Macroeconomic Dynamics, **20**, 2016, 1826–1849. Printed in the United States of America.
doi:10.1017/S1365100515000140

UNIT TOTAL COSTS: AN ALTERNATIVE MARGINAL COST PROXY FOR INFLATION DYNAMICS

GEORGE J. BRATSIOTIS
University of Manchester
and
Centre for Growth and Business Cycle Research (CGBCR)

WAYNE A. ROBINSON
Bank of Jamaica

The New Keynesian Phillips curve (NKPC) driven by *unit labor costs* has been criticized for failing to match inflation dynamics and for failing to explain the duration of price contracts. This paper extends recent attempts in the literature to improve the fit of the NKPC, by introducing a fuller marginal cost proxy, *unit total costs,* that is derived from both *labor* and *nonlabor unit costs*; the latter include capital-related costs and production taxes. Borrowing costs are examined separately, as in the cost channel literature. *Unit total 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. They also imply a duration of fixed nominal contracts that is closer to those suggested by firm-level surveys. The *cost channel* becomes relatively less important when *unit total costs,* rather than *unit labor costs*, are used as a marginal cost proxy.

Keywords: New Keynesian Phillips Curve, Inflation, Price Rigidity, Marginal Cost Proxy, Production Costs, Borrowing Costs, Cost Channel

1. THE UNIT LABOR COST NKPC: A BRIEF OVERVIEW

Despite its recent popularity, there is still an ongoing debate as to whether the New Keynesian Phillips curve (NKPC), can match the observed inflation persistence and the length of fixed nominal price contracts as implied by surveys at the micro level. The widely used hybrid NKPC [see Gali et al. (2005)] specifies log-linearized inflation around its steady state as

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

where π_t is the inflation rate; $\widehat{\text{mc}}_t$ is real marginal cost; ϵ_t is a cost-push shock; and the coefficients are, $\gamma_b = \frac{\omega}{\psi+\omega(1-\psi(1-\beta))}$, $\gamma_f = \frac{\psi\beta}{\psi+\omega(1-\psi(1-\beta))}$, and

Address correspondence to: George J. Bratsiotis, Economics, School of Social Sciences, University of Manchester, Manchester M13 9PL, UK; e-mail: george.bratsiotis@manchester.ac.uk.

© 2015 Cambridge University Press 1365-1005/15

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

$\lambda = \frac{(1-\omega)(1-\psi)(1-\psi\beta)}{\psi+\omega(1-\psi(1-\beta))}$, where ψ is a fraction (constant probability) of firms not adjusting prices, whereas ω is the fraction of backward price-setting firms in this familiar Calvo-type sticky price setup. Gali and Gertler (1999), Gali et al. (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 (2006), Lawless and Whelan (2007), Lindé (2005), Rudd and Whelan (2005, 2007), and Zhang et al. (2008)]. Real marginal cost in these studies, as with the bulk of this literature, is proxied by real *unit labor costs*, where the latter are measured in relation to the deviation of labor income share in the nonfarm business sector from its mean,

$$\widehat{\mathrm{mc}}_t = \mathrm{mc}(\widehat{S}_{n,t}), \tag{2}$$

where $\widehat{S}_{n,t} = \hat{w}_t - (\hat{y}_t - \hat{n}_t)$ and $\hat{w}_t$, $\hat{y}_t$, and $\hat{n}_t$, are deviations of real wages, nonfarm GDP, and labor from their steady states, respectively. In estimating the NKPC, unit labor costs have been shown to be a better marginal cost proxy than the output gap; however, the degree of and the shifts in persistence using this proxy are still not a good fit to inflation. Fuhrer (2006), for example, shows that most of the persistence found in U.S. inflation data appears to be *intrinsic* from the lagged inflation term in the NKPC and thus cannot be attributed to unit labor costs. Rudd and Whelan (2002) and Lindé (2005) show that the labor share version of the NKPC explains a very small proportion of the variation in inflation, whereas Lawless and Whelan (2007), using both sectoral and aggregate data for the EU-15 and the United States, find negative coefficients on the effect of the labor share on inflation.[1] A further weakness is that the estimated coefficient on unit labor cost, as a proxy for real marginal cost, implies price rigidities that are not consistent with micro evidence. For the United States, for example, it implies price contracts of six quarters or much longer. This is inconsistent with a number of firm-level surveys that suggest that price rigidity ranges between 1.5 and 4 quarters.[2]

Following these findings and the contribution of Wolman (1999), there has been an effort to examine whether alternative marginal cost proxies can improve the fit of the NKPC.[3] Sbordone (2005) shows that incorporating adjustment costs does not significantly improve the fit of the NKPC, and a similar conclusion was recently reached by Lubik and Teo (2012), who examine whether inventory specifications of produced goods can improve the fit of the unit labor costs NKPC. Other studies assume different production technologies and aggregation methods and express average marginal cost as a function of both labor unit costs and the output (or employment) gap [see Gagnon and Khan (2005); Matheron and Maury (2004); Sbordone (2002, 2005)]. These studies assume that capital does not change with changes in the relative price of firms, and thus the resulting real marginal cost is still largely driven by labor unit costs. Gwin and VanHoose (2007, 2008), using data from 10,000 firms, construct a measure of PPI inflation and a growth rate of average variable costs as proxies for average price and marginal costs, respectively; although their PPI-inflation measure improves on the

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

fit of inflation, their alternative marginal cost data do not differ significantly from Gali and Gertler (1999). More recently, some studies have focused on the effects of capacity utilization, but their results vary. Mazumder (2010) accounts for the effects of labor utilization in the marginal cost proxy, but finds a negative coefficient for the latter. McAdam and Willman (2011) use a parameterized CES production to arrive at a "full" real marginal cost measure of the NKPC, which is shown to improve the fit of inflation and be more consistent with micro studies. Their "full" marginal cost is derived from a parametric form of effective labor hours that allows for covariation with capital utilization; hence, the main contribution of their paper comes from an augmented real marginal cost that incorporates the parameterized costs associated with the degree of capacity utilization as the driving variable in the NKPC.[4]

2. UNIT TOTAL COSTS: A FULLER MARGINAL COST PROXY

This paper builds on the existing literature by considering a fuller definition of marginal cost, which we define as "unit total costs." *Unit total costs* consist of *labor* and *nonlabor unit costs* data. We also consider the role of borrowing costs, which we examine separately, as in the cost channel literature. Using a standard New Keynesian model, where firms engage in borrowing and production is based on a CES function with capital and labor as inputs, we derive real marginal cost as a function of labor costs, capital unit costs, capital utilization, capital depreciation, production taxes, and borrowing costs (see Section 3). The resulting NKPC is identical to that of Gali et al. (2005), as in (1), but the theory-based marginal cost proxy (see 2) is replaced here with *unit total costs,*

$$\widehat{\mathrm{mc}}_t = \mathrm{mc}\left(\widehat{S}_{n,t}, \widehat{S}_{k,t}, \widehat{\tau}_t^{Y}\right), \tag{3}$$

or, with *unit total costs* and the *cost channel* (see Section 4.6),

$$\widehat{\mathrm{mc}}_t = \mathrm{mc}\left(\widehat{S}_{n,t}, \widehat{S}_{k,t}, \widehat{\tau}_t^{Y}, \hat{\imath}_t^{\mathrm{CB}}\right), \tag{4}$$

where $\widehat{S}_{n,t} = \hat{w}_t - (1-\chi)(\hat{y}_t - \hat{n}_t) - \chi\widehat{a}_t$ and $\widehat{S}_{k,t} = \hat{r}_t^k - (1-\chi)(\widehat{y}_t - \hat{k}_t) - \chi\hat{u}_t$ are the shares of *labor unit costs and capital unit costs,* respectively; $\widehat{\tau}_t^{Y}$ are production-related taxes, and $\hat{\imath}_t^{\mathrm{CB}}$ captures firms' borrowing costs (i.e., the *cost channel* effect), which we examine separately as with the rest of the literature.[5]

2.1. Data

In contrast to previous studies that focus on *labor payments* in the *nonfarm* GDP sector, we focus on *total operating payments* and in *all sectors*, i.e., overall GDP. We construct our marginal cost proxy, *unit total costs*, using data on labor and nonlabor costs in *all sectors* as published by the U.S. Department of Commerce Bureau of Economic Analysis.[6] In particular, *unit total costs* are constructed as the sum of the shares of *unit labor costs* ($\widehat{S}_{n,t}$) and other *nonlabor costs* in overall

