Technology, Utilization and Inflation: Re-assessing the New Keynesian Fundamental*

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Abstract

We argue that the New-Keynesian Phillips Curve (NKPC) literature has failed to deliver a convincing measure of "fundamental inflation". Traditional measures – e.g., marginal costs, the "output gap" – imply incorrect cyclicality properties and/or identification problems. Specifying firms' unit labor costs should instead start from a careful modeling of potential output allowing for non-unitary factor substitution and non-neutral technical change. This ensures that such measures match the volatility reductions witnessed in many US time series. Further, we emphasis the need to disentangle technical progress from factor utilization rates. Incorporation of the latter into real marginal costs allows the data to weigh the contribution of counter-cyclical unit labor costs with pro-cyclical utilization rates. Our NKPC results suggest that, compared to conventional measures, real marginal cost measures including variable utilization empirically dominate and overcome many of the biases that otherwise arise: inflation becomes less forward-looking and the Phillips-curve slope strengthens. Our results have important implications for inflation modeling and for the incorporation of New-Keynesian frictions into policy models.

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Keywords: Inflation, Real Marginal Costs, Production Function, Labor Share, Cyclicality, Utilization, Intensive Labor, Overtime Premia.

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1 Introduction

The New Keynesian Phillips Curve (NKPC) has become the dominant paradigm for analyzing inflation dynamics. Primarily, the specification models inflation as a function of its expectation and some real activity driving variable. NKPCs have been widely estimated (e.g., Roberts (1995), Galí and Gertler (1999)) and their merits much debated (Fuhrer (1997), Batini (2009), Galí (2008)).

Many such debates, though, have focused more on dynamic and expectations issues than on how to treat the driving variable. Indeed, it appears stubbornly difficult to pin down the driving variable. First, estimates of the Phillips-curve slope have been curiously flat (contrary to micro-economic evidence suggesting frequent price adjustments). Such upward bias in the estimation of price stickiness has clear implications the usefulness of associated policy advice. Indeed, at the extreme if modeled inflation is uncoupled from some measure of the real economy, indeterminacy may result. A second criticism is that reductions in inflation volatility do not appear to be matched by that in candidate fundamentals, e.g. Fuhrer (2006, 2010).

Accordingly, a variable unable to map to those features may be considered an improper driving variable, whose use may not only bias estimates of the contribution of fundamental (or "inherited") inflation, but distort our understanding of other sources of inflation persistence. This in turn, has implications for central banks' understanding of the monetary-inflationary process and their communication strategies. In short, the stakes are high.

We argue that these problems arise because conventional measures of the fundamental (or real marginal costs) are flawed. We propose a theoretically well-founded alternative, and, accordingly, reassess the empirical performance of NKPCs. Admittedly, real marginal costs - as implied by the New Keynesian theory - are difficult to measure. An early approach was to use the deviation of output from a HP filter or a linear/quadratic trend. However, often these non-structural measures entered with the "wrong" (negative) sign. Alternatively, Galí and Gertler (1999) and Woodford (2001b) argued in favor of proxying real marginal costs by average real unit labor costs. Under the special case of a (unitary substitution elasticity) Cobb Douglas production function, real marginal costs reduce to the labor share.

The advantage of using the labor share is that it is observable, simple[1] and tended to yield the "correct" slope sign (albeit not always significant or large). The disadvantage is largely three fold: (i) labor share is counter-cyclical (by contrast, theory suggests output

[1]It does not, for instance, even require explicit production function estimation. It also tends to allow researchers to abstract from capital accumulation.

increases not driven by technological improvements tend to raise nominal marginal costs more than prices: Röger (1995), Hall (1998), Rotemberg and Woodford (1999), Rudd and Whelan (2007)); (ii), reflecting its Cobb-Douglas origins, it is underpinned by a unitary elasticity of factor substitution and thus excludes any identifiable role for technical change; and (iii), its use as a measure of real marginal costs implies that either the number of workers or their utilization rate can be adjusted costlessly at a fixed wage rate. Over business-cycle frequencies, *all* of these features (unitary substitution; indeterminate technical progress; zero adjustment costs; fully utilized labor) appear highly restrictive.

Against this background, we attempt a more careful and less restrictive treatment of the driving variable(s). In their landmark overview Rotemberg and Woodford (1999) reviewed means to improve the measurement of real marginal costs, e.g., non Cobb Douglas production, overtime pay, labor adjustment costs, labor hoarding, variable capital utilization and overhead labor. Our paper can be viewed as empirically taking up many of those issues (all but the last in fact) in a unified framework.

As regards the choice of production technology (from which we construct real unit labor costs), we estimate both Cobb Douglas and the more general constant elasticity of substitution (CES) form to capture potential output. Following the seminal work of La Grandville (1989) and Klump and de La Grandville (2000), we do so in "normalized" form.[2] And following Klump et al. (2007), we estimate production and technology relationships in a system with cross-equation restrictions with the factor demands.

The difference production-function forms makes is surprisingly important. The CES production variant not only empirically dominates Cobb Douglas,[3] it also - to recall the above discussion - *does* capture the celebrated volatility reduction in the US economy from the early 1990s.

Using CES forms, in addition, opens up the possibility for non-neutral technical change. Moreover, there appears little reason to suppose that over business-cycle frequencies, technical change will be neutral or mimic balanced growth, Acemoglu (2009) (Ch. 15). Furthermore, the acceleration in US labor productivity and TFP during the second half of the 1990s (Basu et al. (2001), Jorgenson (2001)) underpins the need for

[2]Normalization essentially implies representing production in consistent indexed number form. Without it, production-function parameters can be shown to have no economic interpretation since they are dependent on the normalization point and the elasticity of substitution. This feature significantly undermines estimation and comparative static exercises, e.g. León-Ledesma et al. (2010a,b), Klump and Saam (2008).

[3]For further evidence of this, see Klump et al. (2007), Chirinko (2008), León-Ledesma et al. (2010b). Moreover, Jones (2003, 2005) argues that factor income shares exhibit such protracted swings and trends in many countries as to be inconsistent with Cobb-Douglas (see also Blanchard (1997), McAdam and Willman (2010)).

a careful treatment.[4] Since Solow (1957), we have also known of the need to disentangle technical change from factor utilization rates. We do so by making flexible, though economically interpretable, parametric assumptions for both. For instance, we assume growth in factor-augmenting technical change is non-constant but smoothly evolving. In so doing, we find an intriguing - and so far novel - result that the boom in TFP growth in the 1990s was underpinned by aggressive labor augmenting and declining capital augmentation. This reflected an essentially fully-employed economy and thus - following the insights of the "directed technical change" literature (Acemoglu (2002a)) - the necessity to bias innovations towards the scare factor. Observations of this sort - as we shall see - are very helpful in explaining and rationalizing factor income share movements.

Notwithstanding, we demonstrate that whether real marginal costs measures are Cobb Douglas or CES based, they remain counter-cyclical (and thus contrary to inflation procyclicality). They are, in short, partial measures of firms' real marginal costs, and thus of the pass-through of those costs to inflation.

So what is missing? We rationalize their cyclical short comings as reflecting omitted variations in factor utilization. Regarding employment, following Trejo (1991), Bils (1987) and Hart (2004), we conceive of an arguably more realistic contracts frameworks where the existence of extensive labor adjustment costs leads to a phenomenon we label "Effective Hours". Effective Hours captures firms' familiar costs increases from overtime labor.[5] But it also captures the inability (or reduced ability) of firms to cut labor costs if utilized labor falls below the norm, reflecting labor hoarding essentially. Likewise, costs related to capital utilization are assumed to be convex with a technical upper bound. In line with Basu et al. (2001), we demonstrate that both factor utilization rates closely co-move. We further discuss parameter identification issues arising when using separate utilization rates in the definition of the fundamental as against a measure of overall capacity utilization.

Accordingly, we arrive at a measure of real marginal costs comprising a composite of (*counter-cyclical*) real marginal costs excluding utilization plus (*pro-cyclical*) utilization costs.[6] The overall cyclicality of this measure of real marginal costs depends on how the

[4]We could add many other topics to this list of the importance of technical change and non-unitary substitution: the impact of technical change on the welfare consequences of new technologies (Marquetti (2003)); labor-market inequality and skills premia (Acemoglu (2002b)); the evolution of factor income shares and non-balanced growth (Acemoglu (2002a), McAdam and Willman (2010)) etc. The elasticity of factor substitution is known to have first-order implications in many fields: e.g., growth theory; the dynamics of employment and income distribution; the efficacy of stabilization policy (e.g., Chirinko (2008)).

[5]The share of private US industry jobs with overtime provisions is around 80%, and higher in some occupational groups (machinery operation; transport; administrative services), Barkume (2007).

[6]Since the latter mimics an output gap (the weighting average of factor utilization rates), our driving variable (which can be net pro- or counter-cyclical depending on how estimation weights the two margins) suggests a synthesis between differing New Keynesian approaches (new and traditional). Thus, our work

data weights them together. We find that when our cost measure is inserted into NKPCs as the fundamental (relative to the use of standard unit labor costs), price stickiness is more consistent with micro studies (implying aggregate fixed prices around 2-4 quarters). We also find that the weight given to inflation dynamics change: the slope of the Phillips curve strengthens markedly, and the weight on forward-looking expectations decreases. Indeed, we tend to find a balanced explanation of backward and forward dynamics. We pursue robustness in several directions: the augmented fundamental is, to repeat, estimated under both Cobb Douglas and CES forms and, in NKPC estimation, we use GMM as well as recently-developed moment conditions inference methods.

The paper proceeds as follows. Section 2 defines supply-based measures of marginal costs. Such measures are typically counter cyclical, reflecting pro-cyclical labor productivity. We suggest that standard costs measures are incomplete because they do not account for factor utilization rates. In section 3, we define economically plausible choices for factor utilization and discuss associated identification issues. Next, we define the firm's profit maximization problem incorporating factor adjustment and utilization costs. Section 5 restates the NKPC framework. Section 6 defines our US macro data sources and transformations. Section 7 details our estimates of the aggregate production-supply framework, Effective Hours and the NKPCs incorporating the augmented driving variable. Finally, we conclude.

2 What Measures Real Marginal Costs?

Let us start by assuming output, Y_t, is characterized by a CES production function,[7]

$$Y_t = F\left(\Gamma_t^K, K_t, \Gamma_t^N, N_t\right) = \left[\alpha\left(\Gamma_t^K K_t\right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\left(\Gamma_t^N N_t\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad (1)$$

where capital and labor and labor augmenting technical change are denoted by Γ_t^K and Γ_t^N, respectively. The elasticity of substitution between capital and labor is given by the percentage change in factor proportions due to a change in the marginal products along an isoquant, $\sigma \in [0, \infty] = \frac{d\log(K/N)}{d\log(F_N/F_K)}$. If $\sigma \to 1$ ($\to 0$), the CES function reduces to Cobb-Douglas (Leontief).

Defining real marginal costs as the ratio of real compensation to the marginal product

contributes to the emerging consensus that richer specifications of the Phillips measures that merge new and old elements are required to account for inflation persistence (e.g., Blanchard and Galí (2007, 2010)).

