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Total Unit Costs, Marginal Costs and the New Keynesian Phillips Curve

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Abstract

The bulk of the literature that estimates the new Keynesian Phillips curve, (NKPC), uses unit labor costs as a proxy to marginal cost. This paper considers the contribution of non-labor unit costs to the latter. The theory-based marginal cost is derived as a function of both labor and non-labor unit costs, (including capital, net interest payments and tax related costs). Using data on *labor* and *non-labor payments* in nonfarm GDP for the US, we construct *total unit costs* as our proxy for marginal cost. *Total unit costs* are shown to improve the fit of the short-run variation in inflation and strengthen the empirical support for the role of expectations-based inflation persistence and real marginal cost as the driving variable in the NKPC. They also imply a duration of fixed nominal contracts that is closer to those suggested by firm-level surveys, than that implied by unit labor costs alone.

JEL: E5, E31, E32, E37

Keywords: New Keynesian Phillips Curve; marginal cost proxies; inflation persistence; price rigidity duration.

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1 Introduction

Largely inspired by Gali and Gertler (1999), the New Keynesian Phillips Curve (NKPC) has emerged as a key feature of many dynamic macroeconomic models and a key tool in monetary policy analysis. In spite of its recent popularity however, there is still an ongoing debate as to whether the NKPC can match the observed inflation persistence and the length of fixed nominal price contracts as implied by surveys at the micro level. Accumulating empirical evidence on the performance of the NKPC suggests that in explaining the dynamics of inflation, (a) real marginal cost is a better driving variable than the output gap, and (b) the hybrid NKPC, that includes lagged inflation, performs empirically better than the purely forward looking NKPC. This has led to a wide adoption of the hybrid NKPC which specifies inflation as a function of lagged inflation, expected future inflation (one period ahead) and real marginal cost as the driving variable (see eq. 1, Gali, Gertler and Lopez-Salido 2005),

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda \widehat{mc}_t + \epsilon_t,$$

where π_t is the inflation rate, $\widehat{mc}_t$ is real marginal cost (as a percentage deviation from its steady state value) and ϵ_t is a cost push shock. Gali and Gertler (1999), Gali, Gertler and Lopez-Salido (2001, 2005) and Sbordone (2002, 2005) suggest only a "modest" role for *intrinsic* inflation persistence (γ_b); whereas others find a very limited role for forward looking expected inflation (γ_f) in the NKPC, (see Fuhrer 1997 Rudd and Whelan 2005, 2007, Lindé 2005, Lawless and Whelan 2007 among others).[1] A common feature

[1] In a recent study, Zhang, Osborn and Kim (2008) show that forward-looking behavior played a small role during the higher inflation volatility period 1968-1981 in the US, suggesting that during periods of high inflation volatility, inflation persistence in the NKPC may become more *intrinsic*.

in these studies is that when the coefficient of marginal costs (λ) becomes more significant the NKPC tends to become more forward looking. This is consistent with the theoretical concept that if inflation dynamics are not intrinsic to the model but driven largely by marginal costs, then expectations about future prices should matter more.[2]

Following Gali and Gertler (1999), real marginal cost in the NKPC is usually proxied by *real unit labor costs*, where the latter is measured in relation to the deviation of labor income share in the non-farm business sector from its mean. Until recently, little attention has been placed on the exact contribution of unit labor cost as a proxy to marginal costs. Fuhrer (2006) shows that most of the persistence found in US inflation data appears to be *intrinsic* from the lagged inflation term in the NKPC and thus cannot be attributed to the conventional driving variable in these model, (i.e. the real marginal cost proxied by unit labor costs).

The potential weakness of using unit labor costs as a proxy for marginal cost is suggested by two observations in recent studies. First, the degree of and the shifts in persistence using this proxy are not consistent with those in inflation (see Fuhrer 2006). Second, the estimated coefficient of the real marginal cost implies price rigidities that are not consistent with micro evidence. The size of this coefficient in the empirical literature for the US is typically between 0.01 and 0.02, which assuming that the rate of discount is between 0.9 and 1.0, implies that the degree of price stickiness ranges between 0.8 and 1; this implies a duration of price contracts of 6 quarters or much longer. This is inconsistent with a number of firm-level surveys which suggest that price rigidity ranges between 1.5 to 4 quarters.[3] These two ob-

[2] We discuss this further in section 2.

[3] See Blinder, Canetti, Lebow and Rudd (1998), Hall, Walsh and Yates (2000), Chevalier, Kashyap and Rossi (2003), Bils and Klenow (2004), De Walque, Smets and Wouters

servations suggest that labor unit costs may be a weak proxy to marginal costs, (see Rudd and Whelan 2002, 2007, Lindé 2005). Rudd and Whelan (2002) show that the labor share version of the NKPC explains a very small proportion of the variation in inflation. Lawless and Whelan (2007) use both sectoral and aggregate data from 1979-2001 for all EU-15 countries and the US. They test for both reduced form and structural specifications of inflation and find negative coefficients on the effect of the labor share on inflation.[4] They conclude that the NKPC joint prediction of inflation and labor share cannot explain the trends in the data, particularly at the sectoral level. Earlier, Rotemberg and Woodford (1999) provided evidence that labor income share is a weak proxy for marginal cost in the US and suggest incorporating labor adjustment costs in order to generate more procyclical marginal costs. However, Sbordone (2005) shows that augmenting the marginal cost proxy, by incorporating adjustment costs, does not significantly improve the fit of the NKPC for US data.

Following Wolman (1999), who suggests that more refined estimates of marginal costs should be investigated, a recent strand in the literature examines whether alternative marginal cost proxies can improve the fit of the NKPC.[5] The bulk of this literature assumes different production technologies

(2004), Gwin and VanHoose (2007), Coenen, Levin and Kai (2007) and Rotemberg and Woodford (1997).

[4]Lawless and Whelan (2007) also provide evidence that although there has been a widespread decline in labor shares across a broad range of sectors, these declines have not been associated with large shifts in inflation, indicating that labor share may be an incorrect proxy for marginal cost in estimating the NKPC.

[5]Some studies focus directly on refining proxies for the output gap. For example, using different approaches, Chadha, and Nolan (2004), Neiss and Nelson (2005), and Bjørnland, Leitemo and Maih (2009) show that the use of theory consistent output gaps can be as good a proxy as real marginal cost. They suggest that the output gap proxies may not perform as well because output trends, that are largely used in the literature, are poor approximations to the output gap.

and aggregation methods and express average marginal cost as a function of both labor unit costs and the output (or employment) gap (Sbordone 2002, 2005, Gagnon and Khan 2005, Matheron and Maury 2004).[6] This literature concludes that assumptions about the nature of the production technology and aggregation factors may improve the fit of the NKPC, though this is subject to the production technology parameters assumed. More recently, Gwin and VanHoose (2007, 2008) examine alternative measures of marginal cost and prices in estimating the NKPC. [7] The key contribution in their papers comes from the use of a PPI-inflation measure, which is shown to produce significantly different results to those implied by Gali and Gertler. However, in using their alternative marginal cost data to replicate the tests by Gali and Gertler (1999), they too conclude that their estimates do not differ from what has already been shown in the literature (Gwin and VanHoose 2008).

Building on these recent findings, this paper shows that the inclusion of non-labor unit costs in the marginal cost proxy helps improve the fit of the short-run variation in inflation. We show that the theory-consistent real marginal cost implies that not only changes in labor unit costs but also in non-labor costs, such as capital unit costs, (accounting for capital utilization and depreciation), net finance costs (i.e. net interest payments related to the firm's borrowing costs and financial assets) and production taxes, can determine the variation in the inflation-output trade off. Available aggregate

[6] These studies assume that capital does not change with respect to changes in the relative price of firms, hence the resulting real marginal cost is still largely driven by labor unit costs, as assumed in Gali and Gertler (1999).

[7] They develop a measure of average variable costs using Standard & Poor's Compustat database for publicly traded U.S. companies.This comprises financial data from quarterly and annual *Securities and Exchange Commission* filings by over 10,000 firms. From this database they obtain individual firm revenues and costs of goods sold for the period 1966:1-2004:4 and construct a PPI and a growth rate of average variable costs as proxies to average price and marginal costs, respectively.

data that closely match our description of non-labor costs appear to be the *non-labor payments* in nonfarm GDP as published by the US Bureau of Labor Statistics (BLS) and the U.S. Department of Commerce Bureau of Economic Analysis. Proportionally, non-labor payments are much smaller than labor payments, however, as figure 1 shows the variation in non-labor payments is substantially large, suggesting that this component may be an important source of variation in marginal costs in the short run.[8]

{Figure 1. 12-mth Change in Proxies for Real Marginal Cost}

Using the above data we construct our real marginal cost proxy, *total unit costs,* as the sum of the shares of labor unit costs and non-labor unit costs of all nonfarm business sector in nonfarm GDP, deflated by the non-farm deflator.[9] We show that the addition of non-labor unit costs to the widely used unit labor costs, improves on the existing empirical support for the role of real marginal cost as the driving variable in the NKPC. In particular, by replicating the methodology of Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2005), using non-linear GMM estimates on US data for the sample period 1966:Q1 to 2003:Q4, we find that whereas real *unit labor costs,* as a proxy to marginal cost, produce a coefficient of around 0.02, for the same sample period and methodology the equivalent coefficient for *total unit costs* is around 0.05 or higher. The use of *total units costs* as a marginal cost proxy is also shown to increase the importance of the forward looking or *expectations-based* inflation persistence γ_f; this effect is stronger in periods

[8] See also figures 1a and 1b below

[9] Given the homogeneity in the data source, (US, BLS) we see this as the most natural extension to the already familiar unit labor costs employed widely in the literature. Further details on the definition and construction of *total unit costs* are given in the empirical section below.

of relatively higher inflation volatility, rather than in the more recent years of inflation stability. Our results also suggest that *total unit costs* imply a duration of fixed nominal contracts of around 4 quarters or less, which is much closer to the firm-level surveys based on micro data (1.5 to 4 quarters), than that implied purely by labor unit costs, (i.e. around 5-6 quarters or higher).

The remaining paper is structured as follows. Section 2 sets out the theoretical model which consists of households, a credit market, wholesale and intermediate firms and a monetary authority; from the former sectors we derive the NKPC where non-labor costs are shown to enter the definition of marginal cost. Section 3 discusses the data followed by estimates of the NKPC and fundamental inflation. Section 4 concludes and discusses the implications of the main results.

2 The Model

We consider a dynamic stochastic general equilibrium model describing an economy that consists of households, wholesale and intermediate firms, a credit market and a central bank. Households own capital and provide their labor and capital rental services to firms. Wholesale firms use intermediate goods to produce a final good that is traded competitively. Intermediate firms compete monopolistically; they determine the demand for labor and capital and set prices, but they need to borrow from the credit market to cover their variable costs (wages and rental cost of capital). Firms also hold some safe assets for collateral purposes. The credit market receives deposits from households and provides loans to firms. Given the loan rate determined by banks, firms decide on the demand for loans whereas the supply of loans is determined elastically at the loan rate; we assume that the credit market makes normal profits which together with the profits of firms are distributed back to households.