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

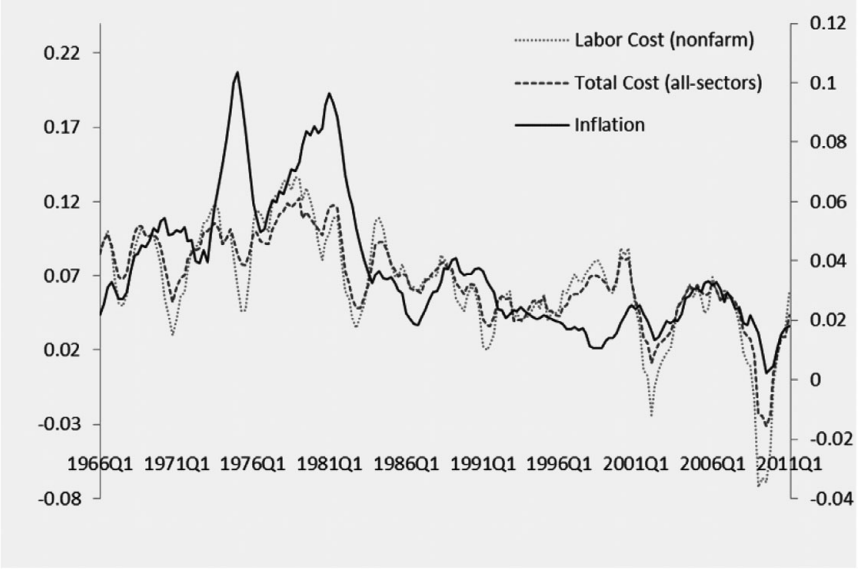


FIGURE 1. ULC (nonfarm), UTC (all sectors), and GDP deflator (on the right axis).

GDP, which includes consumption of fixed capital and net taxes on production (and imports), captured by $\widehat{S}_{k,t}$,and $\widehat{\tau}_t^Y$, respectively.[7] We also account for borrowing costs, as captured by the cost channel, through $\hat{\imath}_t^{\mathrm{CB}}$.[8] As in the cost channel literature [see Chowdhury et al. (2006) and Ravena and Walsh (2006)], we test separately for the contribution of firms' borrowing costs to estimating the NKPC, using three-month U.S. treasury bill rates (captured by $\hat{\imath}_t^{\mathrm{CB}}$) as a measure of short-run nominal interest rates [see Chowdhury et al. (2006)]. The effect of borrowing costs (cost channel) is examined in Section 4.6, whereas throughout the paper *unit total cost* refers to all other production costs *excluding* the cost channel.

The paper compares the results from our *unit total cost* proxy(with and without the cost channel) with those of the traditional *nonfarm unit labor cost* and *unit labor cost* computed using *all sectors* of the economy. Consistent with most studies, inflation is measured as the change in the log of the *all-sector* GDP deflator. The period examined is 1966:Q1 to 2011:Q1.

Figure 1 compares annual inflation with annual change in the marginal cost proxies. Abstracting from the oil price shocks, our measure of total cost more closely matches the dynamics of inflation, when compared to labor cost. Note that, as with the rest of the literature, marginal cost is measured as a deviation from a constant mean. This, however, can have some limitations if inflation changes over different periods are examined. We address these concerns in Section 3.3, where we account for weak identification and structural breaks in our estimation of the NKPC.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

2.2. Some of the Main Findings

By replicating the methodology of Gali et al. (2005), using nonlinear GMM estimates on U.S. data for the sample period from 1966:Q1 to 2011:Q1, we show that in comparison to unit labor costs (nonfarm), the use of *unit total costs* (all sector) helps improve the fit of the short-run variation in inflation and the existing empirical support for the role of real marginal cost as the driving variable in the NKPC. The use of *unit total costs* as a marginal cost proxy is also shown to increase the importance of the forward-looking or *expectations-based* inflation persistence γ_f. It is shown that this latter effect is stronger even in periods of relatively higher inflation volatility.[9] Moreover, *unit total costs* are shown to imply a duration of fixed nominal contracts of less than 5 quarters, 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 (around 5–6 quarters or higher). The results suggesting that *unit total costs (all sectors)* is a better proxy for inflation dynamics than unit labor costs (nonfarm) are robust even when we account for a number of robustness tests including tests for weak identification and for structural breaks in inflation. Finally, although there is clearly a role for borrowing costs in estimating inflation dynamics, the contribution of the *cost channel* is shown to become relatively less important when *unit total costs,* rather than *unit labor costs*, are used as a marginal cost proxy in the estimation of the NKPC.

3. THE THEORETICAL FRAMEWORK

In this section we derive the NKPC, equation (1), with *unit total costs* [as shown in (3)] and with *unit total costs* plusthe *cost channel* [as shown in (4)] as our marginal cost proxies. These are consistent with any general equilibrium model that features a CES production function with labor and capital and with production taxes, but also with credit markets (for the cost channel).

3.1. Households

Households maximize their expected present discounted value utility,[10]

$$E_t \sum_{s=0}^{\infty} \beta^s \left(\frac{c_{t+s}^{1-\sigma}}{1-\sigma} - \frac{\eta_n n_{t+s}^{1+\gamma}}{1+\gamma} \right), \tag{5}$$

where c_t is consumption; n is labor service hours; $\beta < 1$ is the subjective discount factor; σ, η_m, and η_n are elasticities; and $\gamma = 1/\delta$ is the marginal disutility of labor and δ the labor supply elasticity. The household's budget constraint is

$$P_t(c_t + i_t) + D_t = P_t(w_t n_t + r_t^k u_t k_t) + R_{t-1}^D D_{t-1} + V_t + P_t \tau_t, \tag{6}$$

where P_t is the price level; D_t is nominal deposits; $R_t^D = (1 + i_t^D)$ and i_t^D is the nominal deposit rate; w_t is the real wage rate; r_t^k is the real rental price of capital,

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

k_t, and u_t is capital utilization; $V_t = \int V_{j,t} + V_t^b$ are (net) profits from all firms and the banking sector; and $P_t\tau_t$ are nominal transfers. Investment, i_t, is related to the capital stock as follows:

$$i_t = k_{t+1} - [1 - \delta(u_t)]k_t + \upsilon\left(\frac{k_{t+1}}{k_t}\right)k_{t+1}, \tag{7}$$

where, $\delta(u_t) = \delta u_t^{\varphi}$; $\delta'(u) > 0$ is a depreciation function and $\upsilon(\frac{k_{t+1}}{k_t}) = \frac{b}{2}(\frac{k_{t+1}}{k_t} - 1)^2$ are quadratic costs related to capital investment; and φ is the elasticity of marginal depreciation cost. Denoting the Lagrangian multiplier as λ_t, the first-order conditions are

$$c_t^{-\sigma} = \lambda_t P_t, \tag{8}$$

$$c_t^{-\sigma} = \beta E_t\left(\frac{R_t^D c_{t+1}^{-\sigma}}{P_{t+1}/P_t}\right), \tag{9}$$

$$\lambda_t P_t w_t = \eta_n n_t^{\gamma}, \tag{10}$$

$$r_t^k = \delta\varphi u_t^{\varphi-1}, \tag{11}$$

$$P_t\lambda_t\left[1 + b\left(\tfrac{k_{t+1}}{k_t} - 1\right)\right] = \beta E_t P_{t+1}\lambda_{t+1}\left\{r_{t+1}^k u_{t+1} + (1 - \delta u_{t+1}^{\varphi}) + \frac{b}{2}\left[\left(\tfrac{k_{t+2}}{k_{t+1}}\right)^2 - 1\right]\right\}. \tag{12}$$

Equations (8) and (9) determine the marginal utility of consumption and Euler equation, whereas (10)–(12) define the optimal allocations of labor and capital.