[7]Later, we distinguish between potential and actual output as, Y_t^* and Y_t respectively where the former does not account for factor utilization rates (see our later equations, (10) and (11))

of labor, yields,

$$\frac{w_t}{F_N} = \begin{cases} \frac{1}{(1-\alpha)} w_t (\frac{N_t}{Y_t})^{\frac{1}{\sigma}} \left(\Gamma_t^N\right)^{\frac{1-\sigma}{\sigma}} & \text{for} \quad \sigma > 0 \text{ and } \sigma \neq 1 \\ \\ \frac{1}{(1-\alpha)} w_t \frac{N_t}{Y_t} & \text{for} \quad \sigma \to 1 \end{cases} \tag{2}$$

where w_t is the real wage. Under the special case of Cobb Douglas such costs (reducing to unit labor costs) are proportional to the labor share. Under CES they are additionally determined by labor-augmenting technical change for a given substitution elasticity. Overall, real wages increase unit labor costs whilst increases in labor productivity (Y_t/N_t) decrease costs, as do increases in labor-augmenting technical progress if $\sigma < 1$.

If technical change is a-cyclical (see Basu et al. (2006)), a measure of costs based on Cobb-Douglas or CES should have the same cyclicality properties. Naturally, one production function may "fit" better, but for examining cyclical properties we can proceed using the more tractable Cobb-Douglas case:[8]

$$Y_t = F(K, N, A) = A_t K_t^{\alpha} N_t^{1-\alpha} \tag{3}$$

where A is the technology level (i.e., the Solow residual).

Cobb-Douglas implies that labor income share correctly measures real marginal costs. Likewise, it implies that the labor share is stationary.[9] However, this is not sufficient; the Solow residual should also be either white noise or, if cyclical, then the source of cyclicality should be solely technical progress; this is an interpretation many may think counter-intuitive.

If Cobb Douglas is empirically rejected, the labor income share cannot correctly measure real marginal costs. US aggregate data shows that, at least, unless the interpretation of strongly pro-cyclical technical progress is taken seriously, the requirements for the labor share measuring correctly real marginal costs are not fulfilled and a better measure should be developed.

To continue, profit maximization implies the following relations for the marginal pro-

[8]Note, we have expressed technical progress as Hicks neutral in expression (3), but we could have re-expressed it as any form of neutrality in the Cobb Douglas case (e.g., for a simple proof see Barro and Sala-i-Martin (2004), p78-80.)

[9]The CES production function, when technical progress is Harrod neutral, also results in a constant (stationary) labor share.

ductivity of labor:

$$F_N = (1-\alpha)\,\frac{Y_t}{N_t} \tag{4}$$

$$F_N = (1-\alpha)\,A_t\left(\frac{K_t}{N_t}\right)^{\alpha} \tag{5}$$

Equations (4) and (5) express the marginal product in terms of labor productivity and, alternatively, in terms of capital intensity and the Solow residual. Accordingly, labor productivity, capital intensity and the real wage rate should have a common trend that equals the trend component of the Solow-residual in power $(1-\alpha)$. Therefore, the trend deviations of these three variables (as well as the labor share) should be stationary. Further, theory tells that labor productivity and capital intensity decrease as a response to positive demand (or preference) shocks (i.e., both would be counter-cyclical). Therefore, one would expect both labor productivity and capital intensity to be counter cyclical. In turn, unless the real wage were (counter-intuitively) strongly counter-cyclical, we would further expect the labor share to be pro-cyclical.

Figure 1 shows the opposite. It plots the US labor share, real wage, labor productivity and capital intensity measures as deviations from their common trend against the NBER reference dates.[10] The stationarity requirement of the data are, at most, weakly fulfilled. Regarding cyclicality, the top-panel shows that the labor share, instead of being pro-cyclical, is counter-cyclical. Since the real wage is largely a-cyclical (middle-panel) the counter-cyclicality of the labor share reflects mainly the pro-cyclicality of labor productivity (bottom panel). The bottom panel also presents capital intensity, whose cyclicality is almost the mirror image of that of labor productivity. Therefore, on the basis of (4) and (5) the apparent pro-cyclical component in the Solow residual must dominate labor productivity to compensate the counter-cyclicality of capital intensity.

There are two possible explanations for pro-cyclical Solow residual and labor productivity.[11] The first is that exogenous changes in technical progress explain not only the trend development of the Solow residual but also its cyclical variation. The second, and our favored explanation, is that inputs are instead systematically mis-measured and true productivity is counter cyclical even though measured productivity is pro-cyclical; the gap or discrepancy would then arise from unobserved changes in factor utilization rates.

The first explanation leaves no role for demand shocks in business cycles and, accordingly, is quite implausible. To illustrate, Basu et al. (2006) estimated the contribution

[10] We estimated all three variables in a cross-equations system on a cubic trend, with an unrestricted constant.

[11] The third possible explanation might be increasing returns to scale. However, e.g., Basu and Kimball (1997) and Basu et al. (2006) found no significant evidence for this explanation.

of factor utilization to the Solow residual and found that the 'purified' TFP followed a random walk with no residual serial correlation implying a practically a-cyclical evolution for TFP.

Hence, taking the second explanation on board, we should decompose the Solow residual as,

$$A_t = \Gamma_t \kappa_t^{\alpha} h_t^{1-\alpha} \tag{6}$$

where $\Gamma_t = \left(\Gamma_t^K\right)^{\alpha} \left(\Gamma_t^N\right)^{1-\alpha}$ denotes non-cyclical (trend) technical progress and κ and h denote the respective rate of capital and labor utilization rates. Then we have,

$$F_H = (1-\alpha) \frac{Y_t}{h_t N_t} \tag{7}$$

$$F_H = (1-\alpha) \Gamma_t \left(\frac{\kappa_t K_t}{h_t N_t}\right)^{\alpha} \tag{8}$$

Equation (8) suggests that as F_H is *counter*-cyclical, unless variation in the capital utilization rate strongly dominates the labor utilization rate. Accordingly, the true marginal cost of labor $\frac{w_t}{F_H}$ is *pro*-cyclical and its proportionality to the labor share no longer holds.

Summing up, there are at least two grounds to doubt that labor share properly measured real marginal costs. First, the validity of the underlying Cobb-Douglas assumption is doubtful. Second, paid labor and the installed capital stock are not continuously at full use. The remaining sections attempt to correct these weaknesses.

3 Costs of varying factor utilization rates

The prerequisite for variation in factor utilization rates is that a firm cannot costlessly change its factor composition. Without adjustment costs, both inputs would be used at constant maximal intensity. Adjustment costs are not, however, a sufficient condition for varying factor utilization rates; variation in utilization must be coupled with convex costs. This creates a short-run trade-off between changes in hired or installed input quantities and the intensities at which they are used.

Typically, around two-thirds of the variation in total hired hours originates from employment; the rest from changes in hours per worker, e.g., Kydland (1995), Hart (2004). The relatively small proportion of the variation of paid hours per worker reflects the fact that labor contracts are typically framed in terms of "normal" working hours. Therefore, it is difficult for firms to reduce hired hours per worker below that norm and problematic to increase them above without increasing marginal costs.

Under these conditions it may be optimal for firms to allow the *intensity* at which hired labor is utilized to vary in response to shocks. Hired hours may therefore underestimate the true variation of the utilized labor input over the cycle and "effective hours" (i.e., which is employment times labor intensity) would be the correct measure of labor input in production.

Thus, like the indivisible labor literature (e.g., Kinoshita (1987), Trejo (1991), Rogerson (1988)) we assume contracts are defined in terms of fixed (or normal) working hours per employee, i.e. in terms of the "straight-time" wage rate. In general, hours per employee in excess of normal hours attract a premium. This is standard. However, we also assume employers also have limited possibilities to decrease paid hours when effectively worked hours fall below normal ones and, hence, paid wage costs per effective hour increase also when effective hours per employee decrease.

Total wage costs per employee can therefore be presented as a convex function of the deviation of effective hours h_t from normal hours $\overline{h}$.[12] Normalizing the latter to unity and using a variant of the "fixed-wage" model of Trejo (1991) for overtime pay, the following function gives a local approximation of this relation in the neighborhood of effective hours equalling normal hours:[13]

$$W_t = W\left(\overline{W}_t, h_t\right) = \overline{W}_t\left[h_t + \frac{a}{2}\left(h_t - 1\right)^2\right] \tag{9}$$

where W_t is the total nominal wage bill per worker, $\overline{W}_t$ is the nominal straight-time wage rate which each firm takes as given. Parameter $a \geq 0$ may reflect institutional factors such as employment regulation and norms, labor bargaining power etc. Conditional on the contracted straight-time wage rate and the overtime wage premium function, effective hours are completely demand determined.

The linear schedule in **Figure 2** illustrates the dependency of total wage costs if deviations of effective hours from normal hours attract no premium, i.e. $a = 0$. Convex curvature in wage costs arise for $a > 0$. The greater the curvature, the greater is the incentive to adjust total effective hours, H, by changing the number of employees.[14] Indeed, if changing the number of employees is costless, all adjustment may be done via this margin and, independently from $size(a)$, $H_t = N_t \; \forall t$. Naturally, in reality, changes in the number of employees are associated with non-trivial costs.

The conventional assumption for modeling capital utilization function, $\Phi(\kappa)$, is Φ', $\Phi'' > 0$. In other words, increases in the capital utilization rate increases costs, at an

[12]Whilst, the overtime pay schedule of a single worker takes a kinked form, this is not so at a firm level and even less on higher aggregation levels, if there are simultaneously employees working at less than full intensity and those working overtime at full intensity (see the discussion in Bils (1987)).

[13]Shapiro (1986) and Bils (1987) used quite similar overtime premium specifications.

[14]A similar choice of functional form for labor costs is the Linex function, Varian (1974). However, we found results for our NKPC estimations which were very similar when we used this form.

increasing rate. Though strictly speaking unnecessary, we might also assume an upper bound as full capital utilization is approached, $\lim_{\kappa\to 1}\Phi(\kappa)\to\overline{\kappa}\in(0,\infty]$, where $\kappa_t\in[0,1]$. Although, we also could parametrically specify the capital utilization rate function,[15] for our purposes, as we will show, it is sufficient to specify labor adjustment costs and relate the empirical trade offs involved in assuming all utilization variance derives from that measure, or, alternatively, from a measure of the rate of overall factor utilization.