2.1 Households

Households are represented by a typical agent who provides a homogenous labor service, n, to all producing firms, derives utility from holding cash, M_t, for transactions purposes and consumes a basket of all produced goods, c_t. Households maximize their expected present discounted value utility,[10]

$$E_t \sum_{s=0}^{\infty} \beta^s \left\{ \frac{c_{t+s}^{(1-\sigma)}}{1-\sigma} + \frac{\eta_m}{1-\zeta} \left(\frac{M_{t+s}}{P_{t+s}} \right)^{1-\zeta} - \frac{\eta_n n_{t+s}^{1+\gamma}}{1+\gamma} \right\}, \tag{1}$$

where $\beta < 1$ is the subjective discount factor; σ, η_m, η_n are elasticities; $\gamma = 1/\delta$ is the marginal disutility of labor and δ the labor supply elasticity. Households nominal income consists of, cash endowments M_{t-1}; gross interest payments on deposits from the previous period, D_{t-1}, where $R_t^D = (1 + i_t^D)$ and i_t^D is the nominal deposit rate; wage income, $P_t w_t N_t$, where w_t is the real wage rate; capital rental income, $r_t u_t k_t$, from letting their capital to firms, where r_t is the real rental price of capital, k_t, and u_t is capital utilization; and finally, end of period (net of production tax) profits from all firms and the commercial bank, $V_t = \int V_{j,t} + V_t^b$, plus lump nominal sum transfers $P_t \tau_t$. The household's budget constraint is,

$$P_t(c_t + i_t) + M_t + D_t \tag{2}$$

$$= P_t(w_t n_t + r_t u_t k_t) + M_{t-1} + R_{t-1}^D D_{t-1} + V_t + P_t \tau_t$$

[10] Throughout the paper small latin letters, x, indicate real variables of X, (apart from the nominal interest rates, i^X) whereas $\widehat{x}$ denotes the log-linearised value of x as a deviation from its steady state.

We assume that investment, i_t, is related to the capital stock as follows,

$$i_t = k_{t+1} - (1 - \delta(u_t))k_t + \upsilon \left(\frac{k_{t+1}}{k_t} \right) k_{t+1} \tag{3}$$

where $\delta(u_t) = \delta u_t^{\varphi}$; $\delta^{'}(u) > 0$ is a depreciation function and $\upsilon \left(\frac{k_{t+1}}{k_t} \right) = \frac{b}{2}(\frac{k_{t+1}}{k_t} - 1)^2$ are quadratic costs related to capital investment; φ is the elasticity of marginal depreciation cost and so given $\delta^{'}(\cdot) > 0$, more capital utilization and higher values of φ increases the rate of depreciation and thus capital consumption, (see Neiss and Pappa 2005).

Assuming no Ponzi-game conditions for all assets, and denoting the Lagrangian multiplier of the budget constraint as λ_t, the household's first order conditions are,

$$c_t^{-\sigma} = \lambda_t P_t \tag{4}$$

$$c_t^{-\sigma} = \beta E_t \left(\frac{P_t R_t^D c_{t+1}^{-\sigma}}{P_{t+1}} \right) \tag{5}$$

$$\lambda_t P_t w_t = \eta_n n_t^{\gamma} \tag{6}$$

$$\frac{M_t}{P_t} = \frac{C_t^{-\sigma}}{\eta_m} \left(\frac{R_t^D - 1}{R_t^D} \right)^{-1/\zeta} \tag{7}$$

$$r_t = \delta \varphi u_t^{\varphi - 1} \tag{8}$$

$$\begin{aligned} & P_t \lambda_t \left(1 + b \left(\frac{k_{t+1}}{k_t} - 1 \right) \right) \\ = \ & \beta E_t P_{t+1} \lambda_{t+1} \left[r_{t+1} u_{t+1} + (1 - \delta u_{t+1}^{\varphi}) + \frac{b}{2} \left(\left(\frac{k_{t+2}}{k_{t+1}} \right)^2 - 1 \right) \right] \end{aligned} \tag{9}$$

Equation (4) and (5) determine the marginal utility of consumption and Euler equation, while equations (6)-(9) define the optimal allocations of labor, real balances and capital.

2.2 The Credit Market

The credit market is represented by a typical commercial bank, b. The bank accepts deposits from households, D_t, at the rate i_t^D, and makes loans, L_t, to firms at the loan rate i_t^L. The demand for loans is determined by firms whereas the bank sets the interest rate on loans. If the credit market is short of liquidity, it can borrow from the central bank, L_t^{CB} at the refinance (policy) rate, i_t^{CB}. We assume that banks do not have to meet a reserve requirement ratio. The commercial bank's balance sheet is

$$L_t = D_t + L_t^{CB} \tag{10}$$

We assume that in their conduct of intermediation commercial banks also incur some costs, $\Phi_t(\zeta_t, y_t)$; these are increasing in costs related to credit market imperfections (ζ_t), but decreasing with aggregate economic activity and willingness of banks to lend. In particular, we assume that $\Phi_t(\zeta_t, y_t) = \zeta_t + y_t^{-\xi}$, where $\xi > 0$, and ζ_t evolves as follows, $\log(\zeta_t) = \rho_\zeta \log(\zeta) + (1-\rho_\zeta)\log(\zeta_{t-1}) + \epsilon_{\zeta,t}$. Thus at the steady state $\Phi = \log(\zeta) = \overline{\zeta} > 0$, which captures the mark-up over the policy rate due to market structure imperfections in the credit market, whereas $\epsilon_{\zeta,t}$ captures innovations to such costs, (for a similar approach see Cook 1999, Atta-Mensah and Dib 2008).[11] The bank's period profit function is,

$$V_t^b = i_t^L L_t - i_t^D D_t - i_t^{CB} L_t^{CB} - \Phi_t(\zeta_t, y_t) L_t \tag{11}$$

From (10), (11) and the above information and assuming normal profits we derive,

$$i_t^D = i_t^{CB} \qquad \text{and} \qquad i_t^L = i_t^{CB} + \zeta_t + y_t^{-\xi}, \tag{12}$$

[11] As shown below, this assumption also ensures that loan spreads are countercyclical, as supported by empirical evidence. For a paper where such a relationship is explained endogenously see Agénor, Bratsiotis and Pfajfar, (2011).

hence with a zero requirement reserve ratio the deposit rate is equal to the refinance rate whereas the loan rate is a mark-up over the refinance rate driven by intermediation costs.

2.3 Wholesale and Intermediate Firms

There is a continuum of imperfectly competitive firms, $j \in [0,1]$, each engaging in the production of a differentiated good, $y_{j,t}$, which sells at the price $P_{j,t}$. The final goods firm bundles intermediate goods in a composite final good $y_t = \left(\int_0^1 y_{j,t}^{(\theta-1)/\theta} dj\right)^{\theta/(\theta-1)}$, by minimizing the cost, $P_t y_t = \int_0^1 P_{j,t} y_{j,t} dj$. The resulting demand for each intermediate differentiated good is,

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta} y_t, \tag{13}$$

where P_t is the average price index,

$$P_t = \left(\int_0^1 P_{j,t}^{1-\theta} dj\right)^{1/(1-\theta)}. \tag{14}$$

The production of each intermediate good combines capital and labor according to the following CES technology,

$$y_{j,t} = \left[\alpha_k (u_t k_t)^{\chi} + \alpha_n (a_t n_t)^{\chi}\right]^{1/\chi}, \tag{15}$$

where $\chi = \frac{\rho-1}{\rho}$; $0 < \alpha_k,\ \alpha_n < 1$ are the corresponding input shares and a_t measures labor productivity. If $\chi = 0$, equation (15) reduces to a standard Cobb-Douglas production function. The reason for deviating here from the widely used (in this literature) Cobb-Douglas production function, is that the latter assumes a unity elasticity of output with respect to labor and as a result the marginal cost is proportional to the labor share, (see Rotemberg and Woodford, 1999). The use of a CES production function allows the marginal product of labor and hence marginal cost to be affected by varying input shares hence this specification is more appropriate for the purpose of this paper. Note, for simplicity, we assume that employment and capital is common to all firms, which simplifies aggregation while still allowing for the average and marginal products to vary, (see Gali, Gertler and Lopez-Salido, 2007, Cantore Levine and Yang, 2010).[12]

In each period intermediate firms must borrow to cover their variable input costs (capital and labor), but they are required by lenders to hold some risk-free financial assets for risk diversification and collateral purposes. In this paper the latter assumption serves mainly to capture the fact that many firms tend to hold safe assets in their financial portfolio (i.e. for risk hedging, pension plans etc.). This implies that in addition to the borrowing costs, firms also have a source of financial returns, which here we need in order to capture the item "*net interest and miscellaneous payments*" in the additional non-labor payments data used for constructing our *total unit cost* definition of marginal cost below.[13] For simplicity we assume that all risk-free assets held by each firm are summarized in the form of government bonds, $B_{j,t}$.[14] Hence, the existing stock of all government bonds satisfies, $B_t = \int_0^1 B_{j,t} dj$.[15]

[12] Note that assuming firm specific factor inputs within a CES production technology, implies further relative price and inflation effects as the marginal products of labor and capital are aslo affected by the relative price and market power of the firm. Gagnon and Khan (2005) examine such effects in a model of labor input and fixed capital.

[13] For the exact data definitions see in the Appendix.

[14] Note that issues of risk and probability of default are not essential for the purpose of this paper; for recent papers that deal with idiosyncratic risk see Faia and Monacelli (2007) and Agénor, Bratsiotis, and Pfajfar, (2011).

[15] Note that households and commercial banks could also hold government bonds, but for the purpose of this paper we focus on bonds being held only by firms. Within our framework this can be explained by the fact that bonds and deposits bear the same interest, hence the household treats them as very close substitutes. Similarly, given the two assets have the same return, (and given that commercial banks banks do not bear risk in this model), banks would rather use all deposits for loans rather than hold bonds. This however is not true for firms which by assumption are required by banks to back part of their loans

Firms contract labor and capital at their market determined real wage and real rental price of capital, hence the firm's loan is equivalent to its variable cost,

$$L_t = P_t r_t k_t + P_t w_t n_t, \tag{16}$$

We assume that a portion ϑ of loans is collateralized by the firm's holdings of safe assets (before interest payments),[16]

$$\vartheta L_t = B_{j,t} \tag{17}$$

From (15), 16 and (17), the firm's period profits are,

$$V_{j,t} = P_{j,t} y_{j,t}(1 - \tau_t^Y) + i_t^{CB} B_{j,t} - R_t^L L_t \tag{18}$$

where, τ_t^Y is a *net* (i.e. less subsidies or business transfers) *production tax*, and $R_t^L = 1 + i_t^L$. Using (13)-(18), the period optimal real price of firm j is,

$$P_{j,t}^* / P_t = \mu_p mc_t \tag{19}$$

where $\mu_p = \theta/(\theta - 1)$ is the price mark-up and real marginal cost is,[17]

$$mc_t = \left(\frac{1 + i_t^L - \vartheta i_t^{CB}}{1 - \tau_t^Y} \right) \left(\frac{r_t}{\alpha_k u_t^\chi (y_t/k_t)^{1-\chi}} + \frac{w_t}{\alpha_n a_t^\chi (y_t/n_t)^{1-\chi}} \right), \tag{20}$$

where $\alpha_k u_t^\chi (y_t/k_t)^{1-\chi}$ is the marginal product of capital and $\alpha_n a_t^\chi (y_t/n_t)^{1-\chi}$ is the marginal product of labor. With a Cobb-Douglas specification, (i.e. with $\chi = 0$), and with only labor costs, (where $\alpha_n = 1 - \alpha$), (20) reduces to $mc_t = \frac{w_t}{(1-\alpha)(y_t/n_t)}$, which is the widely used marginal cost proxy, known

by collateral, i.e. bonds here.