3.2. The Banking Sector

The banking sector is represented by a commercial bank, b, that 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 rate i_t^{CB}.[11] The bank's balance sheet is $L_t = D_t + L_t^{\mathrm{CB}}$. The bank incurs intermediation costs, $\Phi_t(\cdot)$; these are decreasing with aggregate economic activity and banks' willingness to lend, but can also be affected by shocks to credit market conditions, (ζ_t). In particular, $\Phi_t(\zeta_t, y_t) = \zeta_t(y_t/y)^{-\xi}$, where y_t is output and y is its steady state and $\xi > 0$ [see also Atta-Mensah and Dib (2008) and Cook (1999)].[12] The bank's period profit function is

$$V_t^b = i_t^L L_t - i_t^D D_t - i_t^{\mathrm{CB}} L_t^{\mathrm{CB}} - \Phi_t(\zeta_t, y_t)L_t. \tag{13}$$

From (13) and the preceding information and assuming normal profits we derive

$$i_t^D = i_t^{\mathrm{CB}} \quad \text{and} \quad i_t^L = i_t^{\mathrm{CB}} + \zeta_t(y_t/y)^{-\xi}; \tag{14}$$

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

hence with zero reserve requirements 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.[13]

3.3. 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, $y_{j,t}$, that sells at the price $P_{j,t}$. The final goods firm bundles intermediate goods in a composite final good $y_t = (\int_0^1 y_{j,t}^{(\theta-1)/\theta} dj)^{\theta/(\theta-1)}$ 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

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta} y_t, \tag{15}$$

where, $P_t = (\int_0^1 P_{j,t}^{1-\theta} dj)^{1/(1-\theta)}$ is the average price index. The production of each intermediate good combines capital and labor according to the following CES technology:

$$y_{j,t} = \left[\alpha_k (u_t k_t)^{\chi} + \alpha_n (a_t n_t)^{\chi}\right]^{1/\chi}, \tag{16}$$

where $\chi = \frac{\rho-1}{\rho}$; $0 < \alpha_k, \alpha_n < 1$ are the corresponding input shares and a_t measures labor productivity. If $\chi \to 0$, and $\alpha_k + \alpha_n = 1$, equation (16) reduces to a Cobb–Douglas technology. The latter specification, however, assumes unit elasticity of output with respect to labor, which results in marginal cost being 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, and so this specification is more appropriate for the purpose of this paper.[14]

In each period intermediate firms must borrow to cover their labor and capital costs, but they are required by lenders to hold some risk-free financial assets for risk diversification and collateral purposes. For simplicity we assume that all risk-free assets held by firms are summarized in the form of government bonds, $B_{j,t}$.[15] Hence, the existing stock of all government bonds satisfies $B_t = \int_0^1 B_{j,t} dj$.[16] The firm's loan is equivalent to its *variable cost*,

$$L_t = P_t r_t^k k_t + P_t w_t n_t. \tag{17}$$

We assume that a portion ϑ of loans is collateralized by the firm's holdings of safe assets,[17]

$$\vartheta L_t = B_{j,t}. \tag{18}$$

From (16), (17), and (18), the firm's period profits are

$$V_{j,t} = P_{j,t} y_{j,t} (1 - \tau_t^Y) + i_t^{\mathrm{CB}} B_{j,t} - R_t^L L_t, \tag{19}$$

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

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 (15)–(19), the period optimal real price of firm j is

$$P_{j,t}^*/P_t = \mu_p \mathrm{mc}_t, \tag{20}$$

where $\mu_p = \theta/(\theta - 1)$ is the price mark-up and real marginal cost is[18]

$$\mathrm{mc}_t = \left(\frac{1 + i_t^L - \vartheta i_t^{\mathrm{CB}}}{1 - \tau_t^Y}\right)\left[\frac{r_t^k}{\alpha_k u_t^{\chi}(y_t/k_t)^{1-\chi}} + \frac{w_t}{\alpha_n a_t^{\chi}(y_t/n_t)^{1-\chi}}\right], \tag{21}$$

where $\alpha_n a_t^{\chi}(y_t/n_t)^{1-\chi}$ and $\alpha_k u_t^{\chi}(y_t/k_t)^{1-\chi}$ are the marginal products of labor and capital, respectively.

3.4. The "Unit Total Cost" New Keynesian Phillips Curve

Consider Calvo-type price setting, where the price of each firm has a fixed probability ψ of remaining fixed at the previous period's price and a fixed probability $1 - \psi$ 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, $P_{j,t+s}^*$:

$$E_t \sum_{s=0}^{\infty} \psi^s \Delta_{t,t+s}\left(P_{j,t} - P_{j,t+s}^*\right)^2, \tag{22}$$

where $\Delta_{t,t+s} = \beta^s c_{t+s}^{-\sigma}/c_t^{-\sigma}$ is the discount factor. Minimizing (22) with respect to $P_{j,t}$ and denoting percentage deviations around steady states by a *circumflex*, we obtain

$$\widehat{X}_t = (1 - \psi\beta)\sum_{s=0}^{\infty} \psi^s \beta^s E_t \widehat{P}_{j,t+s}^* = (1 - \psi\beta)(\widehat{P}_{j,t}^*) + \psi\beta E_t \widehat{X}_{t+1}, \tag{23}$$

where $\widehat{X}_t$ is the optimal price contract chosen by all firms that adjust prices in each period t and $\widehat{P}_{j,t}^* = \widehat{P}_t + \widehat{\mathrm{mc}}_t$ is the optimal price [see (20)]. The average price in the economy is

$$\widehat{P}_t = \psi \widehat{P}_{t-1} + (1 - \psi)\widehat{P}_t^N, \tag{24}$$

where newly set prices, $\widehat{P}_t^N = (1 - \omega)\widehat{X}_t + \omega \widehat{P}_t^B$, are a weighted average of optimally set prices, $\widehat{X}_t$ and backward-looking set prices, $\widehat{P}_t^B = \widehat{X}_{t-1} + \pi_{t-1}$ [as in Gali and Gertler (1999)]. Using equations (23) and (24) and $\pi_t = \widehat{P}_t - \widehat{P}_{t-1}$, we derive the hybrid NKPC,

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda \widehat{\mathrm{mc}}_t, \tag{25}$$

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 *unit total cost* (with no borrowing costs), is

$$\widehat{\mathrm{mc}}_t = \frac{S_n}{S_k + S_n}\widehat{S}_{n,t} + \frac{S_k}{S_k + S_n}\widehat{S}_{k,t} + \frac{\tau^Y}{(1 - \tau^Y)}\widehat{\tau}_t^Y, \tag{26}$$

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

and *unit total cost* with the *cost channel* is

$$\widehat{\text{mc}}_t = \frac{S_n}{S_k + S_n}\widehat{S}_{n,t} + \frac{S_k}{S_k + S_n}\widehat{S}_{k,t} + \frac{\tau^Y}{(1-\tau^Y)}\widehat{\tau}_t^Y + \lambda_i \hat{\imath}_t^L, \tag{27}$$

where $\widehat{S}_{n,t} = \hat{w}_t - (1-\chi)(\hat{y}_t - \hat{n}_t) - \chi\widehat{a}_t$ and $\widehat{S}_{k,t} = \hat{r}_t^k - (1-\chi)(\widehat{y}_t - \hat{k}_t) - \chi\hat{u}_t$ are the shares of unit capital costs and unit labor costs, respectively; $S_k = \frac{r^k}{\alpha_k(y/k)^{(1-\chi)}}$ and $S_n = \frac{w}{\alpha_n(y/n)^{(1-\chi)}}$, are their respective steady states; $\lambda_i = \frac{(1-\vartheta)i^{\text{CB}}}{1+i^L-\vartheta i^{\text{CB}}}$ and $\hat{\imath}_t^L = \frac{i^{\text{CB}}}{i^L}\hat{\imath}_t^{\text{CB}} + \frac{\bar{\zeta}}{i^L}(\widehat{\zeta}_t - \xi\widehat{y}_t)$. From (25) and (26) we can express the NKPC as a $\widehat{\text{mc}}$-proxy of only *unit labor costs:* $\widehat{\text{mc}}_t = \widehat{\text{ULC}}_t = \widehat{S}_{n,t}$, so that (25) becomes

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f E_t\pi_{t+1} + \lambda\widehat{\text{ULC}}_t. \tag{28}$$

With *unit total costs* (and no cost channel), based on (26), the NKPC is

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f E_t\pi_{t+1} + \lambda\widehat{\text{UTC}}_t, \tag{29}$$

and with *unit total cost* and the *cost channel,* based on (27), the NKPC is[19]

$$\pi_t = \gamma_b\pi_{t-1} + \gamma_f E_t\pi_{t+1} + \lambda\widehat{\text{UTC}}_t + \lambda\lambda_i\hat{\imath}_t^{\text{CB}}, \tag{30}$$

where $\lambda\lambda_i$ is the coefficient capturing the *credit* or *cost channel* effect.

4. EMPIRICAL ESTIMATION

In this section we replicate some of the key tests performed in the literature. The period examined is from 1966:Q1 to 2011:Q1. This sample covers the most recent period over where the divergence between unit labor cost and inflation has been cited as one of the reasons for the poor performance of the NKPC [King and Watson (2012)].[20] We first examine the role of *unit total cost,* as shown in equations (26) and (29). The role of the *cost channel* in the NKPC [equation (30)] is examined separately, in Section 4.6.

4.1. Structural Estimates

In this section we estimate the hybrid NKPC, equation (1), using nonlinear instrumental variables (GMM, IV) with robust errors over the period from 1966:Q1 to 2011:Q1. To deal with the small sample normalization problem, we follow Gali et al. (2005) and others and use the orthogonality condition[21]

$$E_{t-1}\{(\pi_t - \lambda\widehat{\text{mc}}_t - \gamma_f\pi_{t+1} - \gamma_b\pi_{t-1})z_{t-1}\} = 0, \tag{31}$$

where z_{t-1} is a vector of variables dated $t-1$ and earlier and equation (25) is assumed to include an error term ε_t that is i.i.d.