3.1 Identification of Dual Factor Utilization Rates

Aggregate capital and labor utilization rates are essentially latent variables. Disentangling them without some additional identifying assumptions is problematic. Part of the problem - and part of the solution - lies in the understanding that utilization rates co-move over the cycle.[16]

Let Y_t and Y_t^* denote actual and full-capacity output, respectively,

$$Y_t = F\left(\Gamma_t^K \widetilde{\kappa}_t K_t, \Gamma_t^N h_t N_t\right) \tag{10}$$

$$Y_t^* = F\left(\Gamma_t^K K_t, \quad \Gamma_t^N N_t\right) \tag{11}$$

where $\widetilde{\kappa}_t = \kappa_t/\kappa_{ss}$, is the capital utilization rate re-scaled by its steady state level κ_{ss}. Hence, $\widetilde{\kappa}_t$ varies in the interval $0\leq\widetilde{\kappa}_t\leq 1/\kappa_{ss}$ on both sides of unity. Taking a first-order approximation of (10) around $\widetilde{\kappa}_t = h_t = 1$ yields,

$$\log\frac{Y_t}{Y_t^*} = u_t - 1 \approx \frac{\Gamma_t^K K_t}{Y_t^*}\frac{\partial Y_t^*}{\partial\left(\Gamma_t^K K_t\right)}\left(\widetilde{\kappa}_t - 1\right) + \frac{\Gamma_t^N N_t}{Y_t^*}\frac{\partial Y_t^*}{\partial\left(\Gamma_t^N N_t\right)}\left(h_t - 1\right) \tag{12}$$

$$u_t - 1 \approx \alpha\left(\widetilde{\kappa}_t - 1\right) + (1-\alpha)\left(h_t - 1\right) \tag{13}$$

Thus, the capacity utilization rate u_t is given by the (factor-income-share) weighted average of factor utilization rates. Under Cobb-Douglas, as well under CES with Harrod neutrality, approximation (13) is exact. But the quality of the approximation is also relatively good under factor-augmenting technical progress unless the ratios $\left(\frac{Y_t^*}{\Gamma_t^K K_t}\right)^{\frac{1-\sigma}{\sigma}}$ and $\left(\frac{Y_t^*}{\Gamma_t^N N_t}\right)^{\frac{1-\sigma}{\sigma}}$ contain sufficiently strong trends.

[15] Muns (2009) provides a good review of various functional forms used in the literature approaches.

[16] That is what Basu et al. (2006) showed in their nonparametric cost minimization framework and what Bils and Cho (1994) used as their identification assumption when they introduced factor utilization rates into a RBC model.

4 Maximization Problem

We now derive the firm's first-order inter-temporal maximization conditions accounting for costs associated with the changes of factor inputs and their utilization rates (as already discussed). Wage contracts are framed in terms of "normal" working hours with a convex schedule capturing overtime premiums and the under-utilization of paid labor input as defined by (9). Costs related to time-varying capital utilization rates are defined by the implicit function, $\Phi(\kappa_{it})$, and convex adjustment are associated with changes in the number of workers and the size of the capital stock.

To increase the tractability of our exposition we use two-stage approach in optimal price setting. First, we derive the optimal price in the absence of any frictions in price setting. This allows us to define real marginal costs capturing also the costs resulting from time-varying factor utilization rates. In addition, the first-order conditions of profit maximization gives us the steady-state system that we use in estimating the parameters of the production function needed for constructing real marginal costs.

Assume firm i faces demand function $Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\varepsilon} Y_t$. Its profit function is

$$\Pi_t = P_t \left\{ \begin{array}{c} Y_{it}^{1-\frac{1}{\varepsilon}} Y_t^{\frac{1}{\varepsilon}} - \frac{W\left(\overline{W}_t, h_{it}\right)}{P_t} N_{it} - \frac{\overline{W}_t}{P_t} \Omega_N\left(N_{it}, N_{it-1}\right) - \left[K_{it} - (1-\delta) K_{it-1}\right] \\ -\Phi\left(\kappa_{it}\right) K_{it} - \Omega_K\left(K_{it}, K_{it-1}, K_{it-2}\right) - \left(1+i_{t-1}\right) \frac{P_{t-1}}{P_t} b_{it-1} + b_{it} \end{array} \right\} \quad (14)$$

where Ω_j refers to a generalized adjustment cost function associated to factor j. In the first step, the firm maximizes the discounted sum of profits, subject to its production constraints:

$$\max \sum_{s=t}^{\infty} \prod_{j=0}^{s-t} R_j \left\{ \Pi_s + P_s \Lambda_{is}^{Y} \left[F\left(\Gamma_s^K \widetilde{\kappa}_{is} K_{is}, \Gamma_s^N h_{is} N_{is}\right) - Y_{is} \right] \right\} \quad (15)$$

where $\widetilde{\kappa}_{it} = \frac{\kappa_{it}}{\kappa_{ss}}$ and κ_{ss} the optimal steady-state utilization rate. The first-order conditions are:

$$Y_i : \Lambda_{it}^Y = \frac{P_{it}}{(1+\mu) P_t} \tag{16}$$

$$\kappa_i : \Lambda_{it}^Y = \frac{\kappa_{ss}\Phi'(\kappa_{it})}{F_1 \Gamma_t^K} = \frac{\Phi'(\kappa_{it})\widetilde{\kappa}_{it}}{F_{K_i}} \tag{17}$$

$$h_i : \Lambda_{it}^Y = \frac{\partial W\left(\overline{W}_t, h_{it}\right)/\partial h_{it}}{P_t F_1 \Gamma_t^N} = \frac{\partial W\left(\overline{W}_t, h_{it}\right)/\partial h_{it}}{P_t F_{N_i}} h_{it} \tag{18}$$

$$N_i : \frac{\partial \Omega_N (N_{it}, N_{it-1})}{\partial N_{it}} + R_{t+1} \frac{\overline{W}_{t+1}}{\overline{W}_t} \frac{\partial \Omega_N (N_{it+1}, N_{it})}{\partial N_{it}} = \frac{P_t}{\overline{W}_t} \Lambda_t^Y F_2 \Gamma_t^N h_{it} - \frac{W\left(\overline{W}_t, h_{it}\right)}{\overline{W}_t} \tag{19}$$

$$b_i : R_{t+1} = \frac{1}{1+i_t} \tag{20}$$

$$K_i : \frac{\partial \Omega_K (K_{it}, K_{it-1}, ..)}{\partial K_{it}} + R_{t+1} \frac{P_{t+1}}{P_t} \frac{\partial \Omega_K (K_{it+1}, ..)}{\partial K_{it}} + R_{t+1} \frac{P_{t+1}}{P_t} R_{t+2} \frac{P_{t+2}}{P_{t+1}} \frac{\Omega_K (K_{it+2}, ..)}{\partial K_{it}}$$
$$= \frac{P_{it}}{(1+\mu) P_t} F_{K_i} - \left(1 - R_{t+1} \frac{P_{t+1}}{P_t} (1-\delta) + \Phi(\kappa_{it})\right) \tag{21}$$

$$\Lambda_i^Y : Y_{it} = F\left(\Gamma_t^K \kappa_{it} K_{it}, \Gamma_t^N h_{it} N_{it}\right) \tag{22}$$

where $1+\mu = \frac{\varepsilon}{\varepsilon - 1}$.

4.1 Derivation of the Frictionless Profit Maximizing Price level

Essentially, our interest lies with the first three equilibrium conditions since they define real marginal costs, $\Lambda_{it}^Y = MC_{it}^r$. Conditions (19) and (21) define the dynamic factor demands. Condition (20) defines the discount factor and (22) retrieves the production function.

The optimal (frictionless) price setting rule is obtained by maximizing (15) with respect to Y_{it} and h_{it}. The former first-order condition implies that $\Lambda_{it}^Y = MC_{it}^r = \frac{\varepsilon-1}{\varepsilon}\frac{P_{it}}{P_t}$ which, after inserting into the latter first-order condition, results in the following definition of real marginal costs,

$$MC_{it}^r = \frac{\partial W(\cdot)/\partial h_t}{P_t F_{N_i}} h_{it} = \frac{\partial W(\cdot)/\partial h_t}{P_t F_{N_i|h_{it}=1}} h_{it}^{\frac{1}{\sigma}} \tag{23}$$

$$= \frac{W_t}{P_t F_{N_i|h_{it}=1}} \cdot \frac{1 + a(h_{it}-1)}{h_{it} + \frac{a}{2}(h_{it}-1)^2} \cdot h_{it}^{\frac{1}{\sigma}} \tag{24}$$

In the above we use the fact $F_{h_i} \equiv F_{N_i}\frac{N_{it}}{h_{it}}$. Exploiting an approximation of efficient hours function (9) around $h_{it} = 1$, the impact of labor utilization rate h_{it} on real marginal costs can be presented quite tractably.[17] The optimal frictionless price, P_{it}^f, can now be written

[17]Equation (25) is solved exploiting an approximation of function W_h around $h = 1$. For nu-

as,

$$\log P_{it}^{f}=\log\left(1+\mu\right)+\underbrace{\log\left(\frac{W_{it}}{F_{N_i|h_{it}=1}}\right)+\varphi^{h}\log\left(h_{it}\right)}_{mc_{it}^{n}} \tag{25}$$

where $mc_{it}^{n}=\log\left(P_t\cdot MC_{it}^{r}\right)$, $\log\left(h_{it}\right)\approx h_{it}-1$ and where parameter $\varphi^{h}=\frac{1-\sigma}{\sigma}+a$, and $\varphi^{u}=\frac{\frac{1-\sigma}{\sigma}+a}{1-\alpha_0\left(\rho_{\widetilde{\kappa},h}-1\right)}$ measures the responsiveness of log nominal marginal costs to the chosen utilization rate. Equations (25) and (38) illustrate two ways to define the utilization component of marginal costs, using a definition of effective hours (solved from the inverted production function) or overall utilization. The choice of the former implicitly assumes full capital utilization, $\kappa_{it}=\kappa_{ss}=1$, and no covariation in utilization rates, $\rho_{\widetilde{\kappa},h}=0$.

Ceteris paribus, parameter φ^{u} is increasing in a and $\rho_{\widetilde{\kappa},h}$. It is decreasing in σ: the more easily factors can be substituted for each other, the less need there is to exploit an effective hours margin. For a given a, ρ and α_0, $max(\varphi^{u})\iff\sigma\rightarrow 0$.[18] However, disentangling φ itself reveals an identification problem: parameter a (the curvature of the effective hours schedule) can only be determined for a prior on utilization co-movement. A common assumption (see King and Rebelo (2000) for a discussion) would appear to be that $\rho_{\widetilde{\kappa},h}\geq 1$, reflecting the greater ease (and perhaps flatter local cost profile) of capital utilization costs relative to labor utilization costs.

4.2 The Steady State of the System of First-Order Conditions

Define the inverse of gross real interest rate $\left(1+r_t\right)^{-1}=R_{t+1}\frac{P_{t+1}}{P_t}=\frac{1}{(1+i_t)(1-\pi_{t+1})}$ where π refers to the inflation rate. Now, on the rhs of (21), the real user cost of capital can be denoted as

$$q_{it}=\frac{r_t+\delta}{1+r_t}+\Phi\left(\kappa_{it}\right) \tag{26}$$

The user cost is thus an increasing function of the rate of capital utilization. In the steady state, the capital utilization rate $\kappa_{it}=\kappa_{ss}$ (or equally $\widetilde{\kappa}_{it}=1$) and, hence, the rental price of capital, as defined below,

$$q_{it|\widetilde{\kappa}_t=1}=q_{t|\widetilde{\kappa}_t=1}=\frac{r_t+\delta}{1+r_t}+\Phi\left(\kappa_{ss}\right) \tag{27}$$

meric/estimation purposes this approximation is not at all necessary, but the approximation does put the augmented marginal cost term in a more tractable and interpretable format. We also tried a second-order approximation (which would add the term $-\frac{\left(1+(a^2+a-1)\sigma\right)(\log(h))^2}{2\sigma}$) but, as might be expected, it had no significant effects on estimation.