[16]In Goodfriend and McCallum, (2007), loan makers construct collateral from goverenment bonds and firms' capital; Hnatkovska, Lahiri and Vegh, (2008) show borrowing firms to have government bonds explicitly in their flow constraint.

[17]Note that here marginal cost incudes also the production tax.

as the share of *unit labor costs* in GDP, (Gali, Gertler and Salido-Lopez 2001, 2005, Gali and Gertler 1999). However, from (20), real marginal cost here is a function of both *unit labor costs* and *non-labor unit costs,* the sum of which we define as *total unit cost* in this paper. *Unit labor costs* is the familiar proxy as identified elsewhere in the literature, whereas *non-labor unit costs*, (in combination with (4)-(9) and (12)), are a function of, *real capital costs,* (accounting for *capital consumption* and *depreciation*); *net interest payments* that relate to the firm's borrowing costs and financial returns; *intermediations costs;* and finally *net production taxes.*[18]

2.4 The New Keynesian Phillips Curve

We allow nominal rigidity to be characterized by a Calvo type price setting, according to which the price of each firm has a fixed probability, ψ, of remaining fixed at the previous period's price and a fixed probability of $1-\psi$ of being adjusted. Each firm setting a new price at time t will choose a price contract, X_t, to minimize current and future deviations of prices from optimal prices, $P^*_{j,t+s}$,

$$E_t \sum_{s=0}^{\infty} \psi^s \Delta_{t,t+s} \left(P_{j,t} - P^*_{j,t+s}\right)^2, \tag{21}$$

where, $\Delta_{t,t+s} = \beta^s c_{t+s}^{-\sigma}/c_t^{-\sigma}$, is the discount factor. Minimizing (21) with respect to $P_{j,t}$ and denoting percentage deviations around a zero inflation

[18] Note that (20) is consistent with a some papers in the literature that derive marginal costs as a function of labor costs as well as capital costs, borrowing costs and productions taxes, or combinations of these (see Christiano, Eichenbaum and Evans, 2001, Woodford, M. 2001, Ravenna and Walsh 2006, Chowdhury, Hoffmann, and Schabert, 2006, Faia and Monacelli 2007, Di Bartolomeo, and Manzo, 2007, Agenor, Bratsiotis and Pfajfar 2011).

steady state by a *hat*, we obtain,

$$\begin{aligned}\widehat{X}_t &= (1-\psi\beta)\sum_{s=0}^{\infty}\psi^s\beta^s E_t\widehat{P}^*_{j,t+s}, \\ &= (1-\psi\beta)(\widehat{P}^*_{j,t}) + \psi\beta E_t\widehat{X}_{t+s},\end{aligned} \tag{22}$$

where $\widehat{X}_t$ is the optimal price contract chosen by all firms that adjust prices in each period t and $\widehat{P}^*_{j,t} = \widehat{P}_t + \widehat{mc}_t$ is the optimal price based on (19), approximated around a zero inflation steady state. The average price in the economy is,

$$\widehat{P}_t = \psi\widehat{P}_{t-1} + (1-\psi)\widehat{P}^N_t, \tag{23}$$

where newly set prices, $\widehat{P}^N_t = (1-\omega)\widehat{X}_t + \omega\widehat{P}^B_t$, are a weighted average of optimally set prices, $\widehat{X}_t$ and backward looking set price, $\widehat{P}^B_t = \widehat{X}_{t-1} + \pi_{t-1}$, (as in Gali and Gertler, 1999). Using equations (22) and (23) and the definitions, $\pi_t = \widehat{P}_t - \widehat{P}_{t-1}$, $\pi_{t-1} = \widehat{P}_{t-1} - \widehat{P}_{t-2}$ and $E_t\pi_{t+1} = E_t(\widehat{P}_{t+1} - \widehat{P}_t)$ we derive the hybrid NKPC.

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f E_t\pi_{t+1} + \lambda\widehat{mc}_t, \tag{24}$$

where, $\gamma_b = \frac{\omega}{\psi+\omega(1-\psi(1-\beta))}$; $\gamma_f = \frac{\psi\beta}{\psi+\omega(1-\psi(1-\beta))}$; $\lambda = \frac{(1-\omega)(1-\psi)(1-\psi\beta)}{\psi+\omega(1-\psi(1-\beta))}$; and the log-linearized marginal cost, or *total unit costs,* is[19]

$$\widehat{mc}_t = \frac{i^L\hat{\imath}^L_t - \vartheta i^{CB}\hat{\imath}^{CB}_t}{1+i^L-\vartheta i^{CB}} + \frac{S_k\widehat{S}_{k,t} + S_n\widehat{S}_{n,t}}{S_k+S_n} + \frac{\tau^Y\widehat{\tau}^Y_t}{(1-\tau^Y)},$$

where, $\widehat{S}_{k,t} = \hat{r}_t - (1-\chi)(\widehat{y}_t - \hat{k}_t) - \chi\hat{u}_t$ and $\widehat{S}_{n,t} = \hat{w}_t - (1-\chi)(\hat{y}_t - \hat{n}_t) - \chi\widehat{a}_t$, are the shares of *capital unit costs* and *labor unit costs* respectively and $S_k = \frac{r^k}{\alpha_k(y/k)^{(1-\chi)}}$ and $S_n = \frac{w}{\alpha_n(y/n)^{(1-\chi)}}$, are their respective steady states.

[19] For the log-linearization of the marginal cost see Appendix B.

The log-linearized loan rate is,[20]

$$\hat{\imath}_t^L = \frac{i^{CB}}{i^L}\hat{\imath}_t^{CB} + \frac{\overline{\zeta}}{i^L}\widehat{\zeta}_t - \frac{\xi}{i^L}\widehat{y}_t,$$

where, $\hat{\imath}_t^{CB}$ is described in (25) below and $\widehat{\zeta}_t = (1-\rho_\zeta)\widehat{\zeta}_{t-1} + \epsilon_{\zeta,t}$.

From the coefficients γ_b, γ_f, and λ, (24) implies that for any given probability of firms not adjusting prices (ψ), a smaller weight on backward looking inflation (ω) reduces the coefficient on past inflation (γ_b), while increasing the coefficient on marginal costs (λ) and future expected inflation (γ_f); in which case the role of real marginal cost, as opposed to that of intrinsic inflation, should also become more significant in driving inflation dynamics in the model. Note that (24) is similar to the hybrid NKPC derived in Gali and Gertler (1999) and Gali, Gertler and Salido-Lopez (2001, 2005), with the main difference being the composition of the real marginal cost; in the latter two studies, as with the bulk of the literature, marginal cost is proxied simply by unit labor costs, $\widehat{mc}_t = \widehat{S}_{n,t} = \hat{w}_t - (\hat{y}_t - \hat{n}_t)$.

2.5 Monetary Policy and Macro Equilibrium

We complete the theoretical model by assuming that monetary policy is conducted by a Taylor-type interest rate rule; expressed in terms of deviations from steady state,

$$\widehat{\imath}_t^{CB} = \rho_i \widehat{\imath}_{t-1}^{CB} + (1-\rho_i)\left(\phi_\pi \pi_t + \phi_y \widehat{y}_t\right) + \epsilon_{i,t} \tag{25}$$

where, $0 < \rho_i < 1$ and $\phi_\pi, \phi_\pi > 0$ and $\epsilon_{i,t}$ follows an AR(1) process. We assume that any liquidity offered by central banks as loans to the commercial

[20] At the steady state, $i^{CB} = \beta^{-1}$; $i^L = i^{CB} + \overline{\zeta}$, ($\overline{\zeta} > 0$), and also $a = u = 1$, (see Neiss and Pappa, 2005).

bank enters through exogenous cash injections, (i.e. $L_t^{CB} = M_t - M_{t-1}$).[21] We also assume that at the end of each period, any proceeds from production taxes, or from the central bank's cash loans to the commercial bank, are transferred to households through a lump sum transfer, $P_t\tau_t$. Hence equilibrium in the final goods markets must satisfy the aggregate resource constraint, $y_t = c_t + i_t$.

3 Empirical Estimation

In this section we replicate some of the key tests performed in the literature to show that, as indicated by the theoretical model, *total unit costs* is a more appropriate proxy for marginal cost than *unit labor costs.* We show that although unit-labor costs is the largest component of marginal cost, the addition of non-labor costs to the conventional labor unit costs adds more information to the data and improves the fit of inflation persistence and the proxy for real marginal cost as the driving variable in the NKPC.

3.1 Data

Our choice of data and its source remains as consistent as possible to the data already used in the literature. *Total unit costs* are constructed using quarterly data for *labor costs* and *non-labor costs* for the period 1966:Q1 to 2003:Q4, available from the US Bureau of Labor Statistics (BLS) and the U.S. Department of Commerce Bureau of Economic Analysis.[22] Of these, *la-*

[21] This, in conjuction with the bank's balance sheet (equations 8 and 9), also define the demand for deposits, (see also Ravenna and Walsh, 2006).

[22] This sample period corresponds to Fuhrer (2006) as we want to compare our results with those produced by Fuhrer's ACF graph, (see Figure 4 below). Also, it is important here to emphasize that our *total unit costs* is constructed from all *non-farm business sector* (using raw BLS data), rather than merely on the *non-financial corporate sector.* The data

bor costs are the same data as that used widely in the literature.[23] N*on-labor costs,* are based on *non-labor payments* (non-farm) as published by the BLS, less *corporate profits* (non-farm). Thus, consistent with our theoretical specification n*on-labor costs* consist of, consumption of fixed capital, net taxes on production (and imports), net interest and miscellaneous payments (including borrowing costs and interest earnings on financial assets) and business current transfer payments.[24] Our proxy for real marginal cost, real *total unit costs,* is then constructed as the (log of) the sum of *labor costs* and *non-labor costs* in non-farm GDP, deflated by the (log of) non-farm deflator.[25] As with the rest of the literature, marginal cost is measured as a deviation from its mean, that is also consistent with the log-linearized theoretical model.

{Figure 2a} {Figure 2b}

Figures 2a and 2b compare annual inflation with the annual change in (non-farm) *unit labor cost* and (non-farm) *total unit costs*, respectively. Evidently, both unit labor costs and unit total costs track inflation, however the variance

set we use is also clearly different to that used in Gwin and VanHoose (2007, 2008) that is constructed based on around 10,000 listed firms in S&P, that is part of the six-digit NAICS industry classifications system.

[23] For more details see in the Appendix.

[24] As shown from (20) and (24) our theoretical marginal cost captures most of the key components of the definition of the non-labor payments as given by the BLS, except import taxes. Had we assumed that part of the intermediate goods were imported, the marginal costs would also be a function of imported goods and hence import taxes. For comparative reasons, but also to keep our paper consistent with the bulk of the theoretical literature, we choose not to explore related theoretical issues of an open economy, although we recognize the importance of the latter. For a recent paper that considers open economy issues within a new Keynesian framework, see Adolfson, Laséen, Lindé, and Villani, (2005).

[25] Note that as indicated by a number of studies, the results do not differ much when the all-sector GDP deflator is used instead of the non-farm GDP deflator (see Gali and Gertler 1999, Fuhrer 2006). Also, the use of the GDP deflator, as opposed to the PPI as suggested by Gwin and VanHoose (2007, 2008), is mainly for transparency in assessing the significance of our marginal cost proxy in relation to the conventional estimations of the NKPC.

of unit total costs around inflation appears to be smaller than that of unit labor costs.[26]

Figures 3a-3d present, as a crude measure of persistence, the sample autocorrelations of the *total unit cost* and *unit labor cost* measures of marginal cost and inflation. For completeness, we also show the autocorrelation for *non-labor unit costs*, the additional component of total unit costs. Figure 3a shows that the persistence in inflation is much greater than the persistence of unit labor costs. After the first four periods the autocorrelation in unit labor costs drops substantially in relation to that of actual inflation, whereas the opposite is shown for the persistence of the non-unit labor costs. As a result the combination of these two, that is the persistence in total unit costs, is shown to be much closer to the persistence in actual inflation.

