{84}$$

Substituting (83) and (84) in the inflation process (78), the rational expectations solution for inflation is given by,

$$\hat{\pi}_t = \delta\hat{\pi}_{t-1} - \psi_1\varepsilon^A_t - \psi_2\varepsilon^i_t + \psi_3\varepsilon^i_{t-1} \tag{85}$$

where,

$$\begin{aligned} 0 < \psi_1 &= \tfrac{\kappa_2}{\phi_\pi\kappa_2\kappa_3-\delta(\kappa_1+\kappa_2\kappa_3)+1} < 1 \\ 0 < \psi_2 &= \tfrac{(\phi_\pi-\delta)\kappa_2\kappa_3-\delta\kappa_1}{\phi_\pi(\phi_\pi\kappa_2\kappa_3-\delta(\kappa_1+\kappa_2\kappa_3)+1)} < 1 \\ 0 < \psi_3 &= \tfrac{\delta}{\phi_\pi} < 1 \end{aligned} \tag{86}$$

[19] Clarida et al. (1999), Woodford (2003), and Gali (2008) among others, contain detailed discussions of the Taylor principle, and its significance for the resolution of the price level and inflation indeterminacy problem which affects non contingent interest rate rules.

From (85), fluctuations of inflation around the target of the monetary authorities π^* are as persistent as fluctuations of unemployment and output around their natural rates, and are driven by the current innovation in productivity and current and past monetary policy shocks, as the central bank is using the short run tradeoff between inflation and unemployment to partly counteract the real effects of such shocks.

Note that the inflationary process displays persistence only because of the persistence of unemployment. This is because under the Taylor the central bank seeks to counteract deviations of unemployment and output from their natural rates, something which conflicts with the objectives of wage setters, who are seeking to maintain persistent deviations of unemployment and output from their natural rates. It is because of the clash in the objectives of wage setters and the central bank that inflation persists.[20]

It is also worth noting that all structural parameters, including the parameters of the Taylor rule, affect the inflation process, through the expectations of consumers, wage setters and firms, and through deviations of unemployment, output and the real interest rate from their natural rates.

Because of the persistence of deviations of output from its natural rate, both current and past monetary policy shocks affect the inflationary process. The effects of productivity and monetary policy shocks on inflation also depend on all structural parameters, including the parameters of the Taylor rule.[21]

Having solved for inflation, the solution of the rest of the model is straightforward.

Substituting the Taylor rule (77) into the NNS IS relation (73), which determines deviations of output from its natural rate, and solving out for $\hat{y}_t$, we get that,

$$\begin{aligned} \hat{y}_t &= -\tfrac{1}{\theta(1-\delta)+\phi_y}\left(\phi_\pi \hat{\pi}_t - E_t\hat{\pi}_{t+1} + \varepsilon_t^i\right) = \\ &= -\tfrac{1}{\theta(1-\delta)+\phi_y}\left((\phi_\pi - \delta)\hat{\pi}_t + (1-\psi_3)\varepsilon_t^i\right) \end{aligned} \tag{87}$$

where, $\hat{y}_t = y_t - \bar{y}_t$ denotes deviations of output from its natural rate.

Substituting (85) in (87) and solving out for $\hat{y}_t$, we get that,

$$\hat{y}_t = \delta\hat{y}_{t-1} + \frac{1}{\theta(1-\delta)+\phi_y}\left(\xi_1\varepsilon_t^A - \xi_2\varepsilon_t^i\right) \tag{88}$$

where,

[20] See Alogoskoufis (2018) for a detailed analysis of this point in the context of a related model.

[21] (85) being the inflationary process from a dynamic stochastic general equilibrium model, in which the policy rule of the monetary authorities is taken into account when agents form their expectations, it does not suffer from the Lucas (1976) critique. Changing the parameters of the policy rule, would also change the parameters of the inflationary process in a predictable manner.

$$\begin{aligned}\xi_1 &= (\phi_\pi - \delta)\psi_1 \\ \xi_2 &= 1 - \psi_3 - (\phi_\pi - \delta)\psi_2\end{aligned} \tag{89}$$

Finally, using the Okun relation (62) in conjunction with (88), we can solve for the fluctuations of the unemployment rate around its natural rate as,

$$\hat{u}_t = \delta\hat{u}_{t-1} - \frac{1}{(1-\alpha)\left(\theta(1-\delta)+\phi_y\right)}\left(\xi_1\varepsilon_t^A - \xi_2\varepsilon_t^i\right) \tag{90}$$

Fluctuations in both nominal variables, such as the inflation rate, and real variables, such as deviations of real output and the unemployment rate from their natural rates display the same degree of persistence. This is a result of the clash in the objectives of central bankers and labor market insiders. The central bank, through the Taylor rule, seeks to stabilize both inflation and deviations of output from its natural rate. Labor market insiders seek to secure the maximum wage consistent with their own employment, which depends partly on lagged employment and partly on the natural rate.