[18]This is intuitive: if production can only increase under a fixed-coefficient Leontief factor constraint, the benefit of exploiting utilization rates of given factor proportions will accordingly be high.

is the common across firms. Since in the steady state also $W_{it} = \overline{W}_t$ all firms face the same factor prices and, hence, then on the basis of (21) the marginal product of capital $F_{K_i|\widetilde{\kappa}=1} = F_{K|\widetilde{\kappa}=1}$, which together with the linearly homogeneous production function implies a common steady-state capital intensity for all firms .

The optimal steady-state price level is $P_{it} = P_t$, aggregate full-capacity output $Y_t^* = F\left(\Gamma_t^K K_t, \Gamma_t^N N_t\right)$ and in the steady state firm specific variables can equally be replaced by corresponding aggregates and the steady state system implied by (16)-(22). The steady-state is defined by the following 3-equation system,

$$\frac{W_{t|\widetilde{\kappa}_t=1}}{P_t} = \overline{w}_t = \frac{F_{N|h_t=1}}{(1+\mu)} \tag{28}$$

$$q_{t|\widetilde{\kappa}_t=1} = \frac{F_{K|\widetilde{\kappa}_t=1}}{(1+\mu)} \tag{29}$$

$$Y_{t|\widetilde{\kappa}_t=h_t=1} = Y_t^* = F\left(\Gamma_t^K K_t, \Gamma_t^N N_t\right) \tag{30}$$

4.3 Co-variation of the Factor Utilization Rates

Equations (16)-(18) imply,

$$\frac{\Phi'\left(\kappa_{it}\right)\widetilde{\kappa}_{it}}{F_{K_i}} = \frac{\overline{w_t}\left[1 + a\left(h_{it} - 1\right)\right]h_{it}}{F_{N_i}} \tag{31}$$

Given the normalized CES production function,

$$Y_t = Y_0\left[\alpha_0\left(\frac{\Gamma_t^K K_t}{\Gamma_0^K K_0}\right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha_0)\left(\frac{\Gamma_t^N N_t}{\Gamma_0^N N_0}\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{32}$$

and on the basis of equations (28) and(29) we derive,

$$F_{K_i} = \alpha_0\left(\frac{Y_{i0}}{K_{i0}}\Gamma_t^K\widetilde{\kappa}_{it}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{Y_{it}}{K_{it}}\right)^{\frac{1}{\sigma}} = F_{K_i|\widetilde{\kappa}_{it}=1}\left(\widetilde{\kappa}_{it}\right)^{\frac{\sigma-1}{\sigma}} = (1+\mu)\,q_{t|\widetilde{\kappa}_t=1}\left(\widetilde{\kappa}_{it}\right)^{\frac{\sigma-1}{\sigma}} \tag{33}$$

$$F_{N_i} = (1-\alpha_0)\left(\frac{Y_{i0}}{N_{i0}}\Gamma_t^N h_{it}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{Y_{it}}{N_{it}}\right)^{\frac{1}{\sigma}} = F_{N_i|h=1}\left(h_{it}\right)^{\frac{\sigma-1}{\sigma}} = (1+\mu)\,\overline{w_t}\left(h_{it}\right)^{\frac{\sigma-1}{\sigma}} \tag{34}$$

After inserting (33) and (34) to (31) we derive,

$$\widetilde{\kappa}_{it}^{\frac{1}{\sigma}}\Phi'\left(\kappa_{it}\right) = q_{t|\widetilde{\kappa}_t=1}\left[1 + a\left(h_{it} - 1\right)\right]h_{it}^{\frac{1}{\sigma}} \tag{35}$$

Implicit form (35) defines the interrelationship between the capital and labor utilization rates. A closed-form solution is obtained after taking logarithms and applying the first-order Taylor approximation to $\log\left[\Phi'\left(\kappa_{it}\right)\right] \approx \log\left[\Phi'\left(\kappa_{ss}\right)\right] + \frac{\kappa_{ss}}{\Phi'(\kappa_{ss})}\log\,\widetilde{\kappa}_{it}$ and to

$[1+a(h_{it}-1)] \approx a \log h_{it}$. Now (35) is transformed into,

$$\log \widetilde{\kappa}_{it} = \rho_{\widetilde{\kappa},h} \log h_{it} \tag{36}$$

where $\rho_{\widetilde{\kappa},h}(a,\sigma,\Phi') = \frac{\left(\frac{1}{\sigma}+a\right)}{\frac{1}{\sigma}+\frac{\kappa_{ss}}{\Phi'(\kappa_{ss})}}$.

Accordingly, substituting (36) into (13), we can derive a relationship between effective hours and total capacity utilization measures:

$$h_t - 1 = \frac{u_t - 1}{1+\alpha\left(\rho_{\widetilde{\kappa},h}-1\right)} \tag{37}$$

The capacity-utilization rate u_t is well-defined conditional on the parameters of the production function $F(\cdot)$ being known (i.e., recall $u_t = \log \frac{Y_t}{Y_t^*} + 1$). This information suffices for re-specifying the real marginal costs in estimating the NKPC.

5 The Calvo-NKPC Framework

5.1 Aggregate Optimal Frictionless Price Level

Equation (25) can be transformed on the basis of (37),

$$\log P_{it}^f = \log(1+\mu) + \underbrace{\log\left(\frac{W_{it}}{F_{N_i|h_{it}=1}}\right) + \varphi^u \log\left(\frac{Y_{it}}{\underbrace{F\left(\Gamma_t^K \kappa_{ss} K_{it}, \Gamma_t^N N_{it}\right)}_{Y_{it}^*}}\right)}_{mc_{it}^n} \tag{38}$$

In section 4.2, we proved the following aggregation properties: $Y_{it}^* = F\left(\Gamma_t^K K_{it}, \Gamma_t^N N_{it}\right) = s_{it}^* F\left(\Gamma_t^K K_t, \Gamma_t^N N_t\right)$ and $F_{N_i|h_{it}=1} = F_{N|h_t=1}$. In addition, if no idiosyncratic shocks exist, then the utilization rates $h_{it} = h_t$ and $u_{it} = u_t$, the wage rate per worker $W_{it} = W_t$ and the production shares $s_{it} = Y_{it}/Y_t = Y_{it}^*/Y_t^* = s_{it}^*$. Thus the optimal price P_{it} is common across firms.

Allowing firm-specific, idiosyncratic shocks and, hence, firm-specific utilization rates implies the following relation for the aggregate frictionless optimal aggregate price level,

$$\log P_t^f = \sum \frac{s_{it}}{\sum s_{it}} \log P_{it} = \log(1+\mu) + \overbrace{\underbrace{\sum \frac{s_{it}}{\sum s_{it}} \log\left(\frac{W_{it}}{F_{N_i|h_{it}=1}}\right)}_{\log\left(\frac{W_t}{F_{N|h_t=1}}\right)} + \varphi^u \underbrace{\sum \frac{s_{it}}{\sum s_{it}} \log\left(\frac{Y_{it}}{Y_{it}^*}\right)}_{\log\left(\frac{Y_t}{Y_t^*}\right)}}^{mc_t^n} \tag{39}$$

where $\sum s_{it} \leq 1$ is the share of firms which reset their price following the optimal price setting rule.

Thus, equation (39) represents our fundamental in the NKPC estimations. It embodies both the conventional (what we call partial) measures of real marginal costs as well as a margin reflecting utilization rates of one kind or another. To construct these two components of the marginal costs, the exact parameterization of the production function determining the full-capacity output must be known. For estimating these parameters we derive the steady state system of equations implied by the first order conditions of profit maximization relation (15).

5.2 The NKPC

As in Galí and Gertler (1999) and subsequent literature, we assume a Calvo-type price setting framework under imperfect competition, where a fraction θ of firms do not change their prices in any given period.[19] The remaining firms set prices optimally as a mark-up on discounted expected marginal costs. When resetting, firms also take into account that the price may be fixed for many periods. The NKPC can then be expressed as,

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \lambda \left(mc_t^r + \mu \right) \tag{40}$$

where π_t represents current inflation and $mc_t^r = mc_t^n - p_t$ with mc_t^n as defined by (39). $\mathbb{E}_t$ is the expectation operator, β is a discount factor, θ measures price stickiness (average fixed-price contract duration being $D = \frac{1}{1-\theta}$), $\lambda = \frac{(1-\theta)(1-\theta\beta)}{\theta}$ represents the slope of the Phillips curve (the pass-through of marginal costs). Iterating (40) forward, we see that inflation persistence is "inherited" from that of the driving variable, $\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k \mathbb{E}_t \left(mc_{t+k}^r + \mu \right)$.

The "Hybrid" NKPC additionally assumes that of the $1 - \theta$ price-re-setting firms a fraction, $1 - \omega$, reset prices optimally with the remaining fraction choosing to set their price according to lagged inflation. This implies,

$$\pi_t = \underbrace{\frac{\theta\beta}{\phi}}_{\gamma_f} \mathbb{E}_t \pi_{t+1} + \underbrace{\frac{\omega}{\phi}}_{\gamma_b} \pi_{t-1} + \lambda \left(mc_t^r + \mu \right) \tag{41}$$

where $\lambda \mid_{\omega>0} = \frac{(1-\omega)(1-\theta)(1-\theta\beta)}{\phi}$ and $\phi = \theta + \omega \left[1 - \theta \left(1 - \beta \right) \right]$. The composite parameters

[19] In recent times there have considerable extensions to the NKPC framework: e.g., open-economy variants; time-variation in parameters and inflation trends; sticky-information; non-linearity; non-constant demand elasticities; firm-specificities etc (Walsh (2010) provides an excellent discussion of recent developments). However, given that our interest is the contribution of a new measure of the driving variable, and for benchmarking purposes with the core of the literature, we use the above for our estimations. Using our augmented driving variable in these newer forms would, however, be a valuable offshoot of our work.

γ_f, γ_b and λ capture, respectively, what is often termed extrinsic, intrinsic and inherited inflation persistence. The exact nature of inflation persistence is of direct interest to policy makers: extrinsic persistence relates, for example, to policy credibility and communication, whilst intrinsic persistence may relate to rule-of-thumb, non-rational expectations, rising hazard price-resetting functions, indexation, e.g., Woodford (2001a).

6 Data

We use quarterly series for the US from 1954:1 to 2008:2. Our principal source was the NIPA Tables (National Income and Product Accounts) for production and income.[20] The output series is calculated as Private non-residential Sector Output: i.e., total output minus Indirect Tax Revenues and minus Public-Sector and Housing-Sector Output. After these adjustments, the output concept used is compatible with that of our private, non-residential capital stock series. The output deflator is obtained as a ratio of nominal to constant price output.

Employment is defined as a sum of self-employed persons and the private sector full-time equivalent employees. As this NIPA employment series is annual, total private non-farm employees of the Bureau of Labor Statistics (Table B-1) was used as a quarterly indictor in constructing the quarterly employment series. Labor income is defined as the product of compensation to employees and labor income of self-employed workers. In evaluating the latter, compensation-per-employee is used as a shadow price of labor of self-employed workers as in Blanchard (1997), Gollin (2002) and Klump et al. (2007).

Real capital income was calculated as a residual of the value of production excluding mark-up and labor income:

$$qK = \frac{Y}{1+\mu} - wN$$

where we assume that mark-up $\mu = 0.10$ in line with several other studies, e.g., Klump et al. (2007).