{**Figure 3a**} {**Figure 3b**}

{**Figure 3c**} {**Figure 3d**}

Empirical evidence suggests that most notable shifts in inflation persistence in the US occurred in the early 1980s and in the 1990s. Accordingly, in figures 3b to 3d we plot the sample autocorrelations of the two alternative marginal cost proxies, for the sub-samples 1980-2003 and 1990-2003. Only non-labor unit cost and total unit cost show any perceptible shift in persistence across the samples.[27]The estimated sum of the lag coefficients in a univariate autoregression over the full sample for unit labor cost, non-labor unit cost and total unit costs are 0.90, 0.97 and 0.95, respectively. However it is known

[26]Note the differences in the height of the peaks of total unit costs (which is about 0.02 for the first shock and 0.01 at the second shock) reflect the response of non-labor costs to the oil price shock.

[27]A graph similar to fig 3b in our paper is in Fuhrer 2006, (page 74), that accounts only for unit labor cost.

that in the presence of shifts in persistence these estimates could be biased.

{Table 1: Test for Break Points in the Persistence of...}

Table 1 presents the results of a more formal estimation of persistence in the presence of unknown breaks (as suggested by Perron and Vogelsang 1992). Table 1 shows the break points and the coefficients on the AR term for each resulting sub-sample. The changes in the size of the AR coefficients are relatively small for unit labor costs thus confirming the previous inference of very little change in persistence. The average of the AR coefficients for non-unit labor costs and total unit costs are higher than the average for unit labor cost even after we account for the breaks. However, as Rotemberg (2007) demonstrates, the NKPC can generate inflation that is more persistent than the driving variable. Hence, one cannot rely on the univariate estimates of persistence in assessing alternative measures of marginal cost. In what follows therefore we turn to examine the structural estimates of the NKPC.

3.2 Structural Estimates

In this section we estimate the hybrid NKPC, equation (24), using non-linear instrumental variables (GMM) with robust errors over the period 1966:Q1 to 2003:Q4. To deal with the small sample normalization problem we follow Gali and Gertler (1999) and use the following orthogonality conditions,

$$E_{t-1}\{(\pi_t - \lambda\widehat{mc}_t - \gamma_f\pi_{t+1} - \gamma_b\pi_{t-1})z_{t-1}\} = 0 \qquad (26)$$

$$E_{t-1}\{(\xi\pi_t - (1-\omega)(1-\psi)(1-\psi\beta)\widehat{mc}_t - \psi\beta\pi_{t+1} - \omega\xi^{-1}\pi_{t-1})z_{t-1}\} = 0 \qquad (27)$$

where $\xi = \psi + \omega(1 - \psi(1 - \beta))$, z_{t-1} is a vector of variables dated t-1 and earlier and equation (24) is assumed to include an error term ε_t that is i.i.d.

Equation (26) normalizes the coefficient on inflation to be unity whereas (27) does not.

{Table 2: NKPC Estimates: Unit Labor Cost vs Total Unit Costs}

Table 2 gives non-linear instrumental variables, (GMM, IV) estimates of the deep structural parameters in equation (24) using *labor unit costs* and *total unit costs* as proxies for marginal cost, respectively. The instrument set used is four lags of the measure of real marginal costs, inflation, wage inflation and commodity price inflation.[28] The results in Table 2, suggest that adding *non-labor unit costs* to the familiar *unit labor costs* improves on the existing empirical support for (a) the role of real marginal cost as the driving variable in the NKPC and (b) the forward looking expectations-based new Keynesian Phillips curve.

Focusing first on the real marginal cost coefficient, λ, Table 2 shows that total unit costs imply a higher λ, than the traditional measure of real unit labor cost. Further, t-statistics for the difference in these estimated coefficients, show that even when standard errors are taken into account the size of λ is significantly different (higher in absolute terms) when total unit cost is used as the measure of marginal cost, irrespective of the orthogonality condition and restriction on beta.[29]

To further establish, independently of our structural model, whether the total unit costs NKPC is a better specification than the unit labor costs

[28] Here we use the most parsimonious instrument set possible to avoid the estimation bias that arise in small samples with too many over-identifying restrictions (see Staiger and Stock (1987). However, in Table 3, where we compare our marginal cost proxy to that used in Gali, Gertler and Lopez-Salido (2005) we use, for comparative purposes, exactly the same instruments as those employed by the latter study.

[29] Table 2a in the Appendix, reports the t-statistics for the difference in the estimated parameters in Table 2 using the standard test for difference in means. (see Appendix).

NKPC, we also conduct a non-nested test. The results are summarized in Table 3. Although the definition of total unit cost nests unit labor cost, equation (24) does not lend itself to the traditional F-tests for nested models, since it only includes one marginal cost variable. We therefore treat the unit labor cost NKPC and total unit labor cost NKPC as two different non-nested models focusing on the choice of regressors, that is total unit cost versus unit labor cost. In this regard we employ the Davidson and MacKinnon (1981) J-test which is based on the comprehensive approach and the Godfrey (1983) non-nested test for instrumental variable estimators.[30]

{Table 3: NKPC Estimates: Non-nested Tests}

Table 3, indicates that while we reject the null hypothesis for the labor unit cost NKPC model in favour of the total unit cost model, we cannot reject the null for the total unit cost NKPC model; hence *total unit cost* NKPC appears to be a better explanatory variable for inflation than the standard labor unit cost NKPC.

3.2.1 Total Unit Costs and Forward Looking Behavior

The results in Table 2 also suggest that when *total unit costs* are used as the driving variable in the NKPC, the coefficients on the structural parameters indicating backward looking behavior, (i.e. ω, ψ and γ_b) are generally lower, and those indicating forward looking behavior (i.e. γ_f and β) are generally higher, than their respective *labor unit cost* counterparts. To test the robustness of this result we perform a number of tests, including trying different sample periods, applying a time varying trend and also testing

[30]For more details see in the Appendix

the implications of total unit costs for fundamental inflation and inflation persistence.[31]

First, we test whether the relatively stronger forward looking behavior implied by total unit costs, holds in periods of high inflation volatility. Using *unit labor costs* on US data, Zhang, Osborn and Kim (2008) find very little empirical support for the role of forward expectations-based inflation persistence in the high and volatile inflation period 1968:1 to 1981:4. When we estimate the NKPC structural parameters for the same sample period, we find that the coefficient on unit labor costs is, $\lambda = 0.024$ (0.001) (standard errors in brackets) with $\gamma_b = 0.339$ (0.016) and $\gamma_f = 0.478$ (0.020).[32] However, for the same sample period the use of *total unit costs* produces, $\lambda = 0.0407$ (0.0016), with $\gamma_b = 0.299$ (0.015) and $\gamma_f = 0.570$ (0.024).[33] This, consistently with Table 2, suggests that *total unit costs* indicate a larger role for forward looking behavior than that implied by *unit labor costs*. It also suggests, that much of the evidence supporting a backward NKPC might have been somewhat biased by the use of unit labor costs as a proxy for marginal cost.

Similar results are presented in Table 4, where we examine the role of *total unit costs* using the exact sample period and instruments used by Gali,Gertler and Salido-Lopez (2005) (GGSL 2005),

{Table 4: Comparative estimates of NKPC with GGSL 2005}

Total unit costs are again shown to produce a statistically significant coefficient that is larger than that produced by unit labor costs. Note also

[31] The latter two tests are discussed in sections 3.2.1 and 3.3 respectively.

[32] For the full details see Table 6 in the Appendix.

[33] The difference in the coefficients on γ_f between these two marginal cost proxies is statistically significant (t-stat for difference is 22.037).

that in relation to Table 2, that includes the more recent years of relatively high inflation stability (late 1980s to 2003), Table 4 suggests a larger role of expectations-based inflation persistence, γ_f, when total unit costs are used instead of labor unit costs.

We also find that total unit costs imply a degree of price stickiness, ψ, that is closer to the values supported by micro data. Specifically, the estimate from the first orthogonality condition implies an average price duration of 3.6 quarters, while the second orthogonality condition implies a duration of 4.1 quarters. Even after we account for the standard errors, these estimates are closer to the 3 to 4 quarters found by Blinder (1994) using micro data, than a duration of 5 quarters or higher which is typically found in the empirical NKPC literature.[34]

{Table 5: NKPC, GMM Estimates - detrended unit cost}

Consistently with the literature, the above estimations are based on deviations of unit labor costs and total unit cost from their respective sample mean. However, this may not be appropriate if there are changes in the mean over time, which as figures 1, 2 and 3 suggest, is likely. In this regard, similar to Gwin and VanHoose (2007) we use the HP detrended measures of marginal cost along with the same instrument set. Table 5 indicates that the results do not change significantly for total unit costs. We next check the implications of total unit costs for fundamental inflation and persistence.

[34] Note that Sbordone's (2001) main baseline calibrated results (using labor unit costs) show price contracts of 4.7 quarters. To obtain plausible estimates for price stickiness she had to assume (a) the share of capital was 0.25 , (b) the mark-up firms charged was 20%. The latter assumption is significantly higher than the 10% found in the literature see Gagnon and Khan (2004) and Basu and Fernald (1997). Also Gagnon and Khan's (2004), (also using unit labor costs), estimates of beta (0.86 is the largest value reported) are very low with respect to near unity as suggested for the US in Gali and Gertler (1999).

3.2.2 Actual versus Fundamental Inflation

To assess the explanatory power of the NKPC using total unit cost as opposed to unit labor costs, we estimate the model-consistent or 'fundamental' (Gali and Gertler 1999) inflation rate and compare this with the actual inflation rate. As Gali and Gertler (1999) show, the hybrid NKPC has the following closed form,

$$\pi_t = \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma_f} \sum_{s=0}^{\infty} \delta_2^{-s} E_t \{ \widehat{mc}_{t+s} | z_t \}$$

where $\delta_1 = \frac{1-\sqrt{1-4\gamma_b\gamma_f}}{2\gamma_f}$ and $\delta_2 = \frac{1+\sqrt{1-4\gamma_b\gamma_f}}{2\gamma_f}$ are the small and large roots of (24) respectively and z_t is a subset of the market's information set containing current and lagged values of inflation and real marginal cost i.e. $z_t = \{\pi_t, ..., \pi_{t-q+1}, \widehat{mc}_t, ..., \widehat{mc}_{t-q+1}\}'$. If we assume that the data generating process for z_t can be represented by the following VAR(q), $z_t = \mathbf{A} z_{t-1} + v_t$, where A is a $2q$ x $2q$ companion matrix, then as Campbell and Shiller (1987) demonstrates the second term in the equation, (i.e. discounted future marginal cost) is,

$$\frac{\lambda}{\delta_2 \gamma_f} \sum_{s=0}^{\infty} \delta_2^{-s} E_t \{ \widehat{mc}_{t+s} | z_t \} = \frac{\lambda}{\delta_2 \gamma_f} h' \delta_2 \mathbf{A} (1 - \delta_2 \mathbf{A})^{-1} z_t$$

from which the fundamental inflation is,

$$\pi_t^f = \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma_f} h' \delta_2 \mathbf{A} (1 - \delta_2 \mathbf{A})^{-1} z_t$$

where h' is a 1 x $2q$ selection row vector that extracts the forecast of real marginal cost (i.e. the first element of $\mathbf{A}(1 - \delta_2 \mathbf{A})^{-1} z_t$). Accordingly, we derive the present value of future marginal cost from a VAR(3) model.[35]

[35] The Schwarz and Hannan-Quinn information criteria suggest a lag length of 3 for the VARs for both total unit cost and unit labor cost.