To the extent that the short-term employment objectives of wage setters and the central bank differ, with the central bank seeking to minimize persistent deviations of unemployment from its natural rate, the only way for wage setters to ensure that the central bank does not surprise them is to adapt their inflationary expectations to the central bank rule. Since nominal interest rates react to the persistent fluctuations of deviations of output from its natural rate, inflation and inflationary expectations adapt too. Hence, inflation displays the same degree of persistence as output and unemployment.[22]

7.4 Inflation Stabilization and the Divine Coincidence

It is important to note that, unlike the bechmark "new keynesian" model with staggered prices and wages, this model is not characterized by the "divine coincidence" of output stabilization when inflation itself is stabilized. Stabilization of inflation around the target inflation rate of the central bank does not automatically lead to output and employment stabilization around their "natural rates". This is because of the labor market distortions implied by the wage setting behavior of insiders.[23]

To see this assume that the central bank allows its response to deviations of inflation from its target ϕ_π to become infinite. Then, from the definition of the ψ 's in (86), ψ_1, ψ_2 and ψ_3 would be driven to zero, and neither nominal nor real shocks would affect inflation. Inflation would converge

[22] This point is elaborated in Alogoskoufis (2018) in the context of a simpler insider outsider model.

[23] See Blanchard and Gali (2007) for a discussion of the "divine coincidence". In order to deal with this problem in the benchmark new keynesian model with staggered prices and wages, one has to superimpose ad hoc additional labor market distortions. This is not the case with the model in this paper, as labor market distortions are part and parcel of the model and not an afterthought.

to the target rate of the central bank π^*, and the variance of inflation would driven to zero. Inflation would thus be fully stabilized.

However, from (88) and (90), real shocks would continue to affect deviations of real output and unemployment and output from their "natural rates", even if ϕ_π is driven to infinity.

Thus, the "divine coincidence" does not hold in this model. In the presence of real shocks, inflation stabilization does not result in unemployment and output stabilization, as there is always a tradeoff between the stabilization of inflation and the stabilization of unemployment around its "natural rate" in the presence of real shocks.

The "divine coincidence" also has important implications for monetary policy analysis in a "new keynesian" framework. As shown by Alogoskoufis and Giannoulakis (2020), the optimal monetary policy rule in the context of the benchmark "new Keynesian" model, due to the "divine coincidence" between output and inflation, is the Fisher rule of absolute inflation stabilization. When the "divine coincidence" does not apply, as in the model of this paper, the optimal monetary policy rule takes the form of a Taylor rule, the parameters of which depend on the structural and policy parameters of the model.

8 Optimal Monetary Policy

We have shown that in a model with endogenous unemployment persistence, as is the model in this paper, the Taylor rule results in inflation persistence. One can show that inflation persistence would also be associated with optimal monetary policy, if the loss function of the central bank depends on both deviations of inflation from target and deviations of unemployment from its "natural" rate.[24]

In order to derive optimal monetary policy, one has to specify an appropriate social welfare function. Assuming that the optimal steady state inflation rate is equal to π^*, the only other distortion in this model is the fact that unemployment deviates from its "natural" rate. Thus, one can assume that the central bank would seek to minimize an intertemporal loss function that depends on deviations of inflation from its steady state optimal rate π^*, and deviations of unemployment from its "natural" rate u^N. This can be written as,

$$\Lambda_t = E_t \sum\nolimits_{s=0}^{\infty} \beta^s \left(\frac{1}{2}(\pi_{t+s} - \pi^*)^2 + \frac{\zeta}{2}(u_{t+s} - u^N)^2 \right) \tag{91}$$

β is the discount factor, $\beta = 1/(1+\rho)$, where ρ is the pure rate of time preference, and ζ is the relative weight attached by the central bank to deviations of unemployment from its "natural" rate, relative to deviations of inflation from target.[25]

[24] See Alogoskoufis (2018) for a proof of this proposition and suggested solutions.

[25] In accordance with the conventions of the literature on monetary policy, e.g Barro and Gordon (1983), Rogoff

The optimal policy is the one that minimizes (91) subject to the dynamic expectations-augmented new Keynesian Phillips curve (74) expressed in terms of unemployment through the Okun-type equation (62):

$$u_t - u^N = \delta\left(u_{t-1} - u^N\right) - \frac{1}{\alpha\kappa_2}\left[\pi_t - E_{t-1}\pi_t - \kappa_1\left(E_t\pi_{t+1} - E_{t-1}\pi_{t+1}\right) + \varepsilon_t^A\right] \tag{74'}$$

We term this policy as the *optimal time consistent contingent policy*, because the central bank has no short run incentive to deviate from this policy, and its choice of inflation will depend on the current state of the economy, summarized in the deviations of the current unemployment rate from its "natural" rate.[26]

Note that under this policy, there is a clash between the objectives of the monetary authorities and the objectives of wage setting insiders regarding unemployment. The central bank seeks to minimize deviations of unemployment from its natural rate, whereas wage setters seek to minimize deviations of unemployment from a weighted average of the "natural" rate and past unemployment. This clash is what accounts for the persistence of inflation under the contingent optimal policy.