Table 1 gives nonlinear instrumental variable estimates of the deep structural parameters in equation (1) using *labor unit costs* and *unit total costs* as proxies for

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

TABLE 1. NKPC estimates: Unit labor cost vs unit total costs

	ω	ψ	β	γ_b	γ_f	λ	P(j-stat)
			Unit labor cost (nonfarm)				
Unrestricted	0.486 (0.011)	0.943 (0.023)	0.989 (0.004)	0.341 (0.011)	0.655 (0.010)	0.001 (0.0005)	0.999
Restricted	0.493 (0.010)	0.952 (0.017)	1.00	0.341 (0.005)	0.659 (0.008)	0.001 (0.00007)	0.999
			Unit labor cost (all sectors)				
Unrestricted	0.408 (0.049)	0.879 (0.020)	0.988 (0.007)	0.318 (0.029)	0.677 (0.029)	0.007 (0.002)	0.997
Restricted	0.412 (0.049)	0.883 (0.017)	1.00	0.318 (0.013)	0.682 (0.009)	0.006 (0.0001)	0.999
			Unit total cost (all sectors)				
Unrestricted	0.259 (0.030)	0.794 (0.074)	0.984 (0.011)	0.247 (0.057)	0.744 (0.056)	0.033 (0.009)	0.653
Restricted	0.289 (0.024)	0.783 (0.063)	1.00	0.270 (0.017)	0.729 (0.043)	0.031 (0.002)	0.983

Note: This table reports nonlinear IV estimates (GMM) of the deep structural parameters in equation (25), using labor unit cost and unit total costs as proxies for marginal cost. The estimation uses quarterly data over the period 1966:Q1–2011:Q1. The instrument set includes four lags of the real marginal cost proxy, inflation, output gap, 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.

marginal cost. The instrument set used is four lags of the measure of real marginal costs, inflation, output gap, wage inflation, and commodity price inflation.[22] The results in Table 1 suggest that adding *other operating costs* to the unit labor costs (for all-sectors data) improves 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 1 shows that unit total costs imply a higher λ than the traditional measure of real unit labor cost, as well as real unit labor cost for all sectors. 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 when the unit total costs proxy is used as the measure of marginal cost, irrespective of the restriction on β.[23] To further establish, independent of our structural model, whether the unit total costs NKPC is a better specification than the unit labor costs NKPC, we also conduct a non-nested test.[24] The test is conducted using all-sector total unit cost and all-sector unit labor cost. The results are summarized in Table 2.[25]

Table 2 indicates that although we reject the null hypothesis for the labor unit cost NKPC model in favor of the unit total cost model, we cannot reject the null for the unit total costs NKPC model; hence *unit total costs* appear to be a better explanatory variable for inflation dynamics than *unit labor 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, using unit total cost, ψ is estimated at 0.79, implying an average price duration of 4.8 quarters, whereas the

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

TABLE 2. NKPC estimates: Non-nested tests

	γ_b	γ_f	λ	J-test	Godfrey
Unit labor cost (all sectors)	0.272 (0.053)	0.725 (0.054)	0.04 (0.009)	2.66*	−4.34*
Unit total cost (all sectors)	0.261 (0.057)	0.734 (0.055)	0.023 (0.012)	−0.89	1.11

Note: This table reports the GMM estimates of the reduced form of equation (25), using quarterly data over the period from 1966:Q1 to 2011:Q1. The instrument set includes four lags of the measure of the real marginal cost proxy, inflation, output gap, wage inflation, and commodity price inflation. Standard errors are given in parentheses beneath. 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.

ψ values for the unit labor cost proxies are higher than 0.85, suggesting average price duration *in excess of* 6 quarters. Therefore, the duration of price contracts implied by total unit costs is much closer to the 3 to 4 quarters found by Blinder (1994) using micro data than the duration greater than 5 quarters that is typically found in the empirical NKPC literature.

4.2. Unit Total Costs and Forward-Looking Behavior

The results in Table 1 also suggest that when *unit total 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, whereas γ_f, which indicates forward-looking behavior, is relatively higher, than their respective *unit labor cost* counterparts. To examine the robustness of this result we perform a number of tests, including different sample periods, applying a time-varying trend and also test the implications of unit total costs for fundamental inflation and inflation persistence.

In this section, we test whether the relatively stronger forward-looking behavior implied by unit total costs holds in periods of high inflation volatility. Using *unit labor costs* on U.S. data, Zhang et al. (2008) find very little empirical support for the role of forward expectations-based inflation persistence in the high and volatile inflation period from 1968:1 to 1981:4.

Table 3 shows that when we estimate the NKPC structural parameters for the same sample period, we find that the coefficient on unit labor costs (all sectors) is $\lambda = 0.044$ with $\gamma_b = 0.457$ and $\gamma_f = 0.542$. However, for the same sample period, the use of *unit total costs* produces $\lambda = 0.083$, with $\gamma_b = 0.364$ and $\gamma_f = 0.632$.[26] This, consistently with the results in Table 1, 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.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

TABLE 3. Comparative estimates with Zhang et al. (2008) sample

	γ_b	γ_f	λ	$P(j\text{-stat})$
Unit labor cost (nonfarm)	0.446 (0.013)	0.550 (0.012)	0.013 (0.005)	0.999
Unit labor cost (all sectors)	0.457 (0.029)	0.542 (0.028)	0.044 (0.017)	0.995
Unit total cost (all sectors)	0.364 (0.031)	0.632 (0.032)	0.083 (0.016)	0.906

Note: This table reports the GMM estimates of the reduced form of equation (25), using unit labor cost and unit total cost 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, output gap, 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.

4.3. Actual versus Fundamental Inflation

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

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

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 (25), 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., $z_t = \{\pi_t, ..., \pi_{t-q+1}, \widehat{\text{mc}}_t, ..., \widehat{\text{mc}}_{t-q+1}\}'$. Accordingly, we derive the fundamental inflation, as in Gali and Gertler (1999), whereby z_t follows a VAR(3) process.[27] The resulting fundamental inflation for *unit total costs* and *unit labor costs* (for *nonfarm* and *all-sector*) versus actual inflation is shown in Figure 2.

These figures show that the *unit-total-cost*-driven NKPC matches actual inflation much better than its *unit labor costs* counterpart. Consistent with the observation of King and Watson (2012), the fundamental inflation based on both measures of unit labor cost has been persistently below actual inflation since the 1990s. This is in contrast to the total-unit-cost-based fundamental inflation, which tracks actual inflation very closely.

4.4. Specification Tests

The main tools used thus far to evaluate the NKPC model are the J-test for overidentifying restriction and the goodness of fit. Bardsen et al. (2004) suggest

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

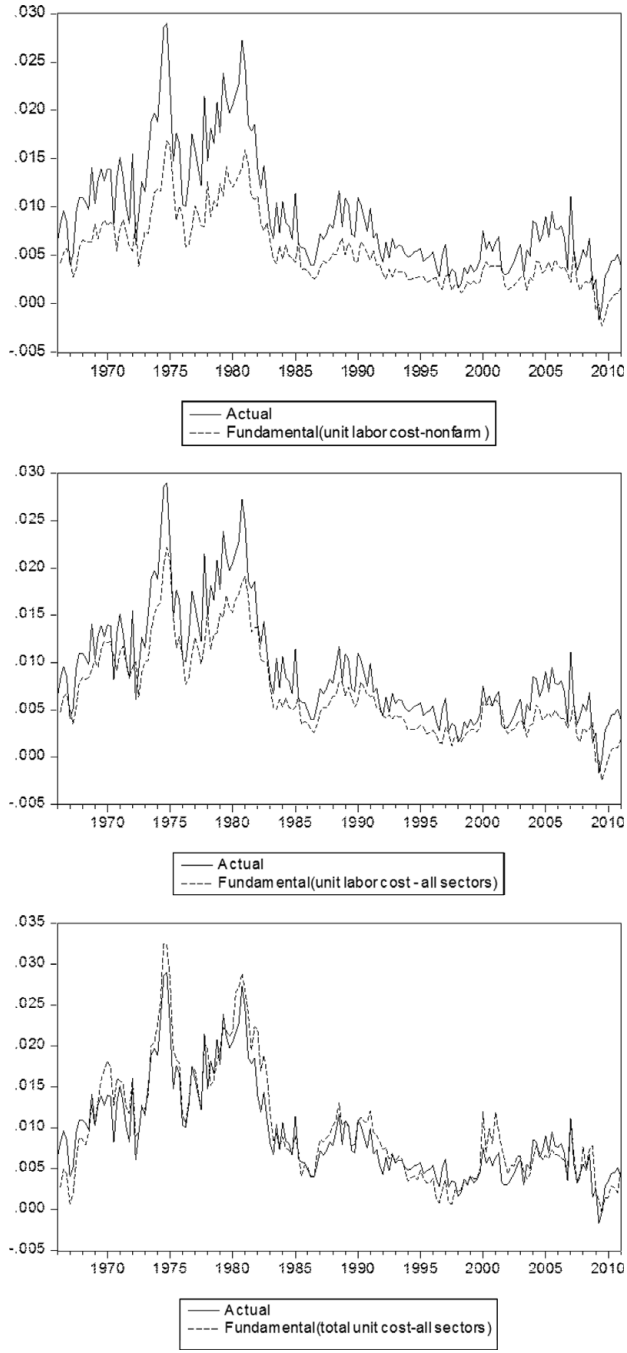


FIGURE 2. Actual vs fundamental inflation.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