To create quarterly private non-residential capital stock compatible with both the annual index of constant replacement cost capital stock, Herman (2000), and the accumulated NIPA net investment, we first estimated the base value for the capital stock as a ratio:

$$KB = \frac{\sum_{t=0}^{T} \text{Net Investment}}{KI_T \; - \; KI_0} \tag{42}$$

where KI_T and KI_0 refer to the values of the capital stock index at the end and beginning

[20]These series can be found at http://www.bea.doc.gov/bea/dn/nipaweb/index.asp

of the sample respectively. The quarterly constant price non-residential private capital stock was then calculated by accumulating (de-cumulating) the base level KB from the midpoint of the sample by using the quarterly NIPA series of non-residential private net investment. This procedure ensures that the constructed quarterly capital stock has the same trend as the annual capital stock index.

7 Results

7.1 Frictionless Supply

In the bulk of empirical studies, linear (constant growth), Harrod or Hicks-neutral, technical progress is assumed. A motivation for this practice is the Diamond et al. (1978) impossibility theorem which claims that the substitution elasticity and biased technical change can not be simultaneously identified. However, León-Ledesma et al. (2010a,b) have shown that this is no longer binding, if system approach is used in estimating the parameters of the CES production function.

In addition, recent contributions, as in Acemoglu (2002a, 2003), have highlighted the role of induced (or directed) innovations in shaping the dynamics of income distribution and TFP developments. Steady factor incomes can only be achieved if technical progress is purely labor-augmenting. However, we might also expect transitional periods of capital-augmenting technical progress induced by endogenous changes in the direction of innovations.

Thus, it is not unreasonable to think of non-constant growth rates of technical progress. The question then becomes how can this be tractably implemented. Klump et al. (2007) proposed the use of a more flexible specification for Γ_t^i based on the Box-Cox transformation. In the normalized CES case, this implies that $\Gamma_t^i = e^{g_i}$ where $g_i = \frac{\gamma_i \bar{t}}{\lambda_i}\left(\left[\frac{t}{\bar{t}}\right]^{\lambda_i} - 1\right), i = K, N$. Curvature parameter λ_i determines the shape of technical progress. $\lambda_i = 1$ yields the (textbook) linear specification; $\lambda_i = 0$ a log-linear specification; and $\lambda_i < 0$ a hyperbolic one for technical progress. This provides a useful, though certainly reduced form, way to capture smoothly-evolving technical progress.

Moreover, since there is substantial evidence (e.g., Hansen (2001), Oliner and Sichel (2000), Benati (2007)) of a structural break in US labor productivity (and hence TFP growth) in the early to mid-1990s, we allow a break in factor augmenting technical progress in the early 1990s.[21] This done by re-normalizing t by its 1994:1 value. Given that we allow for a change in both labor and capital-augmenting technical change, our results

[21] We dated the break point by optimizing the system log determinant across quarterly break increments from 1980q1 until the sample end; our detected break point accords very well with those suggested in the literature.

are also informative about the technical bias underpinning the large improvement in US productivity in the mid-1990s.

For completeness, we state the steady-state system (28-28) together with the normalized CES function (1),

$$\log\left(\frac{wN}{Y}\right)=\log\left(\frac{1-\alpha_0}{1+\mu}\right)+\frac{1-\sigma}{\sigma}\log\left(\frac{Y/(\zeta\bar{Y})}{N/\bar{N}}\right) \qquad (43)$$
$$+\frac{\sigma-1}{\sigma}\left[g_N\left(\gamma_N,\lambda_N,\frac{t}{\bar{t}}\right)+DUM\cdot g\left(\gamma_{N1},\lambda_{N1},\frac{t}{t_{94:1}}\right)\right]$$

$$\log\underbrace{\left(\frac{1}{1+\mu}-\frac{wN}{Y}\right)}_{qk}=\log\left(\frac{\alpha_0}{1+\mu}\right)+\frac{1-\sigma}{\sigma}\log\left(\frac{Y/(\zeta\bar{Y})}{K/\bar{K}}\right) \qquad (44)$$
$$+\frac{\sigma-1}{\sigma}\left[g_K\left(\gamma_K,\lambda_K\right)+DUM\cdot g_K\left(\gamma_{K1},\lambda_{K1}\right)\right]$$

$$\log\left(\frac{Y}{\bar{Y}}\right)=\log\zeta+\frac{\sigma}{\sigma-1}\log\left[\begin{array}{r}\alpha_0\left(\frac{K}{\bar{K}}e^{g_K(\gamma_K,\lambda_K)+DUM\cdot g_K(\gamma_{K1},\lambda_{K1})}\right)^{\frac{\sigma-1}{\sigma}}\\+(1-\alpha_0)\left(\frac{N}{\bar{N}}e^{g_N(\gamma_N,\lambda_N)+DUM\cdot g_K(\gamma_{K1},\lambda_{K1})}\right)^{\frac{\sigma-1}{\sigma}}\end{array}\right] \qquad (45)$$

where $DUM=\begin{cases}0, & t\leq 1993:4\\ 1, & \text{Otherwise}\end{cases}$ and where the normalization point is defined in terms of sample averages (geometric averages for growing variables, except for time, t, and arithmetic ones otherwise). The nonlinearity of the CES function implies that the sample average of production need not exactly coincide with the level of production implied by the production function with sample averages of the right hand variables. Following Klump et al. (2007), we introduce an additional parameter ζ whose expected value is around unity. Hence, we can define $Y_0=\zeta\bar{Y},\ K_0=\bar{K},\ N_0=\bar{N}$ and $t_0=\bar{t}$, where the bar refers to the appropriate type of sample average. In estimation, we fix the aggregate mark-up parameter μ to 0.1 and α_0 to 0.1897 (i.e., to the sample average capital factor income share). This is one of the empirical advantages of normalization.[22]

Table 1 shows results for supply-side system (43-45) for both CES and Cobb Douglas. The table reports the substitution elasticity; the technical change parameters; the (fixed point) TFP growth; residual stationarity; and the system metric (the log determi-

[22] In estimation, we use a Generalized Nonlinear Least Squares (GNLLS) estimator which is equivalent to a nonlinear SUR model, allowing for cross-equation error correlation. As shown in the Monte Carlo study of León-Ledesma et al. (2010b), this estimator is able (unlike single-equation estimators) to identify unbiasedly both the substitution elasticity and factor augmenting technical progress parameters. Since non-linear estimation can be sensitive to initial parameter conditions we varied parameters individually and jointly around plausible supports to ensure global results (details available). Standard errors in Table 1 are heteroscedasticity and autocorrelation consistent.

nant). A structural break in the value and pattern of technical change was tested for in both specifications. In the CES case, this break can affect the value of both labor and capital-augmenting technical progress; under Cobb Douglas, we treat technical progress as degenerating to Harrod Neutrality.

An exact method to calculate the log(TFP) contribution to output is to calculate the log ratio of the estimated production function with and without technical change,[23]

$$\log TFP = \frac{\sigma}{\sigma-1}\log\left[\frac{\alpha_0\left(\frac{K_t}{\bar{K}}e^{g_K}\right)^{\frac{\sigma-1}{\sigma}}+(1-\alpha_0)\left(\frac{N_t}{\bar{N}}e^{g_N}\right)^{\frac{\sigma-1}{\sigma}}}{\alpha_0\left(\frac{K_t}{\bar{K}}\right)^{\frac{\sigma-1}{\sigma}}+(1-\alpha_0)\left(\frac{N_t}{\bar{N}}\right)^{\frac{\sigma-1}{\sigma}}}\right] \tag{46}$$

In terms of the system metric, the CES specification dominates as a means to capture potential supply. Its estimate of the substitution elasticity (at 0.55) is consistent with consensus values (e.g., Chirinko (2008)). Both production specifications detect a rise in technical progress. In the Cobb Douglas case this necessarily implies an increase in the labor augmenting technical progress growth rate. Under CES, it is a mild increase in the growth rate of the labor-augmenting component and a decrease in the capital component.

The path of technical progress (and its components) for our preferred CES case are shown in **Figure 3**. This demonstrates the rapid acceleration of technical progress in the early 1990s. Although the composition of this increase is an empirical finding, our findings can be rationalized quite intuitively: capital augmentation, though initially high, falls continuously through the sample, consistent with the "Acemoglu hypothesis", Acemoglu (2002a, 2003). Labor augmenting technical change starts to rise and dominates overall TFP growth. This pattern was stable until the mid-to-late 1990s, when was a widely-observed structural break in TFP growth (led it appears by IT technological improvements and adaptions) and "directed technical change" in favor of labor. This acceleration in TFP growth appeared to take the more standard labor-augmenting form with a corresponding TFP acceleration (e.g., Fernald and Ramnath (2004), Oliner and Sichel (2000))) reflecting that - in the medium run - US labor availability remained a constraining factor for growth, indicated by low, stable unemployment and stable factor income shares suggesting the profitability of capital saving did not increase over time.

[23] An alternative approximation is also obtained by applying Kmenta (1967) approximation of the normalized production function around $\sigma = 1$ that shows how time varying capital intensity affect the weights of capital and labor augmenting components in TFP,

$$\log TFP \approx \alpha_0\left[1+\frac{2\psi}{\alpha_0}k_t\right]g_K+(1-\alpha_0)\left[1-\frac{2\psi}{(1-\alpha_0)}k_t\right]g_N+\psi\left[g_K-g_N\right]^2$$

where $k_t = \log\left(\frac{K_t/\bar{K}}{N_t/\bar{N}}\right)$ and $\psi = \frac{(\sigma-1)\alpha_0(1-\alpha_0)}{2\sigma}$. Both measures yielded very similar results.

7.2 The Marginal Costs Measures: A Graphical Analysis

In both Cobb Douglas and CES cases (see **Figure 4**[24]), real marginal costs (as in (2), (25) and (38)) are stationary with similar business-cycle properties (i.e., both are counter-cyclical). A striking difference is that the CES variant is substantially more volatile than the Cobb-Douglas case. Another - even more striking - difference is that the CES driving variable undergoes a substantial and sustained reduction in volatility from the mid-1980s onwards, consistent with volatility patterns in many US time series (e.g., McConnell and Perez-Quiros (2000)).[25] The Cobb Douglas based measure does not appear to embody such na volatility reduction regime.

Why should this be so? Recalling definition (2) and taking logs, the difference in second moments between our CES ($\widehat{\sigma} = 0.55$) and Cobb-Douglas measures would respectively be (setting aside covariance for convenience),

$$\sigma^2_{mcr} = \begin{cases} \sigma^2_w + 1.8\sigma^2_{n/y} + 1.2\sigma^2_{\Gamma^N} + \begin{cases} \widehat{\varphi^u}\sigma^2_u \\ \widehat{\varphi^h}\sigma^2_h \end{cases} \\ \\ \sigma^2_w + 1.0\sigma^2_{n/y} \qquad\qquad\quad + \begin{cases} \widehat{\varphi^u_{cd}}\sigma^2_u \\ \widehat{\varphi^h_{cd}}\sigma^2_h \end{cases} \end{cases} \tag{47}$$

Thus, the CES fundamental weights the volatility of inverse labor productivity twice as much. Growth in labor productivity also negatively affects real marginal costs, both in a level and growth sense (since Γ^N has reached a higher level with a break in trend). The contribution of effective hours (or overall utilization) is quite similar (see **Figure 5**) across both cases, although the weights will differ.