From the first order conditions for a minimum of (91) subject to (74'), we get,

$$\pi_t = \pi^* + \frac{\zeta}{\alpha\kappa_2}\left(u_t - u^N\right) + \frac{\zeta\beta\delta}{\alpha\kappa_2}E_t\left(u_{t+1} - u^N\right) \tag{92}$$

Using (74') to substitute for current and expected future deviations of the unemployment rate from its natural rate, after some rearrangement, we get,

$$\pi_t = \delta\pi_{t-1} + (1-\delta)\pi^* - \frac{\zeta(1+\beta\delta^2)}{(\alpha\kappa_2)^2}\left[\pi_t - E_{t-1}\pi_t - \kappa_1\left(E_t\pi_{t+1} - E_{t-1}\pi_{t+1}\right) + \varepsilon_t^A\right] \tag{93}$$

The rational expectations solution of (96) is given by,

$$\pi_t = \delta\pi_{t-1} + (1-\delta)\pi^* - \frac{\zeta(1+\beta\delta^2)}{(\alpha\kappa_2)^2 + \zeta(1+\beta\delta^2)(1-\kappa_1\delta)}\varepsilon_t^A \tag{94}$$

From (94), deviations of the "optimal", time consistent, contingent inflation rate from the inflation target π^* display the same degree of persistence, as the persistence of deviations of unemployment from its "natural" rate. The reason is that the central bank allows inflation to fluctuate in order to minimize deviations of unemployment from its natural rate. Since these deviations in unemployment

(1985), we treat (64) as a measure of the intertemporal welfare costs of inflation and unemployment. However, we assume that the central bank does not seek to systematically reduce unemployment below its inefficiently high "natural" rate. Thus, we abstract from the systematic inflation bias that would result in the case in which the central bank also sought to use inflation in order to reduce unemployment below its "natural rate", as in Kydland and Prescott (1977) and Barro and Gordon (1983).

[26] Note that the optimal contingent policy is time consistent, in the sense of Kydland and Prescott (1977). Alogoskoufis (2018) also examines time inconsistent policy rules which may result in even lower intertemporal losses in the context of a simpler insider-outsider model.

display persistence, deviations of inflation from target will also display persistence under the optimal contingent policy.[27]

It is worth noting that the persistence of inflation under the optimal time consistent contingent monetary policy does not affect the persistence of unemployment. The reason is that wage setters can anticipate the persistent part of the inflation process, incorporate it in their expectations when they set nominal wages, and neutralize the effects of persistent inflation on unemployment. Thus, the only element of monetary policy that matters for unemployment is the unanticipated part, which is a function of the current productivity shock.

9 A Dynamic Simulation of the Model

In order to evaluate the dynamic properties of the model, it is worth simulating it for particular parameter values and presenting the corresponding impulse response functions.

Figures 1 and 2 present the dynamic effects of a real and a monetary shock respectively, for commonly used values of the parameters. In particular, the parameter values for our simulation exercises are: $\beta = 0.99$, $\varepsilon = 6$, $\theta = 2/3$, $a = 1/3$, $\gamma = 2/3$, $\phi_\pi = 1.50$, $\phi_y = 0.125$, and $\delta = 0.51$. The value of the persistence parameter δ corresponds to the estimated persistence of unemployment in the EU over the time period 1999Q1-2022Q3. Following Alogoskoufis (2018), we obtained this estimate from an AR(2) process of the deviations of unemployment from its natural level, the latter proxied by a Hodrick and Prescott (2019) filter. All real variables are defined as percentage deviations from their “natural rates”, while inflation as percentage deviations from the target inflation rate of monetary authorities. For simplicity, we assume that this target is zero.

In the figures that follow, we present the dynamic effects of the shocks for three alternative versions of the model. First, in order to disentangle the role of price stickiness we depict the dynamic behavior of the model under both flexible (blue line) and staggered prices (red line). Furthermore, in order to isolate the contribution of unemployment persistence in the dynamic behavior of the model we also present the impulse response functions for a version of the model with staggered pricing and zero unemployment persistence (dashed black line).

Figure 1 depicts the impulse response functions of the model following an unanticipated 1% shock to productivity a_t. Qualitatively, the dynamic behavior of the model is the same irrespective of whether prices are flexible or sticky. Inflation initially falls, and so do unemployment, nominal and real interest rates relative to their steady state “natural rates”. Output rises above its “natural rate”. Following the initial shock, all variables gradually return to their steady state “natural rates”.

[27] Note from (94) that if deviations of unemployment from its natural rate did not persist, i.e in the case $\delta = 0$, the optimal contingent monetary policy rule would not result in persistent deviations of inflation from target. There would be deviations of inflation from π^* only in response to unanticipated shocks to productivity.

It is worth noting that staggered pricing seems to significantly mitigate the effects of the productivity shock. Moreover, when we eliminate the endogenous persistence of unemployment, the persistence of the effects of the productivity shock vanishes and the model behaves as if the economy was facing an *iid* shock. The reason is that only the unanticipated part of any shock affects unemployment and output in this model.