that the results of such tests may not be sufficient to establish robustness, as they may have low power, particularly in the presence of weak instruments (see also Section 4.6), and the fact that the sum of the coefficients on forward- and backward-looking inflation is close to unity could suggest that a model in the first difference of inflation could be just as good. In fact, we have shown that wage share augmented by nonlabor costs is a more appropriate driving variable. However, it is also important to examine whether there are other variables that drive inflation as well, and whether the omission of these variables contributes to autocorrelated residuals. Against this background, we conduct two specification tests suggested by Bardsen et al. (2004).

The first test examines whether the presence of residual autocorrelation is due to omitted variables, and as such, the autocorrelation is not the result of the rational expectation hypothesis underlying the theory, as Blake (1991) demonstrates, but a symptom of misspecification. Here we present the two-stage least squares (2SLS) estimation, which, unlike GMM estimates, does not correct for autocorrelated residuals. Following Bardsen et al. (2004), two variables that are natural candidates in inflation models are measures of capacity utilization and additional lags of inflation. We therefore removed the lagged output gap and the fourth lag of inflation from the instrument set and included them as explanatory variables. If the model is correctly specified, then these variables should be insignificant and there should be no change in the importance of the forward-looking inflation variable. In this light, Bardsen et al. (2004) interpret this test as a test of richer dynamics.

Table 4 presents the reduced-form 2SLS estimate of the NKPC using both unit labor cost and total unit cost, along with the inclusion of the additional variables (π_{t-4} and gap_{t-1}). The coefficient on the forward-looking inflation is significantly different, with the exception of unit total cost. In all cases, the forward-looking variable is larger than the backward-looking and remains highly significant both statistically and in absolute terms. There is still strong evidence of autocorrelated errors, and the additional variables are insignificant. These results, therefore, suggest that with the exception of unit total cost, there could be some misspecification arising from omitted variables, as the coefficients on forward-looking inflation are rather different.

A complementary specification test uses an encompassing framework. The motivation is that other studies have found cointegrating or long-run relationships between wages adjusted for productivity and prices [Mehra (1993)]. Bardsen et al. (2004) suggest that these relations provide a basis to test the NKPC. They suggest the following procedure: (i) Using the current set of variables and instruments used to identify the NKPC, augment the model with the set of variables suggested by other models of inflation. (ii) Under the assumption that the forward-looking NKPC is the correct model, the coefficients on the additional variables should be zero and the forward-looking term should maintain its significance. Otherwise the encompassing property of the NKPC is refuted.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

TABLE 4. NKPC, 2SLS estimates: Unit labor cost vs unit total cost

	γ_b	γ_f	λ	π_{t-4}	gap_{t-1}
Unit labor cost (nonfarm)	0.286 (0.095)	0.719 (0.131)	0.003 (0.009)	−0.007 (0.093)	−0.013 (0.021)
	$\chi^2_{AR(1)}$=76.58 [0.00]; $\chi^2_{AR(2)}$=83.64 [0.00]; $F_{A,(1-4)}(4,172)$=15.89 [0.00]				
	$F_H(5,175)$=2.67 [0.02]; $F_{IR}(12,161)$=5.39 [0.00]; $\chi^2_{IV}(17)$=15.75 [0.26]				
Unit labor cost (all sectors)	0.273 (0.092)	0.728 (0.121)	0.011 (0.015)	−0.005 (0.088)	−0.013 (0.018)
	$\chi^2_{AR(1)}$=71.48 [0.00]; $\chi^2_{AR(2)}$=76.77 [0.00]; $F_{A,(1-4)}(4,172)$=15.54 [0.00]				
	$F_H(5,175)$=2.87 [0.02]; $F_{IR}(12,161)$=5.41 [0.00]; $\chi^2_{IV}(17)$=7.93 [0.85]				
Unit total cost (all sectors)	0.273 (0.092)	0.753 (0.121)	0.032 (0.027)	−0.029 (0.090)	−0.011 (0.017)
	$\chi^2_{AR(1)}$=67.74 [0.00]; $\chi^2_{AR(2)}$=72.42 [0.00]; $F_{A,(1-4)}(4,172)$=14.85 [0.00]				
	$F_H(5,175)$=3.18 [0.01]; $F_{IR}(12,161)$=5.13 [0.00]; $\chi^2_{IV}(17)$=8.21 [0.83]				

Note: This table reports the 2SLS estimates of the reduced form of equation (25), using unit labor cost and unit total cost as proxies for marginal cost. The estimation uses quarterly data over the period from 1966:Q1 to 2011:Q1. The instrument set includes four lags of the measure of real marginal costs proxy, wage, and commodity price inflation; three lags of inflation; and lags two to four of the output gap. Standard errors are given in parentheses below the coefficients.

Table 5 shows the results of this test, where we use the following cointegrating relation similar to Mehra (1993):[28]

$$\text{ecmw}_t = \ln \text{ULC}_{t,(\text{nonfarm})} + 0.78 + 0.039 \cdot \ln P_t,$$

$$\text{ecmw}_t = \ln \text{ULC}_{t,(\text{all-sectors})} + 0.59 + 0.022 \cdot \ln P_t,$$

where ecmw_t is the error-correction from the cointegrating relation; P_t is the price level (i.e., implicit GDP deflator); and ULC is the unit labor cost of the nonfarm business sector. Estimating the reduced-form model via GMM with these cointegrating relationships and the same instrument set as before yields interesting results (see Table 5). We find that the error correction terms are significant at the 5% level in the models with unit labor cost (both nonfarm and all sectors), and λ is now negative. In contrast, the error correction term is insignificant in the model with unit total cost and there is very marginal change in the other coefficients. These results suggest a rejection of the encompassing principle for the NKPC using unit labor costs [similar to the results for the euro area obtained by Bardsen et al. (2004)], but there is not sufficient evidence to reject it using unit total cost here).

4.5. Identification Robust Estimation

We have so far replicated standard estimation methods, as proposed by Gali and Gertler (1999), and Gali et al. (2001, 2005), to compare the conventional unit

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

TABLE 5. NKPC, error-correction GMM estimates: Unit labor cost vs. unit total cost

	γ_b	γ_f	λ	ecmw_{t-1}	$P(j\text{-stat})$
Unit labor cost (nonfarm)	0.278 (0.047)	0.711 (0.044)	−0.007 (0.004)	0.022 (0.007)	0.938
Unit labor cost (all sectors)	0.263 (0.062)	0.726 (0.061)	−0.004 (0.009)	0.035 (0.018)	0.835
Unit total cost (all sectors)	0.272 (0.066)	0.723 (0.049)	0.031 (0.021)	0.002 (0.019)	0.949

Note: This table reports the GMM estimates of the reduced form of equation (25), using unit labor cost and unit total cost as proxies for marginal cost. The estimation uses quarterly data over the period from 1966:Q1 to 2011:Q1. The instrument set includes four lags of the measure of real marginal costs proxy, inflation, output gap, wage, and commodity price inflation. Standard errors are given in parentheses below the coefficients. A 12-lag Newey–West estimate of the covariance matrix is used. The last column presents the Hansen's J-test for overidentifying restrictions.

labor cost with our alternative marginal cost proxy, unit total costs. In this section we also compare these two marginal cost proxies, by taking into consideration two potential concerns raised recently in the literature: (i) weak identification of conventional GMM estimates and (ii) significant changes in the univariate inflation process over different periods.