In our estimated CES case, **Figure 6** shows in the top and bottom panels the individual components of real marginal costs. The conventional real marginal costs is highly volatile (with a break in the early-mid 1980s) and is clearly counter-cyclical. The utilization measure is also very volatile (with a break in the early-mid 1980s) but this time clearly counter-cyclical. For illustrative purposes, we show what the total real marginal cost measure would be $\varphi = 0.5$ and 2. The former (latter) value gives more weight to the counter- (pro-) cyclical component.

[24]Note the common axis ranges for comparability.

[25]This is interesting because a common criticisms of modeling the NK fundamental has precisely been the absence of such a mapping.

7.3 The NKPC

Tables 2 to **5** present estimations for the NKPC and Hybrid NKPC for the case where the driving variable is derived from CES supply (from the final column in Table 1), where the fundamental is conventional then augmented real marginal costs[26]. Results are shown for constrained ($\beta = 0.99$) and unconstrained discounting. For robustness, we estimate using both 2-step GMM and Generalized Empirical Likelihood (GEL) methods. GEL estimation has superior large and finite-sample properties and is more efficient (Anatolyev (2005)). Two-step GMM methods, by contrast, can display poor small-sample properties, e.g., Hansen et al. (1996) and are not invariant to the specification of the moment conditions (i.e., are sensitive to the normalization).[27] The instrument set for the regressions were 3-period lags of inflation, one-period (Hybrid NKPC) and four-period lags (Conventional NKPC) of the hours deviation from normal, 1-2-period lags (Hybrid NKPC) and 1-period lags (Conventional NKPC) of the conventional real marginal cost, 4-period lags of the growth rates of crude oil price, 2-4-period lags of the interest rate spread (defined as the difference of 5-year and 3-month Treasury bond yields) and 3-4-period lags of hourly compensation growth rates.

For the *NKPC* results, when partial real marginal costs drive inflation, relatively high durations are uncovered and relatively small slope coefficients. Durations almost halve (to around 4 periods) when the augmented fundamental is used and slope coefficients essentially double. This is robust across both estimator types (GMM and CUE-GEL). Assuming $\alpha_0 = 0.35$ and $\rho_{\widetilde{\kappa},h} = \{0.8, ..., 1.2\}$, and for $\overline{\varphi^u} \approx 0.95$ and $\overline{\varphi^h} \approx 0.8$, this would however imply wage premium curvature parameters of $a \in [0.07, 0.2]$, $a \in [-0.07, 0.04]$, respectively. These, admittedly, are on the low side.

The *Hybrid NKPC* results have a relatively similar qualitative pattern. When the partial fundamental is used, we find an apparently high share of forward-looking price setting, $\gamma_f \approx 0.8$, but relatively modest (long) slope (duration) estimates. When we controls for the better measure of marginal costs, a more balanced weighting of backward and forward-looking price setting emerges, and duration estimates fall to a value (around 3 quarters) more aligned with micro studies of price re-setting behavior. For $\overline{\varphi^u} \approx 1.5$ and $\overline{\varphi^h} \approx 1.1$, this would imply premium curvature parameters of $a \in [0.58, 0.80]$, $a \in [0.20, 0.36]$, respectively. Such results accord more closely with our priors for these parameters.

[26]We show the NKPC results only for the CES-generated fundamental. This is done because it is the more data-coherent of the two supply sides, and for reasons of space. Results based on a Cobb-Douglas generated driving variable are available.

[27]Of the family of GEL estimators we report the continuously updated estimator method, see Gabriel and Martins (2009) for a valuable discussion.

8 Conclusions

This paper has argued the following:

- Conventional proxies for real marginal costs are flawed. Non-structural output gap measures tend to have the "wrong" sign and using unit labor costs implies a counter-cyclical fundamental.
- Specifying firms' unit labor costs should instead start from a careful modeling of potential output allowing for non-unitary factor substitution and non-neutral technical change.
- A measure of unit labor costs based on CES technology empirically outperforms that of Cobb Douglas, and, importantly, is able to match the volatility reductions witnessed in many real and nominal US time series.
- To disentangle technical progress from factor utilization, we modeled the latter as a factor-augmenting, smoothly-evolving Box-Cox process. This fits the data well and further highlights that technical progress from the mid-1990s onwards took the labor-augmenting form, reflecting an essentially full-employed economy with the growth rate of capital-augmenting technical progress diminishing substantially. This observation was corroborated by our fitting of factor share movements.
- We introduced a definition of "effective labor hours" to capture costs increases from overtime labor as well as the reduced ability of firms to cut labor costs if utilized labor falls below the norm (reflecting labor hoarding).
- Overall, we thus find that failure to account for non-unitary factor substitution, non-neutral technical change, and factor utilization rates in the derivation of the fundamental biases upward the contribution of extrinsic inflation persistence. Our results, by contrast, show a more balanced weighted of expectations, steeper inflation Phillips curve slopes and, accordingly, more plausible estimates of price stickiness.

References

Acemoglu, D. (2002a). Directed technical change. *Review of Economic Studies*, 69:781–809.

Acemoglu, D. (2002b). Technical Change, Inequality and the Labor Market. *Journal of Economic Literature*, 40(1):7–72.

Acemoglu, D. (2009). *Introduction to Modern Economic Growth*. MIT Press.

Anatolyev, S. (2005). Gmm, gel, serial correlation and asymptotic bias. *Econometrica*, 73:983–1002.

Barkume, A. J. (2007). Some New Evidence on Overtime Use, Total Job Compensation, and Wage Rates. Bureau of Labor Statistics Working Paper 402.

Barro, R. J. and Sala-i-Martin, X. (2004). *Economic Growth*. 2nd Edition, MIT Press, Cambridge, MA.

Basu, S., Fernald, J. G., and Kimball, M. S. (2006). Are Technology Improvements Contractionary? *American Economic Review*, 96(5):1418–1448.

Basu, S., Fernald, J. G., and Shapiro, M. D. (2001). Productivity growth in the 1990s: Technology, utilization, or adjustment? *Carnegie-Rochester Series on Public Policy*, 55(1):117–165.

Basu, S. and Kimball, M. S. (1997). Cyclical Productivity with Unobserved Input Variation. NBER Working Papers 5915.

Batini, N. (2009). Euro area inflation persistence. *Empirical Economics*, 31(4):977–1002.

Benati, L. (2007). Drift and breaks in labor productivity. *Journal of Economic Dynamics and Control*, 31:2847–2877. Also, ECB Working Paper No. 718.

Bils, M. (1987). The Cyclical Behavior of Marginal Cost and Price. *American Economic Review*, 77:838–855.

Bils, M. and Cho, J.-O. (1994). Cyclical factor utilization. *Journal of Monetary Economics*, 33:319–354.

Blanchard, O. J. (1997). The Medium Run. *Brookings Papers on Economic Activity*, 2:89–158.

Blanchard, O. J. and Galí, J. (2007). Real Wage Rigidities and the New Keynesian Model. *Journal of Money, Credit and Banking*, 39(1):35–66.

Blanchard, O. J. and Galí, J. (2010). Labor Market Frictions and Monetary Policy: A New Keynesian Model with Unemployment. *American Economic Journal: Macroeconomics*, 2(2):1–30.

Chirinko, R. S. (2008). Sigma: The Long and Short of It. *Journal of Macroeconomics*, 30(2):671–686.

Diamond, P. A., McFadden, D., and Rodriguez, M. (1978). Measurement of the elasticity of substitution and bias of technical change. In Fuss, M. and McFadden, D., editors, *Production Economics, Vol. 2*, pages 125–147. Amsterdam and North Holland.

Fernald, J. G. and Ramnath, S. (2004). The Acceleration in U.S. Total Factor Productivity after 1995: The Role of Information Technology. *Economics Perspectives, Federal Reserve Bank of Chicago*, 1Q:52–67.

Fuhrer, J. C. (1997). The (un)importance of forward-looking behavior in price specifications. *Journal of Money, Credit and Banking*, 29:338–350.

Fuhrer, J. C. (2006). Intrinsic and inherited inflation persistence. *International Journal of Central Banking*, 4(3):49–86.

Fuhrer, J. C. (2010). Inflation Persistence. In Friedman, B. M. and Woodford, M., editors, *Handbook of Monetary Economics*. forthcoming.

Gabriel, V. J. and Martins, L. F. (2009). New Keynesian Phillips Curves and potential identification failures: A Generalized Empirical Likelihood analysis. *Journal of Macroeconomics*, 31(4):561–571.

Galí, J. (2008). *Monetary Policy, Inflation and the Business Cycle*. Princeton University Press.

Galí, J. and Gertler, M. (1999). Inflation Dynamics: A Structural Econometric Analysis. *Journal of Monetary Economics*, 44:195–222.

Hall, R. E. (1998). The relation between price and marginal cost in u.s. industry. *Journal of Political Economy*, 96(5):921–947.

Hansen, B. E. (2001). The new econometrics of structural change: Dating breaks in u.s. labor productivity. *Journal of Economic Perspectives*, 15(4):117–128.

Hansen, L. P., Heaton, J., and Yaron, A. (1996). Finite-sample properties of some alternative gmm estimators. *Journal of Business and Economic Statistics*, 14:262–280.

Hart, R. A. (2004). *The Economics of Overtime Work*. Cambridge University Press.

Herman, S. W. (2000). Fixed assets and consumer durable goods. *Survey of Current Business*.

Jones, C. I. (2003). Growth, Capital Shares, and a New Perspective on Production Functions. Mimeo, University of California Berkeley.

Jones, C. I. (2005). The shape of production functions and the direction of technical change. *Quarterly Journal of Economics*, 120(2):517–549.

Jorgenson, D. W. (2001). Information technology and the U.S. economy. *American Economic Review*, 91:1–32.

King, R. G. and Rebelo, S. T. (2000). Resuscitating real business cycles. Nber working papers, National Bureau of Economic Research, Inc.

Kinoshita, T. (1987). Working Hours and Hedonic Wages in the Market Equilibrium. *Journal of Political Economy*, 95(6):1262–77.

Klump, R. and de La Grandville, O. (2000). Economic growth and the elasticity of substitution: Two theorems and some suggestions. *American Economic Review*, 90:282–291.

Klump, R., McAdam, P., and Willman, A. (2007). Factor Substitution and Factor Augmenting Technical Progress in the US. *Review of Economics and Statistics*, 89(1):183–92.

Klump, R. and Saam, M. (2008). Calibration of normalized CES production functions in dynamic models. *Economics Letters*, 99(2):256–259.

Kmenta, J. (1967). On Estimation of the CES Production Function. *International Economic Review*, 8:180–189.

Kydland, F. (1995). Frontiers of Business Cycle Research. In Cooley, T. F., editor, *Advances in Economics and Econometrics, volume III.* Princeton University Press.

La Grandville, Olivier de. (1989). In Quest of the Slutzky Diamond. *American Economic Review*, 79:468–481.

León-Ledesma, M. A., McAdam, P., and Willman, A. (2010a). Identifying the Elasticity of Substitution with Biased Technical Change. *American Economic Review*, 100(4):1330–1357.

León-Ledesma, M. A., McAdam, P., and Willman, A. (2010b). In Dubio pro CES: Supply Estimation with Mis-Specified Technical Change. Working Paper No. 1175, European Central Bank.