******** Insert Figure 1 here ********

Figure 2 presents the impulse response functions of the model following an unanticipated temporary 1% shock to the nominal interest rate i_t. Note that such a nominal shock does not affect the "natural rates" of real variables which only depend on real shocks. As we can see, staggered pricing amplifies the effects of the nominal shock. However, although the dynamic behavior of all real variables are qualitatively the same irrespective of whether prices are flexible or staggered, the response of inflation differs. More specifically, inflation initially falls under flexible prices but not in the case of staggered pricing. The reason for that is the current expectations of firms about future inflation that staggered pricing introduces in the model. A contractionary monetary shock leads to a decline in aggregate demand. The decline in aggregate demand is pushing those firms that can change their prices immediately, to reduce them in order to increase their market share. On the other hand, firms expect that aggregate demand will rise in the future. However, the firms that have the ability to adjust their prices now may not be able to reset them in the future, as implied by the Calvo (1983) Pricing Model. Therefore, these firms raise their current prices in anticipation of future price increases due to the future recovery of aggregate demand. The higher the degree of price stickiness (γ), the larger the response of current prices to the anticipated future rise in inflation. We demonstrate this by also plotting (Figure 2, dashed red line) the responses of variables when the proportion of firms that cannot reset their prices is low (in particular we assume it is 10%). As we may observe, in this case inflation initially falls - as it does with flexible prices - because firms expect to be able to raise their prices with a higher probability when aggregate demand recovers.

The dynamic behavior of all the other variables are similar whether prices are flexible or not. Unemployment, nominal and real interest rates rise above their "natural rates" while output falls below its own "natural rate". Thus, a temporary nominal shock has persistent real effects because of the persistence of deviations of employment from its "natural rate", independently of whether prices are sticky or not.

******** Insert Figure 2 here ********

10 An Empirical Appraisal of the DEANKPC

The model put forward in this paper results in a *dynamic expectations-augmented new Keynesian Phillips Curve* (equation 74) that deviates importantly from the *benchmark* NKPC.

Previous tests of the empirical performance of the *benchmark* NKPC revealed the (statistically) significant impact of lagged inflation on current inflation, leading to a rejection of the *benchmark* NKPC in favor of a *hybrid* one with ad hoc lagged inflation terms. The DEANKPC we propose in this study allows current inflation to depend on the past values of unemployment (and thus of inflation) endogenously and not through the addition of ad hoc lagged inflation terms.

In addition, the DEANKPC allows current inflation to depend on both prior expectations for current inflation and current expectations for future inflation, encompassing the characteristics of both the *expectations-augmented Phillips Curve* and the *benchmark NKPC*.

A natural question that may arise here is whether the above two features make the DEANKPC to exhibit a better empirical performance than the *benchmark* and *hybrid* NKPCs. To this end, we are performing a comparative assessment of the empirical performance of the aforementioned three versions of the NKPCs using data for the Euro Area.

Following Blanchard and Gali (2007), the *benchmark* and *hybrid* NKPCs can be expressed by the following econometric specifications:

Benchmark NKPC

$$\hat{\pi}_t = \alpha_0 + \alpha_1 E_t \hat{\pi}_{t+1} + \alpha_2 \hat{u}_t + \epsilon_t^{(1)} \tag{95}$$

Hybrid NKPC

$$\hat{\pi}_t = \beta_0 + \beta_1 \hat{\pi}_{t-1} + \beta_2 E_t \hat{\pi}_{t+1} + \beta_3 \hat{u}_t + \epsilon_t^{(2)} \tag{96}$$

Inflation is expressed in deviations from the monetary authorities' inflation target, while unemployment in deviations from its natural level.

According to the theory, the estimated values for the parameters of the above two reduced-form Phillips Curves should be as follows: α_1 and β_2 should lie between 0 and 1 (as they correspond to the rate of time preference), α_2 and β_3 should be negative since unemployment is negatively related to inflation, and the persistence parameter β_1 should lie between 0 and 1 to ensure the stability of specification (96).

In the same spirit, we can express the DEANKPC (74) as follows:

$$[\hat{\pi}_t - E_{t-1}\hat{\pi}_t] = \gamma_0 + \gamma_1 [E_t \hat{\pi}_{t+1} - E_{t-1}\hat{\pi}_{t+1}] + \gamma_2 \hat{u}_t + \gamma_3 \hat{u}_{t-1} + \epsilon_t^{(3)} \tag{97}$$

The DEANKPC has two important differences from the *benchmark* and *hybrid* NCPCs. First, it is dynamic comprising a lagged unemployment term as a result of the endogenous persistence arising from the power of labor market insiders to periodically pre-set nominal wages, without full current information. This term offsets the ad hoc lagged inflation term of the hybrid NKPC. Second, the DEANKPC is expectations-augmented as it is expressed in terms of unanticipated inflation, i.e. deviations of current inflation from prior expectations for its level. This is due to the fact that nominal wages are set in advance, on the basis of the prior expectations of wage setters about current variables, and remain fixed for one period. Since current shocks to productivity and aggregate demand are not known when nominal wages are determined, unanticipated current inflation reduces real wages and causes employment to increase, like in the "original" models of the "expectations augmented Phillips curve".