Several recent papers argue that the traditional GMM estimates of the NKPC may be unreliable, as the conventional GMM estimator may yield biased estimates in the presence of weak identification [see, for example, Mavroeidis (2005) and Nason and Smith (2008)]. This literature also suggests that conventional inference after pretesting for identification is unreliable if the size of the pretesting procedure cannot be controlled [see Kleibergen and Mavroeidis (2009)]. We therefore reestimate the model using the continuous updating (CUE) GMM estimator, which is the MQLR statistic recommended by Kleibergen and Mavroeidis 2009 for inference, which allows for the application of weak instrument robust statistics. Specifically, we use the 95% confidence derived from inverting the subset MQLR statistic using the same instrument set as before, which is widely used. The choice of the instrument set is important for the results here. The standard approach is the Hansen (1982) criterion, which we also report (i.e., the p-value).[29] We find that the output gap Granger-causes marginal cost, which should lead to a role for lagged inflation in the instrument set [see Nason and Smith (2008)] and also Granger-causes the real marginal cost proxies. Therefore, in Table 6, we also report the results for an instrument set that includes three lags of inflation and the output gap.[30]

Given that β is close to 1, we focus on the results for $\beta = 1$.[31] Focusing first on the larger instrument set (instrument set A) for the full sample, the estimates of γ_f and λ for unit total costs are not significantly different form the conventional GMM estimate in Table 1. Thus the estimates of total unit cost NKPC (i.e., $\gamma_f \approx 0.7$ and $\lambda \approx 0.03$) seem to be robust to the estimation method and instrument set. The

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

TABLE 6. Robust GMM CUE estimates

Instruments (A,B)	ω	ψ	γ_f	λ	$P(j\text{-stat})$
			Unit labor cost (nonfarm)		
A	0.530 [0.00, 1.00]	0.910 [0.85, 1.00]	0.986 [0.48, 1.50]	0.008 [−0.040, 0.028]	0.058
B	0.209 [0.00, 0.82]	0.840 [0.00, 1.00]	0.623 [0.45, 1.32]	0.002 [*n.a.*, *n.a.*]	0.507
			Unit labor cost (all sectors)		
A	0.322 [0.00, 0.87]	0.974 [0.82, 1.00]	0.788 [0.55, 1.50]	0.010 [−0.004, 0.037]	0.287
B	0.460 [0.40, 1.00]	0.840 [0.00, 1.00]	0.648 [0.46, *n.a.*]	0.011 [−0.093, *n.a.*]	0.614
			Unit total cost (all sectors)		
A	0.280 [0.00, 0.77]	0.790 [0.00, 0.93]	0.737 [0.51, *n.a.*]	0.031 [0.004, *n.a.*]	0.339
B	0.290 [0.00, 1.00]	0.790 [0.73, 1.00]	0.733 [0.50, 1.18]	0.028 [−0.009, 0.081]	0.986

Note: This table reports continuously updating GMM estimates of the parameters of equation (25) under the assumption that $\beta = 1$, with Newey and West (1987) weight matrix. The estimate uses quarterly data over the period from 1966:Q1 to 2011:Q1. *Instruments* A: Four lags of inflation, real marginal cost proxy, output gap, wage and commodity price inflation; *Instruments* B: Three lags of inflation and output gap. The numbers in square brackets are the 95% confidence interval based on the subset MQLR test. (n.a. implies that the inverted MQLR statistic is below the 0.95 line).

estimates for price stickiness, ψ, for unit total costs are virtually unchanged from the conventional GMM estimate in Table 1. However, the size of the confidence interval for γ_f in all cases using instrument set A suggests that there could be an identification issue, although the 95% confidence excludes values close to zero, implying a role for forward-looking behavior. The results using the smaller instrument set (instrument set B) provide stronger support for the unit total cost NKPC and confirm the conclusion of the preceding section; that is, compared to the coefficients using unit labor costs, the unit total costs measure of real marginal cost indicates a stronger role for forward looking inflation and a steeper slope for the Phillips curve (i.e., a larger λ). Also, the fact that the confidence intervals for the unit total cost NKPC with instrument set B are relatively small around the point estimates suggests that the coefficients are more accurately estimated.[32]

We also estimate over two subsample periods, 1966–1983 and 1983–2011, to account for the inflation break at the end of 1983.[33] There is wide consensus that the U.S. economy has become more stable since the latter half of the 1980s, with significant changes (statistical and economic) in the univariate inflation process. Following much empirical evidence on U.S. inflation data, we estimate the NKPC over two subsamples, 1966:Q1 to 1983:Q4 and 1984:Q1 to 2011:Q1 [see, for example, Kleibergen and Mavroeidis (2009), Roberts (2006), and Stock and Watson (2007)].[34] These test again show that the forward-looking term γ_f is stronger and λ is generally larger with unit total cost in the 1966 to 1983 period. Also,

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

the 95% confidence bands indicate that the forward-looking variable is more accurately estimated for unit total cost than for labor unit costs. In most cases, the estimate for λ is tight around zero, with the exception of unit total costs, using instrument set B. Also, in the latter sample, unit total costs exhibit an increase in the size of λ (or the slope of the NKPC) and the role of the forward-looking inflation. Overall, unit total costs produce the most robust estimate, although the confidence band around γ_f, despite indicating that the forward-looking variable is significantly different from zero and could include unity, also raises an issue of identification.

4.6. The Cost Channel

Much attention has been given recently to the role of the cost channel of monetary policy in inflation dynamics [see Barth and Ramey (2001), Chowdhury et al. (2006), and Ravenna and Walsh (2006)]. Changes in interest rates directly affect firms' operating cost through the cost of working capital loans [see (27) and (30)]. We follow the literature and test separately for the contribution of the cost channel by estimating the interest-rate-augmented NKPC as given in (30), where ($\lambda\lambda_i$) is the coefficient of the cost channel and λ_i is a measure of its relative importance [see also Chowdhury et al. (2006)]. Consistent with this literature, the interest rate used is the three-month U.S. treasury bill rate.[35]

The conventional GMM results are shown in Table 7. We find that the cost channel is significant in all cases except for nonfarm unit labor cost. In particular, using unit total costs, the cost channel appears to be statistically significant both in terms of the coefficient of the cost channel $\lambda\lambda_i$ and in terms of its measure

TABLE 7. Interest rate augmented NKPC: Unit total cost with cost channel

ω	ψ	β	γ_b	γ_f	λ	$\lambda\lambda_i$	λ_i	$P(j\text{-stat})$
Unit labor cost (nonfarm)								
0.309 (0.057)	0.921 (0.086)	0.993 (0.007)	0.251 (0.043)	0.745 (0.044)	0.004 (0.006)	0.002 (0.005)	0.530 (2.270)	0.991
Unit labor cost (all sectors)								
0.452 (0.041)	0.932 (0.036)	0.985 (0.006)	0.328 (0.021)	0.666 (0.021)	0.002 (0.002)	0.003 (0.001)	1.34 (1.68)	0.999
Unit total cost (all sectors)								
0.349 (0.009)	0.799 (0.039)	0.985 (0.003)	0.306 (0.026)	0.688 (0.025)	0.024 (0.009)	0.002 (0.001)	0.066 (0.028)	0.871

Note: This table reports nonlinear IV estimates (GMM) of the deep structural parameters in equation (29), using labor unit cost and total unit costs as proxies for marginal cost. The estimation uses quarterly data over the period 1966:Q1–2011:Q1. The instrument set includes four lags of the real marginal cost proxy, inflation, output gap, wage inflation, commodity price inflation and 3-month treasury bill rate. Standard errors are shown in brackets. For nonfarm labor share the instrument set includes four lags of the real marginal cost proxy, inflation, commodity price inflation and 3-month treasury bill rate. A 12-lag Newey–West estimate of the covariance matrix is used. The last column presents the Hansen's J-test for overidentifying restrictions.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

of its relative importance λ_i, suggesting that there is a role for the inclusion of borrowing costs. However, notice that when other, nonlabor unit costs are taken into account, as in unit total costs, the cost channel appears to be relatively less important for estimating the NKPC than other costs in the marginal cost. For example, the inclusion of the cost channel appears to moderate the coefficients λ and γ_f in relation to their estimates without the cost channel (see earlier tables), thus suggesting that part of the effects of interest rates on inflation were partially captured in other nonlabor costs (such as investment and capital-related factors).

5. CONCLUDING REMARKS

This paper builds on recent attempts in the literature to find an alternative marginal cost proxy that can explain inflation dynamics better than the conventional *output gap* or *unit labor costs,* which have been criticized as poor proxies. We construct our alternative real marginal cost proxy, *unit total costs,* by extending the data already used in the literature in two dimensions: first by using both *labor* and *nonlabor costs* as a proxy for marginal cost and second by extending the data from *nonfarm* GDP to *all-sector* GDP. *Unit total costs* are shown to (i) improve 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 unit labor costs; and (iii) suggest a larger role for forward-looking behavior and expectations-based inflation persistence than that implied by the conventional *unit labor costs*. These findings are robust when we account for the mean break in U.S. inflation data at the end of 1983, and they also hold even in the relatively high and volatile inflation periods of the 1970s, where the use of unit labor costs has been reported in other studies to exhibit 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 nonlabor costs, such as borrowing costs and investment in new capital, which may also explain a further finding: (iv) Consistent with earlier studies, there is a role for the cost channel, though when other nonlabor unit costs are included in the marginal cost, as in our unit total cost proxy, the contribution of borrowing costs becomes relatively less important. This, as explained in the preceding, may be because other nonlabor costs (such as investment and capital-related costs) may partly capture the effects of interest rates and forward expectations on inflation.