The resulting fundamental inflation for *total unit cost* and *unit labor cost* versus actual inflation are shown in figures 4a and 4b.

{Figure 4a} {Figure 4b}

These figures show that the *total unit cost* driven NKPC matches actual inflation much better than its *unit labor cost* counterpart. [36]

3.3 Total Unit Costs and Inflation Persistence

In this section we examine how the inflation persistence implied by our *total unit cost* driven NKPC, that is based on the structural parameters of our model, compares to that implied by a VAR model using real data. Following Fuhrer (2006), we compute the theoretical autocorrelation function (ACF) for the NKPC using the coefficients from Table 2 (as implied by the orthogonality condition (27) for the unrestricted case) and then compare it to the autocorrelation function from the simple three variable VAR in the inflation rate, federal funds rate and real marginal cost, estimated over the period 1966 to 2003.[37] The ACF of the VAR gives an estimate of the persistence that is consistent with the data and is independent of any structural or theoretical restriction. Fuhrer (2006) suggests that the reduced-form persistence obtained from the VAR serves as a useful benchmark. By comparing this reduced-form persistence with that implied by the pure NKPC model we can

[36] Moreover, the generalized R^2 of Pesaran and Smith (1994), which is an asymptotically valid model selection criterion and measure of fit for nested and non-nested models estimated with instrumental variables, are 0.899 for the total unit cost NKPC and 0.706 for unit labor cost NKPC.

[37] We are grateful to Jeff Fuhrer for sharing his programs for generating the ACFs and confidence bands for the NKPC and VAR. For a detailed derivation of the ACF for inflation see Fuhrer (2006).

assess whether the persistence in inflation emanates from the driving variable or whether it is intrinsic.

Fuhrer (2006) shows that since the coefficient on the real marginal cost (as implied by unit labor costs) is at most around 0.035, for the theoretical NKPC to lie within the 75% confidence the coefficient on the backward looking inflation needs to have a value of 0.6, which contradicts the suggested values in the Gali et al studies, (which is around 0.3).

However, when we use Fuhrer's ACF graph with *total unit costs* as the marginal cost proxy, the theoretical NKPC lies well within the 70% confidence. In particular, using the coefficient estimates in Table 2, figure 5 shows the graph of the theoretical ACF implied by the total unit cost driven NKPC, (TUC NKPC - solid line). This figure also shows the ACF graph as implied by the unit labor cost driven NKPC, (Fuhrer (2006) - dashed line), as well as the ACF and the corresponding confidence interval implied by the VAR (VAR – dotted line).[38]

{Figure 5}

In contrast to the ACF derived from the unit labor cost model (Fuhrer 2006), the ACF derived from the total unit cost driven NKPC is much closer to the benchmark VAR ACF, and although at points is slightly higher, it is still within the 70% confidence band corresponding to Fuhrer (2006). In general, the *total unit cost* driven NKPC generates persistence that matches the data reasonably well. This also means that a lower γ_b is now required to capture the observed persistence in inflation, as a larger part of inflation is now captured by the real marginal cost proxy. In particular, the estimated value of $\gamma_b = 0.245$, that we use to derive the theoretical ACF in Figure 5, is much lower than the value of $\gamma_b = 0.6$ that Fuhrer (2006) found was required

[38] The shaded area gives the 70% confidence interval for the ACF from the VAR.

for the NKPC to sufficiently capture the persistence in inflation under unit labor costs.

4 Concluding Remarks

Wolman (1999), suggests that in assessing the new Keynesian Phillips curve more refined estimates of marginal cost than the labor income share should be investigated. Extending the data already used in the literature, by using both *labor* and *non-labor payments* in nonfarm GDP so as to match our theory-based marginal cost, we construct a *total unit cost* that we use as our real marginal cost proxy in the new Keynesian Phillips curve.

It is shown that adding non-labor unit costs to the familiar labor unit costs, (i) improves on the fit of observed inflation and hence on the existing empirical support for real marginal costs as the driving variable in the NKPC; (ii) imply a duration of fixed nominal contracts that is much closer to those suggested by firm-level surveys, than that implied by merely labor unit costs; (iii) *total unit costs* suggest a larger role for forward looking behavior and expectations-based inflation persistence than that implied by the conventional *unit labor costs.* This effect is shown to hold even in the relatively high and volatile inflation periods of the 1970's where the use of unit labor costs suggest a very weak forward looking behavior. Intuitively, this might be because in periods of increased uncertainty and high inflation volatility, expectations about future inflation may be more relevant to firms' decisions about non-labor costs, such as on borrowing costs and investment in new capital.

Wolman's suggestion to investigate more refined estimates of marginal cost is recently attracting more attention. We believe that richer data of marginal cost proxies, particularly from data that also reflect information about key leading economic indicators, such as expectations about interest rates, borrowing costs and investment, that are so far largely neglected in empirical estimations of the NKPC, may substantially improve the existing empirical evidence on forward looking behavior in price setting and inflation.

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Data Definitions

All the data, with the exception of commodity price index, are sourced from the U.S. Department of Commerce Bureau of Economic Analysis and the US Bureau of Labor Statistics. The commodity price index is the spot commodity index sourced from the Commodity Research Bureau at: http://www.crbtrader.com/crbindex/

Labor Cost (nonfarm): Source: US Bureau of Labor Statistics

Non-Labor Costs (nonfarm) = Non-Labor Payment (non farm) - Corporate Profits (nonfarm)

Non-Labor Payments (nonfarm): Source: US Bureau of Labor Statistics. These payments include profits, consumption of fixed capital, taxes on production and imports less subsidies, net interest and miscellaneous payments, business current transfer payments, rental income of persons, and the current surplus of government enterprises.

Corporate Profits (nonfarm):US Bureau of Economic Analysis, Table 6.16D (sum of profits of all non-farm domestic industries)

Inflation - Change in the log of the GDP deflator.

Nominal (nonfarm) GDP: US Bureau of Economic Analysis, Table 1.3.5

Output Gap: Log difference between real GDP and the Hodrick-Prescott filtered trend.

Total Costs (nonfarm) = Labor Cost (nonfarm) + Non-Labor Costs (nonfarm)

Unit Labor Costs (nonfarm)= (log) *Labor Cost (nonfarm)* - (log) *Nominal (nonfarm) GDP*

Total Unit Costs (nonfarm)= (log) *Total Costs (nonfarm)* - (log) *Nominal (nonfarm) GDP*

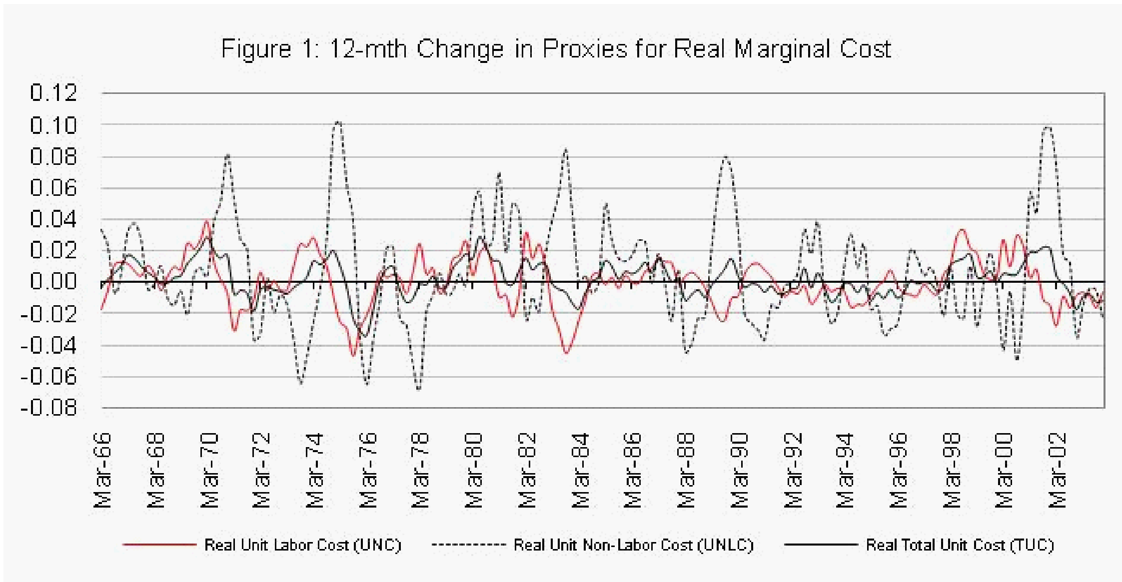


Figure 1: 12-mth Change in Proxies for Real Marginal Cost
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
Mar-66
Mar-68
Mar-70
Mar-72
Mar-74
Mar-76
Mar-78
Mar-80
Mar-82
Mar-84
Mar-86
Mar-88
Mar-90
Mar-92
Mar-94
Mar-96
Mar-98
Mar-00
Mar-02
Real Unit Labor Cost (UNC)
Real Unit Non-Labor Cost (UNLC)
Real Total Unit Cost (TUC)