For the estimation of specifications (95)-(97), we utilize data for the Euro Area at a quarterly frequency. The data for inflation (measured as the annualized quarterly change of the CPI) and unemployment rates were obtained from the database of the Organization for Economic Cooperation and Development (OECD). We model $\hat{\pi}_t$ as the difference between the current inflation rate (from OECD) and the European Central Bank (ECB)âs inflation target of 2%. We approximate the deviation of the unemployment rate from its natural level, $\hat{u}_t$, by using a Hodrick-Prescott Filter (Hodrick and Prescott (2019)).

Finding the appropriate proxy for inflation expectations is a more complex issue. There are two main approaches in the relevant literature. The first one utilizes survey data based on questionnaires to consumers or firms about their expectations on the evolution of inflation (see for instance Roberts (1995)). The most widespread source for such data for the Euro Area is the *Consumer Expectations Survey (CES)* of the ECB. An important drawback of this survey is that comprises data up to one year ahead inflation expectations. However, the presence of the deviations of current from past expectations for future inflation, $[E_t\hat{\pi}_{t+1} - E_{t-1}\hat{\pi}_{t+1}]$, in the DEANKPC requires data for two years ahead inflation expectations for its proper estimation.

The second approach utilizes inflation forecasts from central banks as proxies for inflation expectations. Building on the work of Brissimis and Magginas (2008) and Zhang et al. (2009), we proxy inflation expectations by using ECB's inflation forecasts, obtained from the *Survey of Professional Forecasters (SPF)*. An important advantage of these forecasts is that they are available for both the short- and the long-term (there are available forecasts for up to five years ahead inflation). The data is available at quarterly frequency for the period 1999Q1-2022Q3.

Therefore, we utilize ECB's one-year ahead inflation forecast as a proxy for the current expectations for future inflation, $E_t\hat{\pi}_{t+1}$. In the same spirit, $E_{t-1}\hat{\pi}_t$ and $E_{t-1}\hat{\pi}_{t+1}$, denoting the past expectations for the current and future inflation, are proxied by the lagged values of the one- and two-year ahead

ECBâs inflation forecasts, respectively.

To deal with potential measurement errors that may arise from the use of inflation forecasts as proxies for (unobservable) inflation expectations we utilize a two-stage GMM estimator. Following Brissimis and Magginas (2008), our instrument set includes three lags of the (real-time) inflation, the output and unemployment gaps (obtained from the OECD Database), and two lags of change in Brent crude oil prices for Europe (obtained from the FRED Database). All variables were tested for unit roots (we employed the Augmented DickeyâFuller Fisher type test). All variables apart from the output gap (and of course the change in Brent crude oil prices) were found to be non-stationary, so we use them in first differences.

******** Insert Table 1 here ********

Table 1 presents the results from the estimation of models (95)-(96). Starting with the *benchmark* and *hybrid* versions of the NKPC, we can see that the estimated coefficients of the parameters have the correct sign and are statistically significant. Current inflation is positively related with (one-year ahead) inflation expectations and negatively with the unemployment rate. Also, inflation exhibits significant persistence as the *hybrid* NKPC reveals.

Turning to the DEANKPC, we can see that unanticipated inflation is positively affected by the deviations of current from past expectations for future inflation. This relationship is notably stronger than the one between current and expected future inflation described by models (95) and (96). Moreover, the unanticipated inflation is negatively affected by the current but positively by the lagged unemployment rate. This means that (endogenous) unemployment persistence is solidly connected with unanticipated inflation as our theoretical model suggests. Therefore, the DEANKPC, that our theoretical model builds, is empirically verified and its explanatory power is at least as good as that of the *benchmark* and *hybrid* versions of the NKPC, as the R^2 implies.[28]

11 Conclusions

This paper suggests an analytically tractable DSGE model, with both labor and product market frictions, as an alternative to the benchmark "New Keynesian" model. Frictions in the labor market arise from the power of labor market insiders, to periodically set nominal wages, without full current information. Product market frictions arise from monopolistic competition and staggered pricing, as in the benchmark "New Keynesian" model. Aggregate fluctuations are analyzed under a Taylor nominal interest rate rule for monetary policy.

[28] Of course, R^2 is a very loose measure of the goodness of fit for GMM estimators since it is not bounded between 0 and 1 as for OLS estimators.

The combination of these frictions results in persistent deviations of unemployment and output from their natural rates, following real and nominal shocks. The model can also explain the high persistence of inflation, as the result of attempts by central banks to stabilize persistent deviations of unemployment and output from their natural rate through the Taylor rule. We also demonstrate that equilibrium inflation persists even when monetary policy is chosen in an optimal fashion.

The main distinguishing characteristic of the model put forward in this paper is a "Dynamic Expectations-augmented New Keynesian Phillips Curve (DEANKPC)" that encompasses the characteristics of both the EAPC and the NKPC. It is *dynamic* as past inflation affects current inflation, because of the labour market induced persistence of deviations of unemployment and output from their natural rates due to wage setting. It is *expectations-augmented* as current inflation depends on prior expectations about current inflation itself. It is *new Keynesian* as current inflation depends on expectations about future inflation.