Marquetti, A. A. (2003). Analyzing historical and regional patterns of technical change from a classical-marxian perspective. *Journal of Economic Behavior and Organization*, 52:191–200.

McAdam, P. and Willman, A. (2010). Medium Run Redux. *Macroeconomic Dynamics*, (forthcoming).

McConnell, M. and Perez-Quiros, G. (2000). Output fluctuations in the united states: What has changed since the early 80s? *American Economic Review*, 90(5):1464–1476.

Muns, S. (2009). Growth, Structure and Knowledge economics. Netherlands Bureau for Economic Policy Analysis, mimeo.

Oliner, S. D. and Sichel, D. E. (2000). The Resurgence of Growth in the Late 1990s: Is Information Technology the Story? *Journal of Economic Perspectives*, 14(4):3–22.

Roberts, J. M. (1995). New Keynesian Economics and the Phillips Curve. *Journal of Money, Credit and Banking*, 27(4):975–984.

Röger, W. (1995). Can imperfect competition explain the difference between primal and dual productivity measures? estimates for u.s. manufacturing. *Journal of Political Economy*, 103(2):316–326.

Rogerson, R. (1988). Indivisible labor, lotteries and equilibrium. *Journal of Monetary Economics*, 21:3–16.

Rotemberg, J. J. and Woodford, M. (1999). The Cyclical Behavior of Prices and Costs. In Taylor, J. and Woodford, M., editors, *Handbook of Macroeconomics, vol. 1B.* Elsevier.

Rudd, J. and Whelan, K. (2007). Modeling Inflation Dynamics: A Critical Survey of Recent Research. *Journal of Money Credit and Banking*, 39:155–170.

Shapiro, M. D. (1986). The Dynamic Demand for Capital and Labor. *Quarterly Journal of Economics*, 101:513–542.

Solow, R. M. (1957). Technical change and the aggregate production function. *Review of Economics and Statistics*, 39(3):312–320.

Trejo, S. J. (1991). The Effects of Overtime Pay Regulation on Worker Compensation. *American Economic Review*, 81(2):719–740.

Varian, H. (1974). A Bayesian approach to real estate assessment. In Feinberg, S. E. and Zellner, A., editors, *Studies in Bayesian Economics in Honour of L. J. Savage*, pages 195–208. Amsterdam: North Holland.

Walsh, C. E. (2010). *Monetary Theory and Policy*. MIT Press, 3^{rd} edition.

Woodford, M. (2001a). Interpreting inflation persistence: Comments on the conference on Quantitative Evidence on Price Determination. *Journal of Money, Credit and Banking*, 39(1):203–210. supplement.

Woodford, M. (2001b). The Taylor Rule and Optimal Monetary Policy. *American Economic Review*, 91(2):232–237.

Figure 1: Factor Components

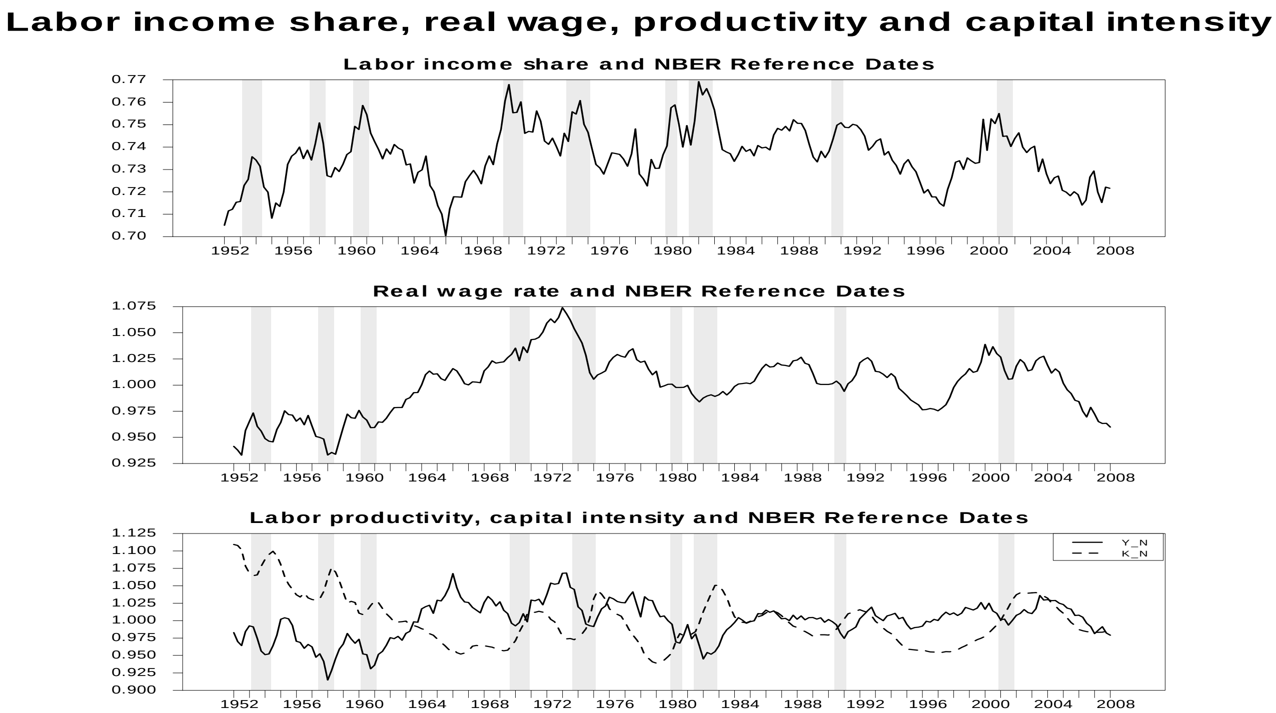

Figure 2: Utilization Rates under Effective Hours

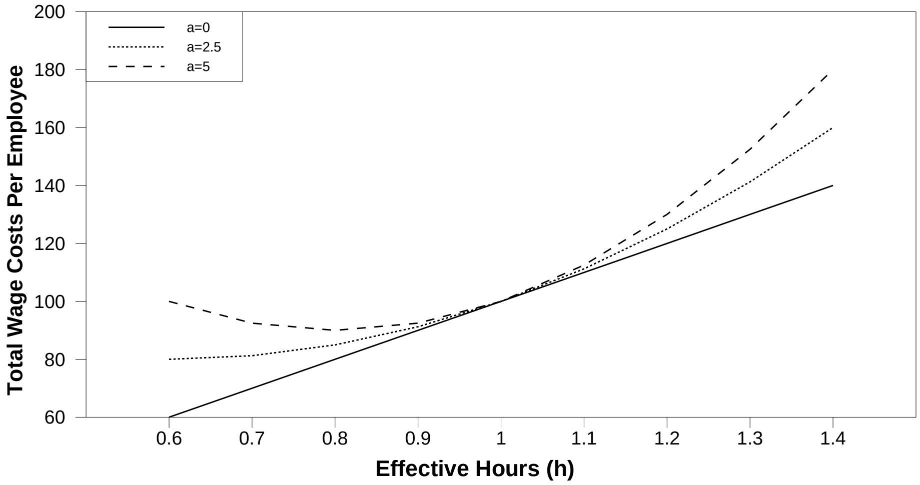

Table 1: Supply-Side Results

	CD	**CES**
ξ	1.035 (0.005)	1.034 (0.002)
γ_N	0.014 (0.001)	0.013 (0.000)
γ_{N1}	0.009 (0.004)	0.016 (0.001)
γ_K	–	0.004 (0.000)
γ_{K1}	–	-0.014 (0.001)
σ	1.000 (–)	0.548 (0.001)
TFP	0.012	0.011
ADF_N	-4.416	-3.919
ADF_K	-4.306	-4.000
ADF_Y	-4.253	-4.153
Log. Det	-26.733	-26.335