Figure 2a: 12-month change in logs of total unit costs & GDP deflator

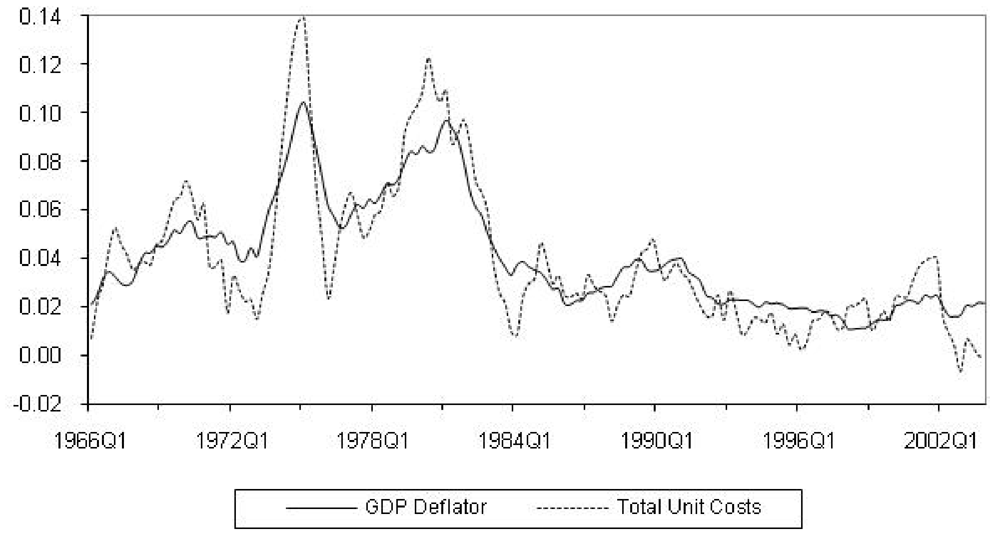


Figure 2b: 12-month change in logs of unit labor costs & GDP deflator

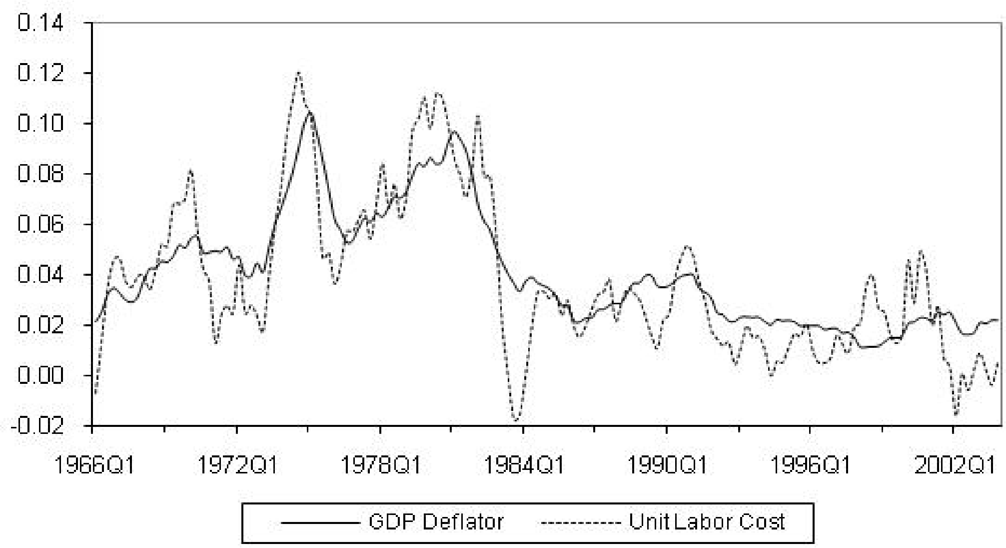


Figure 3a: Autocorrelation Functions (ACF)

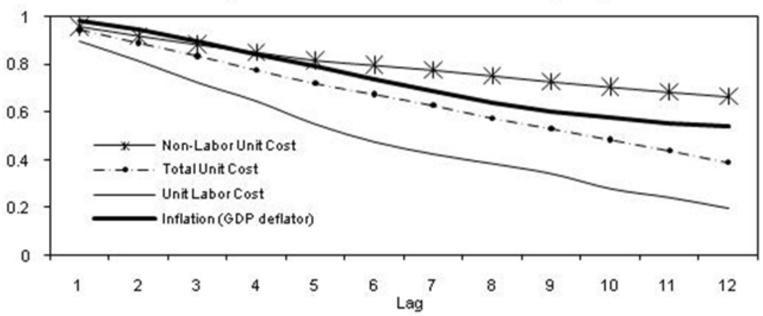


Figure 3b: Unit Labour Cost ACF

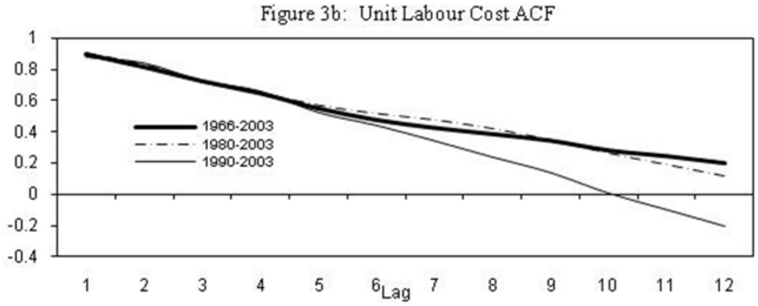


Figure 3c: Non-Labour Unit Cost ACF

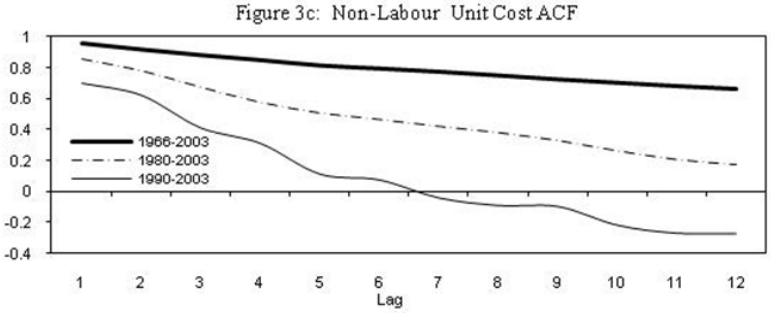


Figure 3d: Total Unit Cost ACF

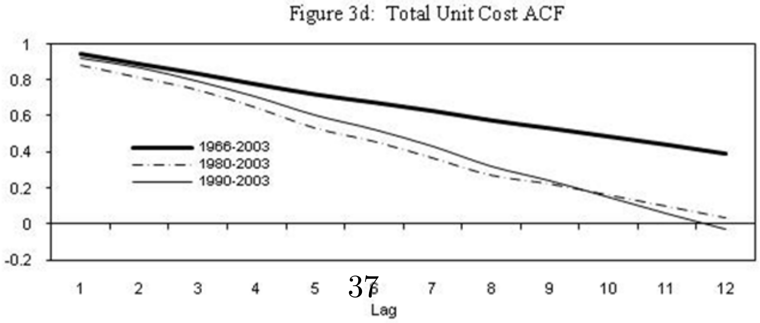


Figure 4a. Inflation: Actual vs Fundamental (Unit Labor Cost)

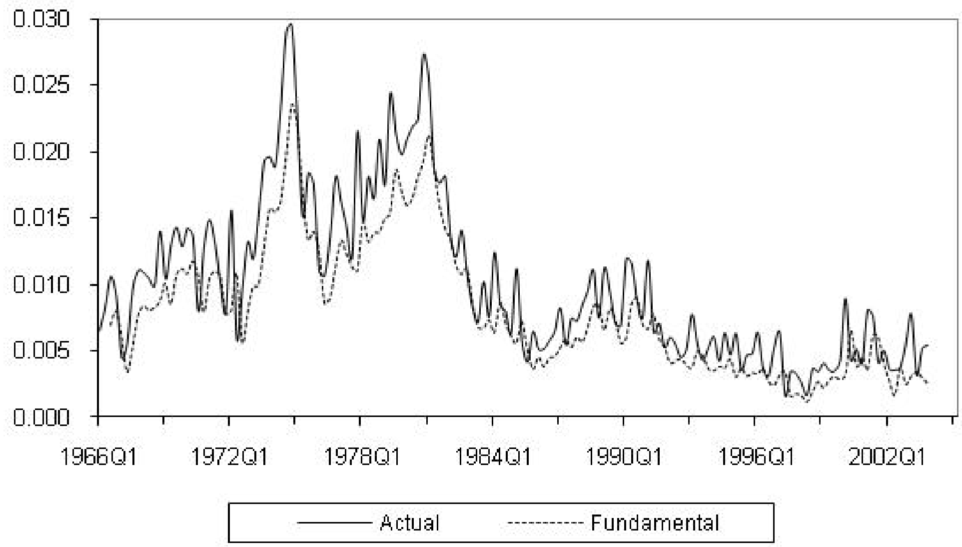
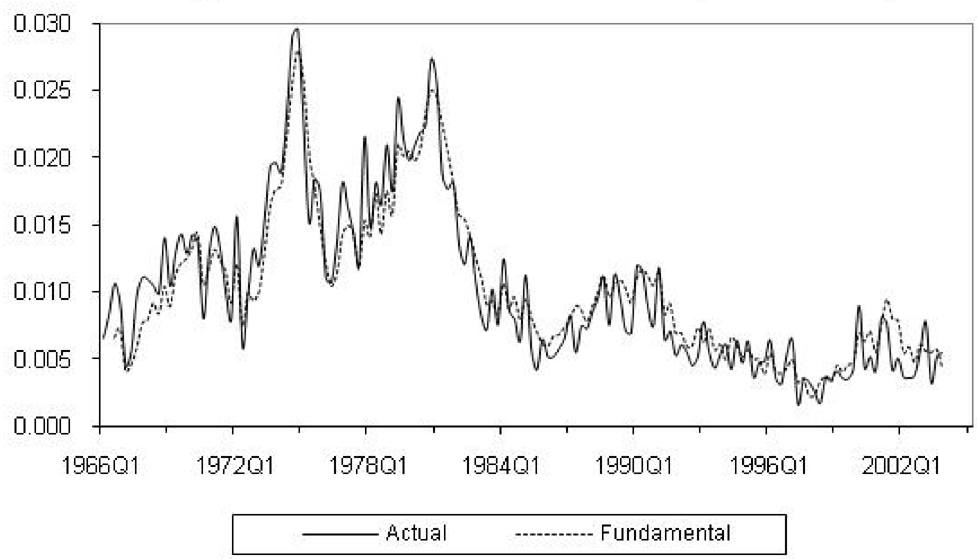


Figure 4b. Inflation: Actual vs Fundamental (Total Unit Cost)



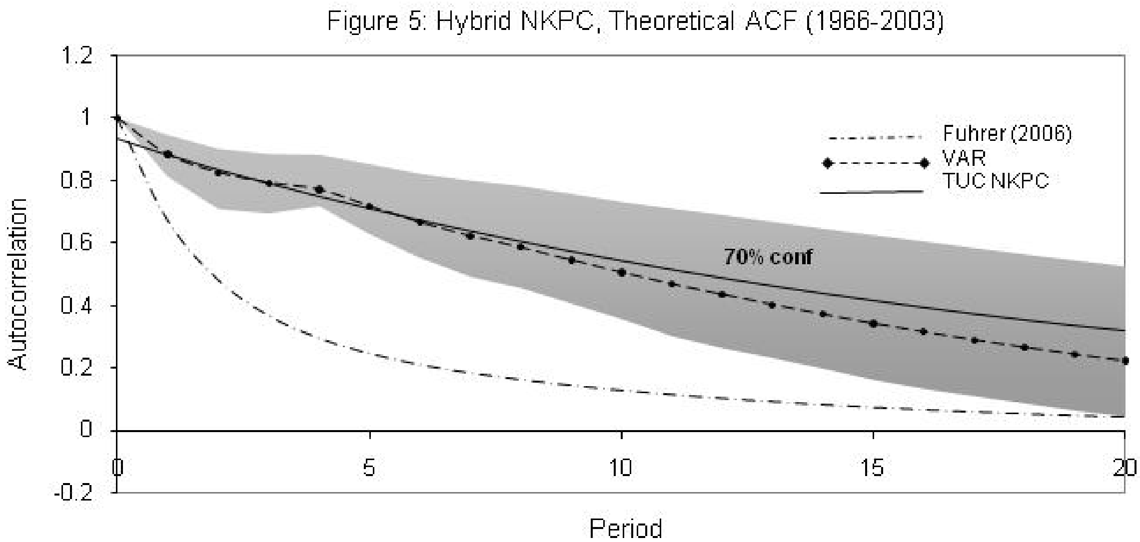


Figure 5: Hybrid NKPC, Theoretical ACF (1966-2003)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
Autocorrelation
0
5
10
15
20
Period
Fuhrer (2006)
VAR
TUC NKPC
70% conf

Table 1: Break Point Tests in the Persistence of Marginal Cost

Break Point	Autocorrelation Coefficient
Unit Labor Costs	
1981:04	0.8262*
1990:01	0.8082*
1997:02	0.7627*
Non-Labor Unit Costs	
1980:03	0.8568*
2000:02	0.7947*
Total Unit Costs	
1978:03	0.9008*
1997:02	0.8579*
2000:01	0.6774*

Note: This table presents results of tests for shifts in persistence using the Perron and Vogelsang (1992) innovational outlier model over the period: 1966Q1 to 2003Q4. * indicates significance at the 5% level.