Indeed, we believe that adding data that reflect information about key leading economic indicators, such as expectations about interest rates, investment, and borrowing decisions, which until recently have been given relatively little attention in the empirical estimation of the NKPC, may substantially improve the existing empirical support for the role of forward-looking behavior in price setting and inflation.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

NOTES

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

2. See Bils and Klenow (2004), Blinder et al. (1998), Chevalier et al. (2003), Coenen et al. (2007), De Walque et al. (2004), Gwin and VanHoose (2007), Hall et al. (2000), and Rotemberg and Woodford (1997).

3. Another strand in the literature focus on refining proxies for the output gap. For example, using different approaches, Bjørnland et al. (2009), Chadha and Nolan (2004), and Neiss and Nelson (2005) 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, which are largely used in the literature, are poor approximations to the output gap.

4. Note that both Mazumder (2010) and McAdam and Willman (2011) also focus on the cyclical properties of the utilization rates and how these affect the cyclicality of the marginal cost. In this paper we do not address this issue. It is a well-documented fact that although, on the average, real wages in the U.S. tend to be weakly procyclical, this depends on a number of factors induding the technology used as well as the periods and shocks examined, a conclusion also reached in Amarasekara and Bratsiotis (2012) and McAdam and Willman (2011).

5. For details see Section 4.6.

6. As published on 5 December 2013.

7. Also included in the computation of total cost is business transfer payments, which was suppressed in the theoretical model without loss of generality, given that this is a very small component of total unit cost. For more details on the data used see the Appendix.

8. There are no available quarterly data for all firms' borrowing costs (in all sectors) in the BEA data series we use (see Table 1.10 of BEA). Note that the item "Net Interest and Miscellaneous Payments" in that table is excluded from our marginal cost proxy, unit total cost (UTC), because it includes interest receipts and also net payments on mortgage and home improvement loans by households, as well as other items that are not related to firms' borrowing costs. Although the inclusion of "netinterest and miscellaneous payments" still shows UTC to perform better than the two measures of ULC examined in the paper, their inclusion, as expected, also weakens the results of UTC as a marginal cost proxy in estimating the NKPC.

9. Using *unit labor cost* as a marginal cost proxy, Zhang et al. (2008) found that forward-looking behavior played a very small role during the volatile inflation period 1968–1981 in the United States.

10. Throughout the paper small italic letters, x_t, indicate real variables of X_t (except the nominal interest rates, i_t^X), and $\widehat{x}_t$ denotes the log-linearized value of x_t as a deviation from its steady state.

11. We assume that extra liquidity is covered by the nominal lump sum tax so that $L_t^{\mathrm{CB}} = P_t \tau_t$.

12. This assumption also ensures that loan spreads are countercyclical, as supported by empirical evidence. For a paper where this relationship is derived endogenously, see Agénor et al. (2013).

13. In these studies ζ_t evolves as $\log(\zeta_t) = \rho_\zeta \log(\zeta) + (1 - \rho_\zeta) \log(\zeta_{t-1}) + \epsilon_{\zeta,t}$. Thus, in the steady state, $\Phi = \log(\zeta) = \overline{\zeta} > 0$, which captures the steady state mark-up over the policy rate due to imperfections in the credit market, whereas $\epsilon_{\zeta,t}$ captures innovations to such costs.

14. For simplicity, we assume that employment and capital are common to all firms, which simplifies aggregation while still allowing the average and marginal products to vary (see Gali et al. (2007) and Cantore et al. (2010)]. Assuming firm-specific factor inputs within a CES production technology implies further relative price and inflation effects [see Gagnon and Khan (2005)].

15. Note that the role of risk is not essential for the purpose of this paper. For a recent paper that deals with endogenous idiosyncratic risk in marginal cost, see Agénor et al. (2013).

16. 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, which, by assumption, are required by banks to back part of their loans by collateral.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

17. In Goodfriend and McCallum (2007), loan makers construct collateral from government bonds and firms' capital. Others show borrowing firms to have government bonds explicitly in their flow constraint (Hnatkovska et al. 2008).

18. Note that here marginal cost also includes production taxes.

19. Here we set the loan rate markup to zero (i.e., $\overline{\zeta} = 0$) so that $\hat{\imath}_t^L = \hat{\imath}_t^{\mathrm{CB}}$, as with the conventional cost channel literature.

20. We thank an anonymous referee for pointing this out.

21. See also Gagnon and Khan (2005) and Gali et al. (2001).

22. Here we use the most parsimonious instrument set possible to avoid the estimation bias that arises in small samples with too many overidentifying restrictions [see Staiger and Stock (1987)].

23. These tests are available in Appendix B of the working paper (available online).

24. Although the definition of unit total cost nests unit labor cost, equation (25) does not lend itself to the traditional F-tests for nested models, because it includes only one marginal cost variable. We therefore treat the unit labor cost NKPC and unit total labor cost NKPC as two different non-nested models, focusing on the choice of regressors. 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.

25. For more details see the Appendix.

26. The difference in the coefficients on γ_f between these two marginal cost proxies is statistically significant (t-stat for difference is 3.30).

27. The Schwarz and Hannan–Quinn information criteria suggest a lag length of 2 for the VARs for both unit total costs and unit labor costs.

28. Similar to Mehra (1993), productivity-adjusted wage is measured by unit labor cost. The cointegrating relations are estimated using FMOLS.

29. The application of this criterion to this estimator is also robust to the weak instrument problem.

30. Identification requires that π_{t+1} can be predicted by at least one variable other than π_t, π_{t-1}, and mc_t [see Nason and Smith (2008)].

31. Many studies impose the restriction that [see, for example, Buiter and Jewitt (1989), Fuhrer and Moore (1995), and Kleibergen and Mavroeidis (2009)]. In this framework, the test of the null hypothesis, $\gamma_b + \gamma_f - 1 = 0$, is generally accepted.

32. The interval for λ, in particular, is noticeably smaller than those found in Kleibergen and Mavroeidis (2009).

33. The subsample tests are available in Appendix B of the working paper (available online).

34. This breakpoint corresponds with estimates of the onset of the Great Moderation [see Stock and Watson (2007)].

35. The relative importance of the cost channel depends on both the extent to which firms rely on external finance and the pass-through from the policy rate to market interest rates.

REFERENCES

Agénor, P.R., G.J. Bratsiotis, and D. Pfajfar (2014) Credit frictions, collateral and the cyclical behavior of the finance premium. *Macroeconomic Dynamics* 18(5), 985–997.

Amarasekara, C. and G.J. Bratsiotis (2012) Monetary policy and real wage cyclicality. *Applied Economics* 44(33), 4391–4408.

Atta-Mensah, J. and A. Dib (2008) Bank lending, credit shocks, and the transmission of Canadian monetary policy. *International Review of Economics and Finance* 17, 159–176.

Bardsen, G., E. Jansen, and R. Nymoen (2004) Econometric evaluation of the New Keynesian Phillips curve. *Oxford Bulletin of Economics and Statistics* 66(Supplement), 671–686.

Barth, M.J. and V.A. Ramey (2001) The cost channel of monetary transmission. *NBER Macroeconomics Annual* 16, 199–240.