Moreover, inflation stabilization does not result in the stabilization of output and employment, because real shocks endogenously induce a short run tradeoff between inflation and unemployment. Thus, the divine coincidence does not apply in this model, rendering a Taylor-type interest rate rule optimal, if the loss function of the central bank depends on both deviations of inflation from target and deviations of unemployment from its "natural" rate.

Therefore, the model presented in this paper does not suffer from the two main shortcomings of models based on the benchmark "New Keynesian Phillips Curve": the absence of endogenous unemployment (output) and inflation persistence, leading to much faster adjustment of inflation and unemployment to both nominal and real shocks than actually observed in the data, and the presence of the "divine coincidence" between the stabilization of inflation and employment (output).

We evaluate the dynamic properties of our model through a simulation exercise. We find that our model exhibits richer inflation dynamics (than the benchmark NKPC model), responding to real and nominal shocks. The intensity of these dynamics depends highly on the degree of the price stickiness in the economy. We finally assess the empirical validity of the DEANKPC through an empirical application for the Euro Area. The data verifies the structure of the DEANKPC, while its explanatory power is at least as good as that of the *benchmark* and *hybrid* versions of the NKPC.

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Figures

Figure 1: Impulse Response Functions following a 1% Unanticipated Persistent Shock to Productivity

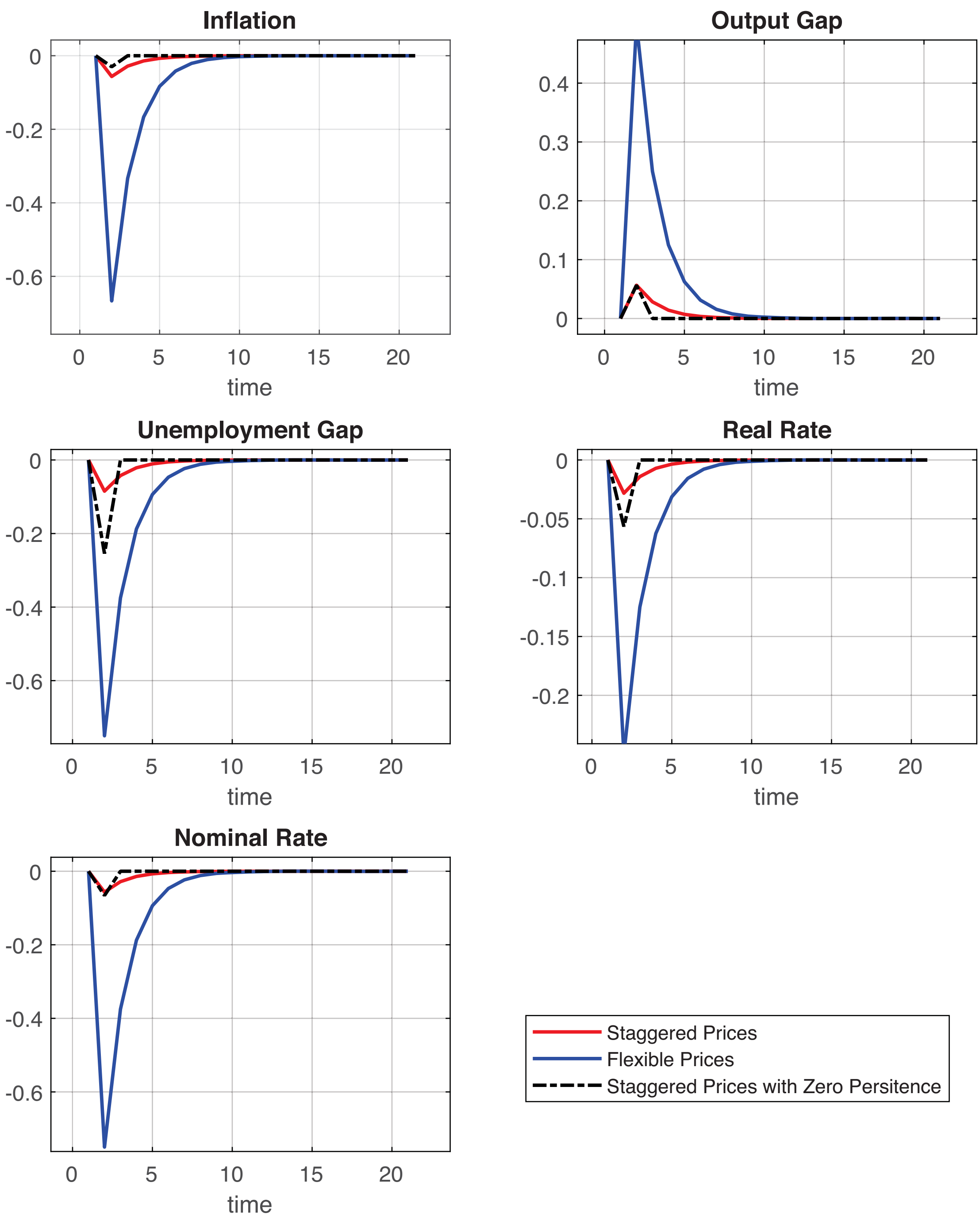
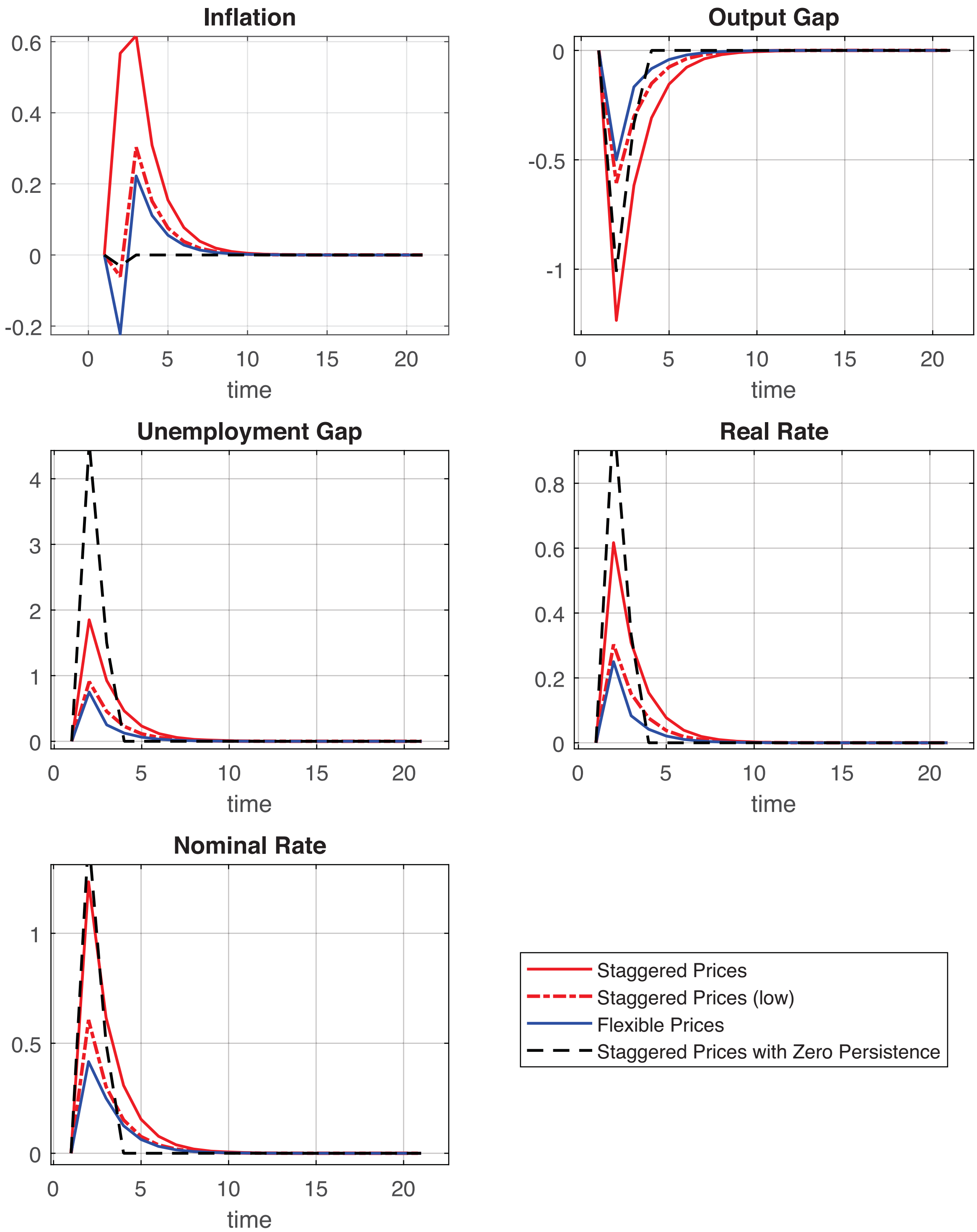


Figure 2: Impulse Response Functions following a 1% Unanticipated Persistent Shock to Nominal Interest Rate



Tables

Table 1: Estimation of Bnhcmark, Hybrid and Dynamic NKPC for the Euro Area

	Benchmark NKPC	**Hybrid NKPC**	**Dynamic EANKPC**
	$\hat{\pi}_t$	$\hat{\pi}_t$	$\hat{\pi}_t - E_t\hat{\pi}_t$
$\hat{\pi}_{t-1}$		0.229**	
		(0.110)	
$E_t\hat{\pi}_{t+1}$	0.643***	0.552***	
	(0.253)	(0.262)	
$E_t\hat{\pi}_{t+1} - E_{t-1}\hat{\pi}_{t+1}$			0.711***
			(0.270)
$\hat{u}_t$	-0.927***	-0.6988**	-0.722***
	(0.304)	(0.211)	(0.218)
$\hat{u}_{t-1}$			0.757***
			(0.210)
R^2 **(uncentered)**	0.295	0.291	0.354
Hansen's J-Test	0.497	0.150	0.420