Figure 3: TFP Growth

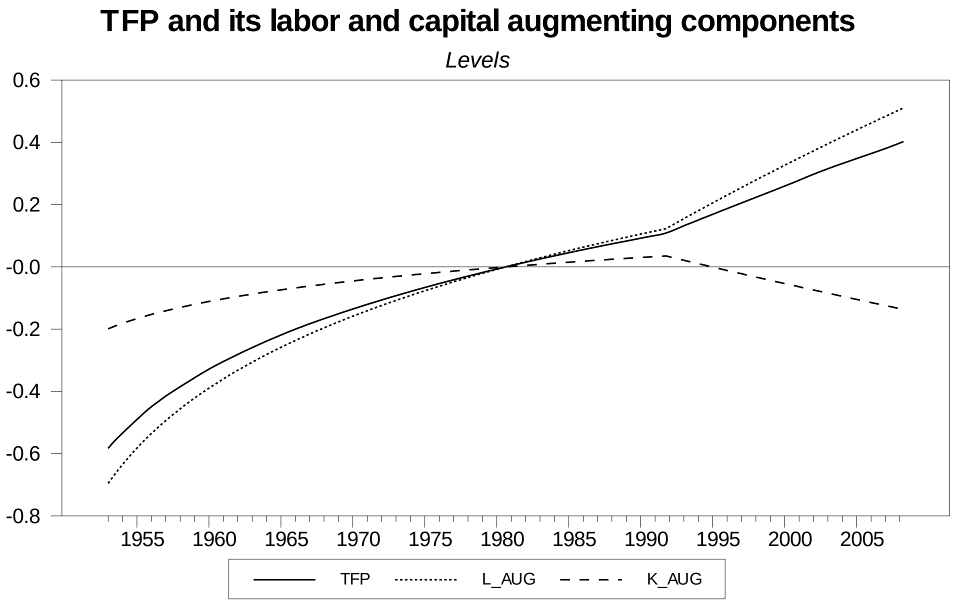

Figure 4: Partial Real Marginal Costs: CES and CD

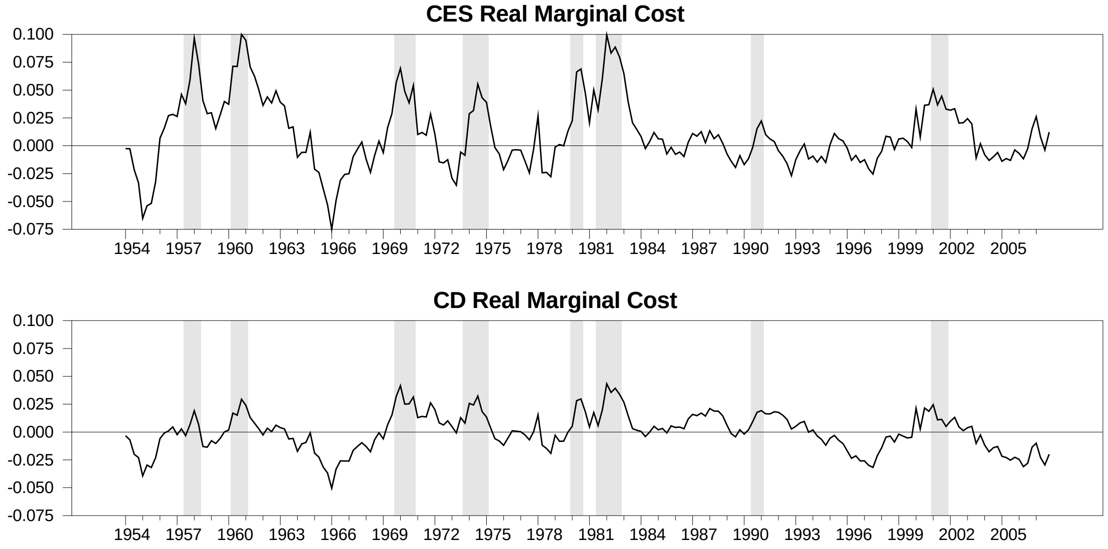

Figure 5: Effective Hours Real Marginal Costs: CES and CD

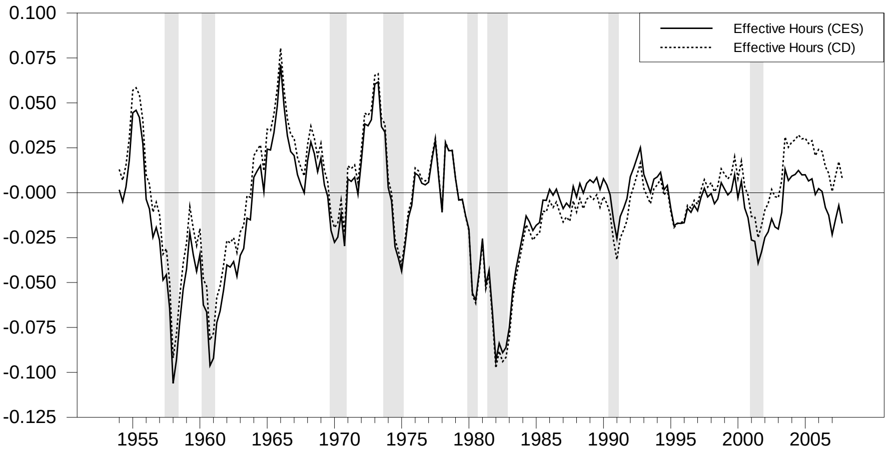

Figure 6: CES Real Marginal Costs and Components

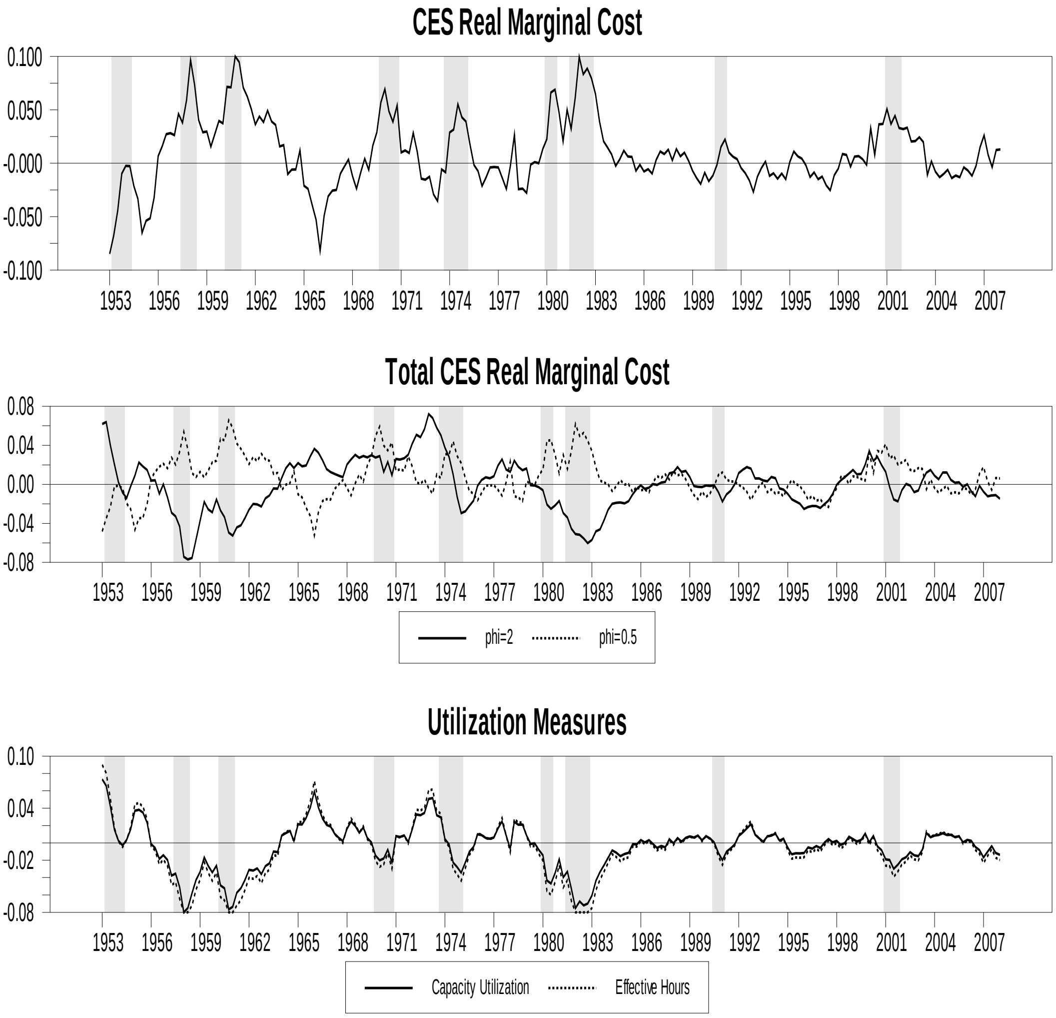

Table 2: NKPC Estimates: Capacity utilization

	GMM				GEL			
θ	0.876 (0.013)	0.875 (0.013)	0.786 (0.047)	0.792 (0.045)	0.887 (0.020)	0.891 (0.021)	0799 (0.053)	0.797 (0.055)
β	0.977 (0.010)	0.990	0.962 (0.020)	0.990	0.966 (0.018)	0.990	0.952 (0.024)	0.990
φ	-		0.956 (0.094)	0.920 (0.033)	-		0.935 (0.247)	1.002 (0.249)
λ	0.020 (0.004)	0.019 (0.004)	0.067 (0.033)	0.057 (0.027)	0.018 (0.007)	0.014 (0.006)	0.060 (0.034)	0.054 (0.032)
D	8.08 (0.86)	8.01 (0.80)	4.67 (0.65)	4.81 (0.55)	8.86 (1.55	9.20 (1.81)	4.97 (0.859)	4.94 (0.943)
J	[0.872]	[0.880]	[0.910]	[0.872]	[0.893]	[0.737]	[0.988]	[0.853]

Notes for all NKPC estimation tables:
Standard errors, with a Newey-West correction, are in parenthesis. Probability-value for the Hansen's J statistic of the over-identifying restrictions are in squared brackets

Table 3: NKPC Estimates: Effective Hours

	GMM				GEL			
θ	0.876 (0.017)	0.875 (0.016)	0.781 (0.054)	0.774 (0.054)	0.887 (0.020)	0.891 (0.021)	0.797 (0.054)	0.779 (0.053)
β	0.977 (0.015)	0.990	0.971 (0.021)	0.990	0.966 (0.018)	0.990	0.963 (0.022)	0.990
φ	-		0.781 (0.164)	0.797 (0.154)	-		0.749 (0.197)	0.833 (0.155)
λ	0.020 (0.006)	0.019 (0.0052)	0.068 (0.024)	0.068 (0.025)	0.020 (0.008)	0.014 (0.006)	0.060 (0.023)	0.065 (0.026)
D	8.085 (1.088)	8.014 (1.052)	4.57 (1.13)	4.42 (1.06)	8.86 (1.55)	9.20 (1.81)	4.92 (1.30)	4.53 (1.09)
J	[0.713]	[0.618]	[0.913]	[0.925]	[0.893]	[0.735]	[0.988]	[0.937]

Table 4: Hybrid NKPC Estimates: Capacity utilization

	GMM				GEL			
θ	0.884 (0.019)	0.882 (0.012)	0.621 (0.086)	0.619 (0.119)	0.890 (0.019)	0.890 (0.020)	0.655 (0.145)	0.612 (0.156)
β	0.979 (0.011)	0.990	0.937 (0.090)	0.990	0.966 (0.018)	0.990	0.931 (0.069)	0.990
ω	0.167 (0.185)	0.207 (0.178)	0.763 (0.035)	0.758 (0.078)	0.079 (0.167)	0.074 (0.177)	0.723 (0.158)	0.767 (0.131)
φ	-		1.508 (0.134)	1.493 (0.184)	-		1.400 (0.250)	1.482 (0.245)
γ_f	0.826 (0.008)	0.803 (0.002)	0.430 (0.037)	0.446 (0.047)	0.890 (0.024)	0.914 (0.021)	0.454 (0.094)	0.441 (0.074)
γ_b	0.159 (0.149)	0.191 (0.133)	0.563 (0.038)	0.553 (0.069)	0.082 (0.159)	0.077 (0.170)	0.537 (0.115)	0.558 (0.082)
λ	0.012 (0.005)	0.011 (0.004)	0.028 (0.012)	0.026 (0.013)	0.015 (0.008)	0.013 (0.007)	0.028 (0.012)	0.026 (0.018)
D	8.63 (0.98)	8.50 (0.89)	2.64 (0.71)	2.62 (0.67)	9.08 (1.57)	9.09 (1.65)	2.90 (0.960)	2.57 (0.899)
J	[0.955]	[0.962]	[0.972]	[0.979]	[0.897]	[0.933]	[0.998]	[0.986]

Table 5: Hybrid NKPC Estimates: Effective Hours

	GMM				GEL			
θ	0.884 (0.018)	0.882 (0.018)	0.672 (0.150)	0.675 (0.139)	0.890 (0.019)	0.890 (0.020)	0.689 (0.142)	0.665 (0.130)
β	0.979 (0.016)	0.990	0.991 (0.066)	0.990	0.966 (0.023)	0.990	0.977 (0.051)	0.990
ω	0.163 (0.197)	0.203 (0.194)	0.694 (0.192)	0.692 (0.185)	0.078 (0.167)	0.069 (0.178)	0.671 (0.188)	0.701 (0.155)
φ	-	-	1.150 (0.231)	1.147 (0.226)	-	-	1.077 (0.229)	1.111 (0.194)
γ_f	0.829 (0.012)	0.806 (0.003)	0.489 (0.051)	0.491 (0.051)	0.891 (0.025)	0.919 (0.069)	0.499 (0.077)	0.484 (0.057)
γ_b	0.156 (0.160)	0.188 (0.145)	0.509 (0.119)	0.508 (0.116)	0.081 (0.159)	0.072 (0.172)	0.498 (0.117)	0.515 (0.081)
λ	0.013 (0.007)	0.0109 (0.006)	0.025 (0.011)	0.025 (0.011)	0.015 (0.008)	0.013 (0.007)	0.025 (0.011)	0.025 (0.011)
D	8.63 (1.342)	8.499 (1.325)	3.05 (1.40)	3.07 (1.31)	9.08 (1.57)	9.09 (1.67)	3.21 (1.46)	2.98 (1.16)
J	[0.938]	[0.887]	[0.959]	[0.981]	[0.987]	[0.933]	[0.997]	[0.995]