Bils, M. and P. Klenow (2004) Some evidence on the importance of sticky prices. *Journal of Political Economy* 112, 947–985.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

Bjørnland, H. C., K. Leitemo and J. Maih (2009) Estimating the Natural Rates in a Simple New Keynesian Framework. Norges Bank working paper 2007/10.
Blake, D. (1991) The estimation of rational expectations models: A survey. *Journal of Economic Studies* 18, 31–70.
Blinder, A. (1994) On sticky prices: Academic theories meet the real world. In N. G. Mankiw (ed.), *Monetary Policy*. Chicago: University of Chicago Press.
Blinder, A., E. Canetti, D. Lebow, and J. Rudd (1998) *Asking about Prices: A New Approach to Understanding Price Stickiness*. New York: Russell Sage Foundation.
Buiter, W. and I. Jewitt (1989) Staggered wage setting with real wage relativities: Variations on a theme of Taylor. In W. Buiter (ed.), *Macroeconomic Theory and Stabilization Policy*, pp. 183–199. Ann Arbor: University of Michigan Press.
Cantore, C., P. Levine, and B. Yang (2010) CES Technology and Business Cycle Fluctuations. Working paper, University of Surrey.
Chadha, J.S. and C. Nolan (2004) Output, inflation and the New Keynesian Phillips curve. *International Review of Applied Economics* 18(3), 271–287.
Chevalier, J., A. Kashyap, and P. Rossi (2003) Why don't prices rise during periods of peak demand? Evidence from scanner data. *American Economic Review* 93, 15–37.
Chowdhury, I., M. Hoffmann, and A. Schabert (2006) Inflation dynamics and the cost channel of monetary transmission. *European Economic Review* 50, 995–1016.
Coenen, G., A.T. Levin, and C. Kai (2007) Identifying the influences of nominal and real rigidities in aggregate price-setting behavior. *Journal of Monetary Economics* 54(8), 2439–2466.
Cook, D. 1999. The liquidity effect and money demand. *Journal of Monetary Economics* 43, 377–390.
Davidson, R., and J. MacKinnon (1981) Several tests for model specification in the presence of alternative hypotheses. *Econometrica* 49(3), 781–793.
De Walque, G., F. Smets, and R. Wouters (2004) Price Setting in General Equilibrium: Alternative Specifications. Mimeo, National Bank of Belgium.
Fuhrer, J. (2006) Intrinsic and inherited inflation persistence. *International Journal of Central Banking* 3(2), 49–86.
Fuhrer, J. and G. Moore (1995) Inflation persistence. *Quarterly Journal of Economics* 110, 127–159.
Gagnon, E., and H. Khan (2005) New Phillips curve under alternative production technologies for Canada, the United States and the Euro area. *European Economic Review* 49, 1571–1602.
Gali, J., and M. Gertler (1999) Inflation dynamics: A structural econometric analysis. *Journal of Monetary Economics* 44(2), 195–258.
Gali, J., M. Gertler, and J.D. Lopez-Salido (2001) European inflation dynamics. *European Economic Review* 45, 1237–1270.
Gali, J., M. Gertler, and J.D. Lopez-Salido (2005) Robustness of the estimates of the hybrid New Keynesian Phillips curve. *Journal of Monetary Economics* 52(2), 1107–1118.
Gali, J., M. Gertler, and J.D. Lopez-Salido (2007) Markups, gaps and the welfare costs of business fluctuations. *Review of Economics and Statistics* 89, 44–59.
Godfrey, L.G. (1983) Testing non-nested models after estimation by instrumental variables or least squares. *Econometrica* 51(2), 355–365.
Goodfriend, M., and B.T. McCallum (2007) Banking and interest rates in monetary policy analysis: A quantitative exploration. *Journal of Monetary Economics* 54, 1480–1507.
Gwin, C.R. and D.D. VanHoose (2007) Disaggregate evidence on price stickiness and implications for macro models. *Economic Inquiry, Western Economic Association International* 46(4) 561–575.
Gwin, C.R. and D.D. VanHoose (2008) Alternative measures of marginal cost and inflation in estimations of new Keynesian inflation dynamics. *Journal of Macroeconomics* 30(3), 928–940.
Hall, S., M. Walsh, and T. Yates (2000) Are UK companies' prices sticky? *Oxford Economic Papers* 52, 425–446.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

Hnatkovska, V., A. Lahiri, and C.A. Vegh (2008) Interest Rates and the Exchange Rate: A Non-monotonic Tale. NBER working pPaper W13925.

Kleibergen, K. and S. Mavroeidis (2009) Weak instrument robust tests in GMM and the New Keynesian Phillips curve. *Journal of Business and Economic Statistics* 27(3), 293–311.

Lawless, M., and K. Whelan (2007) Understanding the Dynamics of Labour Shares and Inflation. Working papers series 784, European Central Bank.

Lindé, J. (2005) Estimating New Keynesian Phillips curve: A full information maximum likelihood approach. *Journal of Monetary Economics* 52(6), 1135–1149.

Lubik, T.A. and W.L. Teo (2012) Inventories, inflation dynamics and the New Keynesian Phillips curve. *European Economic Review* 56(3), 327–346.

Matheron, J. and T. Maury (2004) Supply-side refinements and the New Keynesian Phillips curve. *Economic Letters* 82, 391–396.

Mavroeidis, S. (2005) Identification issues in forward-looking models estimated by GMM with an application to the Phillips curve. *Journal of Money, Credit and Banking* 37(3), 421–449.

Mazumder, S. (2010) The New Keynesian Phillips curve and the cyclicality of marginal cost. *Journal of Macroeconomics* 32(3), 747–765.

McAdam, P. and A. Willman (2011) Technology, Utilization and Inflation: What Drives the New Keynesian Phillips Curve? Working paper series 1369, European Central Bank.

Mehra, Y. (1993) Unit labor costs and the price level. *Economic Quarterly Federal Reserve Bank of Richmond* 79(4), 35–51.

Nason, J.M. and G.W. Smith (2008) Identifying the New Keynesian Phillips curve. *Journal of Applied Econometrics* 23(5), 525–551.

Neiss, K., S. and E. Nelson (2005) Inflation dynamics, marginal cost, and the output gap: Evidence from three countries. *Journal of Money, Credit and Banking* 37(6), 1019–1045.

Ravenna, F. and C.E. Walsh (2006) Optimal monetary policy with the cost channel. *Journal of Monetary Economics* 53, 199–216.

Roberts, J.M. (2006) Monetary policy and inflation dynamics. *International Journal of Central Banking* 2(3), 193–230.

Rotemberg, J. and M. Woodford (1997) An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy. NBER technical working paper T233.

Rotemberg, J. and M. Woodford (1999) The Cyclical Behaviour of Prices and Costs. NBER working paper 6909

Rudd, J. and K. Whelan (2002) Does labour income share drive inflation. *Finance and Economics Discussion Series*. (30).

Rudd, J. and K. Whelan (2005) New tests of the New-Keynesian Phillips curve. *Journal of Monetary Economics* 52(6), 1167–1181.

Rudd, J. and K. Whelan (2007) Modelling inflation dynamics a critical review of the research. *Journal of Money, Credit and Banking* 39, 155–170.

Sbordone, A. (2002) Prices and unit labor costs: A new test of price stickiness. *Journal of Monetary Economics* 49(2), 265–292.

Sbordone, A. (2005) Do expected future marginal cost drive inflation dynamics. *Journal of Monetary Economics* 52(6), 1183–1197.

Staiger, J. and J. Stock (1987) Instrumental variables regression with weak instruments. *Econometrica* 65(3), 557–586.

Stock, J. and M. Watson (2007) Why has US inflation become harder to forecast. *Journal of Money, Credit and Banking* 39, 3–33.

Wolman, A. (1999) Sticky prices, marginal cost, and the behavior of inflation. *Federal Reserve Bank of Richmond Economic Quarterly* 85, 29–48.

Zhang, C., Osborn, D. R., and D.H. Kim (2008) The New Keynesian Phillips curve: From sticky inflation to sticky prices. *Journal of Money, Credit and Banking* 40(4), 667–699.

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press

APPENDIX: DATA DEFINITIONS

All data, with the exception of nonfarm labor costs, the commodity price index, and the 3-month treasury bill rate, are sourced from the U.S. Department of Commerce Bureau of Economic Analysis and the U.S. Bureau of Labor Statistics, as published on 5 December 2013. The *commodity price index* is the spot commodity index sourced from the Commodity Research Bureau at http://www.crbtrader.com/crbindex/ and the *3-month treasury bill rate* is sourced from the U.S. Federal Reserve.

Labor Cost (nonfarm): Source: U.S. Bureau of Labor Statistics

Labor Costs (all sectors): Source: U.S. Department of Commerce Bureau of Economic Analysis, Table 1.10, compensation of employees

Nonlabor Costs (*all sectors*): Source: U.S. Department of Commerce Bureau of Economic Analysis, Table 1.10 (these payments include *consumption of fixed capital*, *taxes on production and imports*, and *business current transfer payments*)

GDP deflator: Source: U.S. Department of Commerce Bureau of Economic Analysis, Table 1.1.9

Inflation = Change in the log of the *GDP deflator*.

Nominal GDP (nonfarm and all sectors): Source: U.S. Bureau of Economic Analysis, Table 1.3.5

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

Total Costs (all sectors) = Labor Cost (all sectors) + *Nonlabor Costs* (all sectors)

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

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

Unit Total Costs (all sectors) = (log) *Total Costs (all sectors)* - (log) *Nominal GDP (all sectors)*

https://doi.org/10.1017/S1365100515000140 Published online by Cambridge University Press