Table 2: NKPC Estimates: Unit Labor Cost vs Total Unit Costs

	ω	ψ	β	γ_b	γ_f	λ	P(j-stat)
			Unit Labor Costs				
Unrestricted							
(eq. 28)	0.333 (0.056)	0.858 (0.030)	0.986 (0.018)	0.280 (0.081)	0.713 (0.099)	0.012 (0.001)	0.940
(eq. 29)	0.266 (0.037)	0.951 (0.023)	0.712 (0.041)	0.233 (0.012)	0.592 (0.017)	0.010 (0.001)	0.940
Restricted β							
(eq. 28)	0.338 (0.057)	0.862 (0.029)	1.00	0.282 (0.034)	0.718 (0.057)	0.010 (0.001)	0.959
(eq. 29)	0.171 (0.023)	0.819 (0.027)	1.00	0.173 (0.006)	0.827 (0.032)	0.027 (0.001)	0.946
			Total Unit Costs				
Unrestricted							
(eq 28)	0.250 (0.058)	0.724 (0.034)	1.03 (0.021)	0.255 (0.067)	0.763 (0.102)	0.053 (0.007)	0.922
(eq. 29)	0.243 (0.043)	0.757 (0.082)	0.957 (0.147)	0.245 (0.025)	0.731 (0.067)	0.051 (0.005)	0.923
Restricted β							
(eq 28)	0.267 (0.059)	0.768 (0.025)	1.00	0.258 (0.069)	0.742 (0.108)	0.038 (0.004)	0.950
(eq 29)	0.267 (0.031)	0.748 (0.025)	1.00	0.263 (0.011)	0.737 (0.027)	0.046 (0.001)	0.948

Note: This table reports non-linear IV (GMM) estimates of the deep structural parameters in equation (24), using labor unit cost and total unit costs as proxies to marginal cost. The estimation uses quarterly data over the period: 1966:Q1-2003:Q4. The instrument set includes four lags of the real marginal cost proxy, inflation, wage inflation and commodity price inflation. Standard errors are shown in brackets. A 12-lag Newey-West estimate of the covariance matrix is used. The last column presents the Hansen's J-test for overidentifying restrictions.

Table 3: NKPC Estimates: Non-nested Tests

	γ_b	γ_f	λ	*J-Test*	*Godfrey*
Unit Labor Costs	0.280 (0.035)	0.713 (0.037)	0.012 (0.006)	2.72*	3.44*
Total Unit Costs	0.255 (0.045)	0.763 (0.046)	0.053 (0.015)	−0.17	0.11

Note: This table reports the GMM estimates of the reduced-form of equation (24), using quarterly data over the period 1966 Q1 to 2003 Q4. The instrument set includes four lags of the measure of real marginal costs, detrended output, wage inflation and inflation. Standard errors are given in parenthesis below. A 12-lag Newey-West estimate of the covariance matrix is used. The last two columns give the Davidson –McKinnon J-test and Godfrey non-nested tests. Asterisks (*) denote significance at the 5% level.

Table 4: Comparative estimates of NKPC with GGSL (2005)

	γ_b	γ_f	λ	*P(j-stat)*
Unit Labor Costs (GGSL 2005)	0.349 (0.041)	0.635 (0.042)	0.013 (0.006)	n.a.
Total Unit Costs	0.205 (0.10)	0.786 (0.097)	0.028 (0.014)	0.458

Note: This table reports GMM estimates of equation (24), using quarterly data over the period 1960 Q1 to 1997 Q4. As in Gali, Gertler and Lopez-Salido (2005) the instrument set includes two lags of the real marginal costs proxy, inflation, detrended output, and wage inflation and four lags of inflation. The upper panel reports the comparative results from the baseline estimates in Gali, Gertler and Lopez-Salido (2005). Standard errors are given in parenthesis below. A 12-lag Newey-West estimate of the covariance matrix is used. The last column presents the Hansen's J-test for overidentifying restrictions.

Table 5: NKPC, GMM Estimates - detrended unit cost

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda mc_t$$

	γ_b	γ_f	λ	*Prob(j-stat)*
Unit Labor Costs	0.288 (0.035)	0.706 (0.037)	0.036 (0.012)	0.954
Total Unit Costs	0.266 (0.039)	0.729 (0.040)	0.047 (0.016)	0.939

Note: This table reports the GMM estimates of equation (24), using the Hodrick-Prescott filtered detrended measures of marginal cost. The estimation uses quarterly data over the period 1966:Q1 to 2003:Q4. The instrument set includes four lags of the measure of real marginal costs, inflation, wage inflation and commodity price inflation. Standard errors are given in parenthesis below. A 12-lag Newey-West estimate of the covariance matrix is used. The last column presents the Hansen's J-test for overidentifying restrictions.

APPENDIX

(Not for Publishing)

Appendix A: Further empirical tests

Table 2a, gives the t-statistics for the difference in the estimated parameters in Table 2 using the standard test for difference in means. The null hypothesis is that there is no significant difference in the estimates. The critical value of the t-statistics at the 5 percent level with 302 degrees of freedom is 1.98 and as such we reject the null hypothesis in all cases for all coefficients. Therefore, we conclude that, even when the standard errors are taken into account, the size of lambda is significantly different (higher in absolute terms) when total unit cost is used as the measure of marginal cost, irrespective of the orthogonality condition and restriction on beta.

Table 2a: NKPC Estimates: t- test for statistical difference

	ω	ψ	β	γ_b	γ_f	λ
		Total unit costs vs *Unit labor costs*				
Unrestricted						
(eq. 26)	-12.65^*	-36.31^*	19.55^*	-2.92^*	4.32^*	71.25^*
(eq. 27)	-4.98^*	-27.19^*	19.27^*	5.15^*	24.00^*	98.81^*
Restricted β						
(eq. 26)	-10.64^*	-30.17^*	*n.a.*	-3.83^*	2.42^*	83.45^*
(eq. 27)	30.56^*	-23.24^*	*n.a.*	88.26^*	-26.41^*	165.09^*

Note: This table reports the t-statistic for differences in coefficients of the NKPC estimates using total unit cost and unit labor cost. The test is a two-tailed test with the null hypothesis, $H_0 : x_{TUC} - x_{ULC} = 0$, against the alternative $H_0 : x_{TUC} \neq x_{ULC}$. The test statistic is $t = (x_{TUC} - x_{ULC})/\sqrt{s_p}$, where $s_p = 2(s^2_{TUC} + s^2_{ULC})/v$ and the degrees of freedom are $v = 2n - 2 = 302$; s is the standard error of the coefficient estimate. Stars (*) denotes the significance at the 5% level.

Test for the Non-Nested Model

We are interested in comparing two competing models:

$$M_x : \pi_t = X_t A + u_t$$

$$M_z : \pi_t = Z_t B + e_t,$$

where π_t is the inflation rate, $X_t = (\pi_{t-1}, E\pi_{t+1}, \textit{total unit costs})'$ and $Z_t = (\pi_{t-1}, E\pi_{t+1}, \textit{unit labor costs})'$; u_t and e_t are random errors and A and B are the matrix of coefficients estimated using GMM (instrumental variables). Define W as the matrix of instruments and $Q(W)$ the projection $W(W'W)^{-1}W'$. The null hypothesis is that M_i, $i = x, z$ is the valid model against the alternative M_j, $j = x, z$ $(i \neq j)$. The augmented model is $\pi_t = (1 - \varphi)X_t A + \varphi Z_t B + \varepsilon_t$. The null hypothesis tested is $\varphi = 0$. Yet, since φ cannot be separately estimated in this model we use the Davidson and MacKinnon's (1981) test.

For the Godfrey non-nested test for instrumental variables estimators, the augmented model is,

$$\pi_t = X_t A + (\widetilde{X}_t \widetilde{A})\theta + \varepsilon_t,$$

where $\widetilde{A}$ is the IV estimate of A; $\widetilde{X}_t$ is the matrix of OLS residuals of the regression of $\widehat{X}_t$ on $\widehat{Z}_t$; where $\widehat{X}_t = Q(W)\ X$ is the fitted values of the OLS regression of X on W and $\widehat{Z}_t = Q(W)\ Z$ is the fitted values of the OLS regression of Z on W. The test for the validity of M_x is therefore a standard t-test that $\theta = 0$, (for more details see Godfrey, 1983).

Table 6, provides the empirical estimates for the high and volatile inflation period sample used in Zhang, Osborn and Kim (2008). In the text we only report the key coefficients as shown by (eq 27), for the unrestricted case.

Table 6: NKPC Estimates: Unit Labor Cost vs Total Unit Cost (1968Q1-1981Q4)

	ω	ψ	β	γ_b	γ_f	λ	Prob(*j-stat*)
			Unit Labor Cost				
Unrestricted							
(eq. 26)	0.511	0.739	0.975	0.412	0.581	0.029	0.998
	(0.036)	(0.039)	(0.018)	(0.106)	(0.110)	(0.004)	
(eq. 27)	0.391	0.899	0.613	0.339	0.478	0.024	0.998
	(0.021)	(0.031)	(0.026)	(0.016)	(0.019)	(0.001)	
Restricted							
(eq. 26)	0.518	0.734	1.0	0.414	0.586	0.027	0.999
	(0.035)	(0.037)		(0.041)	(0.060)	(0.002)	
(eq. 27)	0.304	0.691	1.0	0.306	0.694	0.066	0.999
	(0.027)	(0.024)		(0.011)	(0.023)	(0.002)	
			Total Unit Cost				
Unrestricted							
(eq. 26)	0.372	0.722	0.984	0.342	0.651	0.046	0.998
	(0.039)	(0.021)	(0.013)	(0.017)	(0.015)	(0.001)	
(eq. 27)	0.325	0.828	0.747	0.299	0.570	0.041	0.998
	(0.023)	(0.036)	(0.051)	(0.015)	(0.024)	(0.002)	
Restricted							
(eq. 26)	0.379	0.718	1.0	0.345	0.655	0.045	0.999
	(0.040)	(0.019)		(0.068)	(0.080)	(0.003)	
(eq. 27)	0.295	0.699	1.0	0.297	0.703	0.064	0.999
	(0.016)	(0.016)		(0.007)	(0.016)	(0.001)	

Note: This table reports non-linear IV estimates (GMM) of the deep structural parameters in equation (25), using labor unit cost and total unit costs as proxies for marginal cost. The estimation uses quarterly data over the period: 1968:Q1-1981:Q4. The instrument set includes four lags of the real marginal cost proxy, inflation, wage inflation and commodity price inflation. Standard errors are shown in brackets. A 12-lag Newey-West estimate of the covariance matrix is used. The last column presents the Hansen's J-test for overidentifying restrictions.

Appendix B: Log-linearization of $\widehat{mc}_t$

At the steady state, $R^D = 1 + i^D$; $R = 1 + i^{CB}$; $i^{CB} = \frac{1}{\beta} > 1$; $R^L = 1 + i^L$; $i^L = i^{CB} + \overline{\zeta}$; where $\overline{\zeta} > 0$. We denote log-linearization from steady state by a hat, i.e. $\widehat{X}$.