Notes: This table presents the estimation results for the *benchmark* (eq. 95), the *hybrid* (eq. 96) and the *dynamic expectations-augmented* NKPC (eq. 97), described in Section 10. Inflation and unemployment data were obtained from the OECD database, while inflation expectations were proxied by ECB's forecasts obtained from the *Survey of Professional Forecasters (SPF)*. Our sample covers the period 1999Q1-2022Q3. Inflation, $\hat{\pi}_t$, either current or expected, is expressed in deviations from the ECB's 2% target, while unemployment, $\hat{u}_t$, in deviations from its natural level proxied by a Hodrick-Prescott filter. We utilize a two-stage GMM estimator to deal with potential measurement errors that may arise from the use of inflation forecasts as proxies for (unobservable) inflation expectations. Our instrument set includes three lags of the (real-time) inflation, the output and unemployment gaps, and two lags of change in Brent crude oil prices for Europe. All variables tested for unit roots. The intercepts of models (95)-(97) were excluded from the analysis as they are not justified by the theory. The statistic of the Hansen's J Test for over-identifying restrictions shows that the null hypothesis of the joint validity of all instruments is not rejected for any of the estimated models.

Appendix

Does Staggered Pricing Matter for Inflation Persistence?

It is important to demonstrate that the results in this paper go through even in the absence of staggered pricing. Inflation displays persistence under a Taylor rule, even in the case where prices are fully flexible, as long as nominal wage contracts are determined as assumed by the model.

To demonstrate that staggered pricing does not matter for inflation persistence, assume that $\gamma = 0$. Then, in follows that the dynamic expectations-augmented new Keynesian Phillips curve (74) takes the form,

$$\pi_t = E_{t-1}\pi_t + \frac{\alpha}{1-\alpha}\left(\left(y_t - \bar{y}_t\right) - \delta\left(y_{t-1} - \bar{y}_{t-1}\right)\right) - \varepsilon_t^A \tag{A1}$$

Deviations of output from its natural rate still cause unanticipated inflation, but the extra terms involving expected future inflation drop out.

Using the Taylor rule (77), to substitute for the nominal interest rate in the aggregate demand equation (73), and then substituting for deviations of output from its natural rate in the Phillips curve (A1), results in a transformed inflation process of the form,

$$\hat{\pi}_t = E_{t-1}\hat{\pi}_t - \kappa_3\left(\phi_\pi\left(\hat{\pi}_t - \delta\hat{\pi}_{t-1}\right) - \left(E_t\hat{\pi}_{t+1} - \delta E_{t-1}\hat{\pi}_t\right) + \varepsilon_t^i - \delta\varepsilon_{t-1}^i\right) + \varepsilon_t^A \tag{A2}$$

where κ_3 is defined in the same way as before, in equation (79). However, because of the assumption that $\gamma = 0$, it follows from (79) that $\kappa_1 = 0$ and that $\kappa_2 = 1$.

The rational expectations solution for expected inflation is the same as before, given by (80), as ex ante expected current inflation does not depend on staggered pricing, but only on the degree of persistence of unemployment δ and the Taylor rule response to inflation ϕ_π.

The rational expectations solution for actual inflation is the same as (85), only that the parameters measuring the impact of the unanticipated shocks are now simplified to,

$$\begin{aligned} 0 < \psi_1 &= \tfrac{1}{(\phi_\pi - \delta)\kappa_3 + 1} < 1 \\ 0 < \psi_2 &= \tfrac{(\phi_\pi - \delta)\kappa_3}{\phi_\pi((\phi_\pi - \delta)\kappa_3 + 1)} < 1 \\ 0 < \psi_3 &= \tfrac{\delta}{\phi_\pi} < 1 \end{aligned} \tag{A3}$$

Hence, inflation follows a process similar to (85), with a degree of persistence equal to δ, even in the absence of staggered pricing.

Substituting the modified inflation process in the NNS IS relation (73), using the Taylor rule to substitute for the nominal interest rate and solving out, the processes determining the fluctuations of real output and unemployment are given by equations similar to (88) and (90), with the $\psi' s$ redefined as in (A3). Hence, staggered pricing does not matter for the persistence of either inflation or real variables in this model. It only matters for the transmission of current real and nominal shocks, through the ψ parameters.

Specifically, staggered pricing plays a quantitatively important role in the dynamic behaviour of the model. As we demonstrated in Section 9, staggered pricing amplifies the effects of both real and nominal shocks. Moreover, staggered pricing affects strongly inflation dynamics as a response to a nominal shock. As Figure 2 shows, inflation initially falls under flexible prices but not in the case of staggered pricing. The reason for that is the current expectations of firms about future inflation that staggered pricing introduces in the model. A contractionary monetary shock leads to a decline in aggregate demand. The decline in aggregate demand is pushing those firms that can change their prices immediately, to reduce them in order to increase their market share. On the other hand, firms expect that aggregate demand will rise in the future. However, the firms that have the ability to adjust their prices now may not be able to reset them in the future, as implied by the Calvo (1983) Pricing Model. Therefore, these firms raise their current prices in anticipation of future price increases due to the future recovery of aggregate demand. The higher the degree of price stickiness (γ), the larger the response of current prices to the anticipated future rise in inflation.

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