Derivation of $\widehat{mc}_t$

$$mc_t = \left(\frac{1 + i_t^L - \vartheta i_t^{CB}}{1 - \tau_t^Y}\right)\left(\frac{r_t}{\alpha_k u_t^\chi (y_t/k_t)^{1-\chi}} + \frac{w_t}{\alpha_n a_t^\chi (y_t/n_t)^{1-\chi}}\right)$$

or

$$\left(1 - \tau_t^Y\right) mc_t = \left(1 + i_t^L - \vartheta i_t^{CB}\right)\left[\left(r_t \alpha_k^{-1} u_t^{-\chi} y_t^{-(1-\chi)} k_t^{(1-\chi)}\right) + \left(w_t \alpha_n^{-1} a_t^{-\chi} y_t^{-(1-\chi)} n_t^{(1-\chi)}\right)\right]$$

Log-linearizing:

$$\begin{aligned}
& mc\left(1 - \tau^Y\right)\left[1 + \widehat{mc}_t + \widehat{1 - \tau_t^Y}\right] \\
= & \left[\left(1 + i^L\right)\left(1 + \widehat{1 + i_t^L}\right) - \vartheta i^{CB}\left(1 + \hat{\imath}_t^{CB}\right)\right] \\
& r\alpha_k^{-1} u^{-\chi} y^{-(1-\chi)} k^{(1-\chi)}\left(1 + \hat{r}_t - \chi \hat{u}_t - (1-\chi)\hat{y}_t + (1-\chi)\hat{k}_t\right) \\
& + w\alpha_n^{-1} a^{-\chi} y^{-(1-\chi)} n^{(1-\chi)}\left(1 + \hat{w}_t - \chi \hat{a}_t - (1-\chi)\hat{y}_t + (1-\chi)\hat{n}_t\right)
\end{aligned}$$

which can be expressed as

$$\begin{aligned}
& mc\left(1 - \tau^Y\right)\left[1 + \widehat{mc}_t + \widehat{1 - \tau_t^Y}\right] \\
= & \left[\left(1 + i^L\right)\left(1 + \widehat{1 + i_t^L}\right) - \vartheta i^{CB}(1 + \hat{\imath}_t^{CB})\right]\left[S_k\left(1 + \widehat{S}_{k,t}\right) + S_n\left(1 + \widehat{S}_{n,t}\right)\right]
\end{aligned}$$

where, $\widehat{S}_{k,t} = \hat{r}_t - (1-\chi)(\widehat{y}_t - \hat{k}_t) - \chi \hat{u}_t$, and $\widehat{S}_{n,t} = \hat{w}_t - (1-\chi)(\hat{y}_t - \hat{n}_t) - \chi \widehat{a}_t$ are the shares of *capital unit costs* and *labor unit costs* respectively and $S_k = \frac{r^k}{\alpha_k (y/k)^{(1-\chi)}}$ and $S_n = \frac{w}{\alpha_n (y/n)^{(1-\chi)}}$ are their respective steady states.

We define deviations in the gross loan rate as

$$\widehat{1 + i_t^L} \approx \frac{1 + i_t^L - (1 + i^L)}{(1 + i^L)} = \frac{i_t^L - i^L}{(1 + i^L)}$$

as well as

$$i^L \hat{\imath}_t^L = i_t^L - i^L$$

so that

$$(1+i^L)\widehat{1+i_t^L} = i_t^L - i^L$$

$$(1+i^L)\left(\widehat{1+i_t^L}\right) = i^L \hat{\imath}_t^L$$

Substitute these into the marginal cost expression above

$$\begin{aligned} & mc\left(1-\tau^Y\right)\left[1+\widehat{mc}_t+\widehat{1-\tau_t^Y}\right] \\ = & \left[(1+i^L)\left(1+\frac{i^L}{(1+i^L)}\hat{\imath}_t^L\right)-\vartheta i^{CB}(1+\hat{\imath}_t^{CB})\right]\left[S_k\left(1+\widehat{S}_{k,t}\right)+S_n\left(1+\widehat{S}_{n,t}\right)\right] \end{aligned}$$

$$\begin{aligned} & mc\left(1-\tau^Y\right)\left[1+\widehat{mc}_t+\widehat{1-\tau_t^Y}\right] \\ = & \left[R^L+i^L\hat{\imath}_t^L-\vartheta i^{CB}(1+\hat{\imath}_t^{CB})\right]\left[S_k\left(1+\widehat{S}_{k,t}\right)+S_n\left(1+\widehat{S}_{n,t}\right)\right] \end{aligned}$$

The Tax:

$$\left(1-\tau^Y\right)\left[1+\widehat{1-\tau_t^Y}\right]$$

$$\left(1-\tau^Y\right)+\left(1-\tau^Y\right)\left(\widehat{1-\tau_t^Y}\right)$$

$$\widehat{1-\tau_t^Y} \approx \frac{(1-\tau_t^Y)-(1-\tau^Y)}{(1-\tau^Y)} = -\frac{(\tau_t^Y-\tau^Y)}{(1-\tau^Y)}$$

$$\widehat{\tau}_t^Y \approx \frac{\tau_t^Y-\tau^Y}{\tau^Y} \quad \text{or} \quad \tau^Y\widehat{\tau}_t^Y \approx \tau_t^Y-\tau^Y$$

$$(1-\tau^Y)\left(\widehat{1-\tau_t^Y}\right) = -\tau^Y\widehat{\tau}_t^Y$$

so that

$$mc\left(1-\tau^Y\right)\left[1+\widehat{mc}_t+\widehat{1-\tau_t^Y}\right] = \left[R^L+i^L\hat{\imath}_t^L-\vartheta i^{CB}(1+\hat{\imath}_t^{CB})\right]\left[S_k\left(1+\widehat{S}_{k,t}\right)+S_n\left(1+\widehat{S}_{n,t}\right)\right]$$

$$mc\left(1-\tau^{Y}\right)\left[1+\widehat{mc}_{t}-\frac{\tau^{Y}\widehat{\tau}_{t}^{Y}}{(1-\tau^{Y})}\right]=\left[R^{L}+i^{L}\hat{\imath}_{t}^{L}-\vartheta i^{CB}(1+\hat{\imath}_{t}^{CB})\right]\left[S_{k}\left(1+\widehat{S}_{k,t}\right)+S_{n}\left(1+\widehat{S}_{n,t}\right)\right]$$

$$\begin{aligned}&mc\left(1-\tau^{Y}\right)\widehat{mc}_{t}\\=&\left[R^{L}+i^{L}\hat{\imath}_{t}^{L}-\vartheta i^{CB}(1+\hat{\imath}_{t}^{CB})\right]\left[S_{k}\left(1+\widehat{S}_{k,t}\right)+S_{n}\left(1+\widehat{S}_{n,t}\right)\right]+mc\tau^{Y}\widehat{\tau}_{t}^{Y}-mc\left(1-\tau^{Y}\right)\end{aligned}$$

or

$$\widehat{mc}_{t}=\frac{\left[R^{L}+i^{L}\hat{\imath}_{t}^{L}-\vartheta i^{CB}(1+\hat{\imath}_{t}^{CB})\right]}{mc\left(1-\tau^{Y}\right)}\left[S_{k}\left(1+\widehat{S}_{k,t}\right)+S_{n}\left(1+\widehat{S}_{n,t}\right)\right]+\frac{\tau^{Y}\widehat{\tau}_{t}^{Y}}{(1-\tau^{Y})}-1$$

Use $mc=\frac{\left(1+i^{L}-\kappa i^{CB}\right)}{(1-\tau^{Y})}\left[S_{K}+S_{n}\right]$,

$$\widehat{mc}_{t}=\frac{\left[R^{L}+i^{L}\hat{\imath}_{t}^{L}-\vartheta i^{CB}\left[1+\hat{\imath}_{t}^{CB}\right]\right]}{\left(1+i^{L}-\vartheta i^{CB}\right)\left[S_{k}+S_{n}\right]}\left[S_{k}\left(1+\widehat{S}_{k,t}\right)+S_{n}\left(1+\widehat{S}_{n,t}\right)\right]+\frac{\tau^{Y}\widehat{\tau}_{t}^{Y}}{(1-\tau^{Y})}-1$$

Expanding, using $\widehat{x}_{t}\widehat{y}_{t}\approx 0$,

$$\widehat{mc}_{t}=\frac{R^{L}+i^{L}\hat{\imath}_{t}^{L}-\vartheta i^{CB}(1+\hat{\imath}_{t}^{CB})}{(1+i^{L}-\vartheta i^{CB})}+\frac{S_{k}\widehat{S}_{k,t}+S_{n}\widehat{S}_{n,t}}{S_{k}+S_{n}}+\frac{\tau^{Y}\widehat{\tau}_{t}^{Y}}{(1-\tau^{Y})}-1$$

Use $i^{L}=i^{CB}+\overline{\zeta}$, which implies $\frac{R^{L}+i^{L}\hat{\imath}_{t}^{L}-\vartheta i^{CB}(1+\hat{\imath}_{t}^{CB})}{(1+i^{L}-\vartheta i^{CB})}=1+\frac{i^{L}\hat{\imath}_{t}^{L}-\ i^{CB}\vartheta\hat{\imath}_{t}^{CB}}{(1+i^{L}-\vartheta i^{CB})}$ we obtain,

$$\widehat{mc}_{t}=\frac{i^{L}\hat{\imath}_{t}^{L}-\ i^{CB}\vartheta\hat{\imath}_{t}^{CB}}{1+i^{L}-\vartheta i^{CB}}+\frac{S_{k}\widehat{S}_{k,t}+S_{n}\widehat{S}_{n,t}}{S_{k}+S_{n}}+\frac{\tau^{Y}\widehat{\tau}_{t}^{Y}}{(1-\tau^{Y})}$$

The Loan Rate

$$i_{t}^{L}=i_{t}^{CB}+\zeta_{t}+(\frac{y_{t}}{y_{n}})^{-\xi}$$

$$i^{L}=i^{CB}+\overline{\zeta}$$

$$i^{L}(1+\hat{\imath}_{t}^{L})=i^{CB}(1+\hat{\imath}_{t}^{CB})+\overline{\zeta}(1+\widehat{\zeta}_{t})-\xi(1+\widehat{y}_{t})$$

$$\hat{\imath}_{t}^{L}=\frac{i^{CB}}{i^{L}}\hat{\imath}_{t}^{CB}+\frac{\overline{\zeta}}{i^{L}}\widehat{\zeta}_{t}-\frac{\xi}{i^{L}}(1+\widehat{y}_{t})$$

where here we assume that y_t is given proportionally to the natural rate of output so that its steady state value is unity.

The process of ζ_t

$$\log(\zeta_t) = \rho_z \log(\zeta) + (1-\rho_z)\log(\zeta_{t-1}) + \epsilon_{z,t};$$

$$\log(\zeta) + \widehat{\zeta}_t = \rho_z \log(\zeta) + (1-\rho_z)(\log(\zeta) + \widehat{\zeta}_{t-1}) + \epsilon_{z,t}$$

$$\log(\zeta) = \rho_z \log(\zeta) + (1-\rho_z)\log(\zeta) = \overline{\zeta} > 0$$

Here we assume that due the imperfections in the credit markets, the steady state mark-up $\zeta > 1$, so that $\overline{\zeta} = \log(\zeta) > 0$. Subtract $\log(\zeta)$ from both sides,

$$\log(\overline{\zeta}) + \widehat{\zeta}_t - \log(\overline{\zeta}) = \log(\overline{\zeta}) - \log(\overline{\zeta}) + (1-\rho_z)\widehat{\zeta}_{t-1} + \epsilon_{z,t}$$

$$\widehat{\zeta}_t = (1-\rho_z)\widehat{\zeta}_{t-1} + \epsilon_{z,t}$$