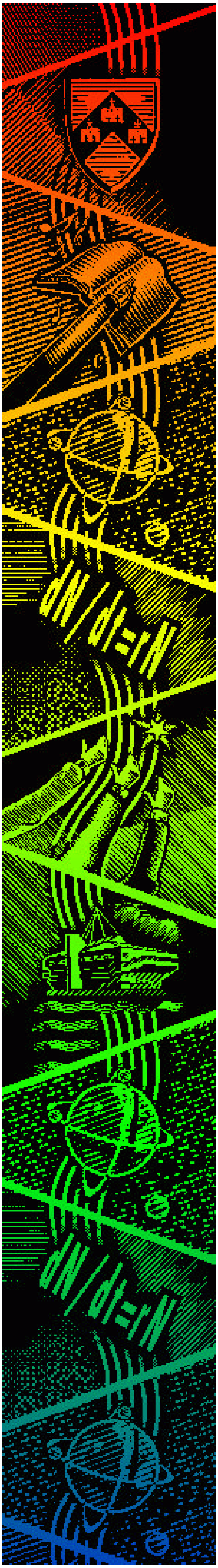

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Sticky Prices, Markups and the Business Cycle: Some Evidence

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Sticky Prices, Markups and the Business Cycle: Some Evidence

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Abstract

In this paper we provide empirical evidence of a positive correlation between the degree of competition and the persistence of the deviation of real output from trend. Under the assumption of imperfect competition and sticky prices we simulate a simple dynamic general equilibrium model to derive the theoretical correlation between competition and persistence. We then use a panel of 24 OECD countries to estimate the correlation between a measure of the markup and a measure of persistence. The markup is measured using the observed unit labour cost. On the basis of our theoretical results, we find it easier to believe that the observed unit labour cost does indeed reflect the size of the markup. Our result is consistent with existing microeconomic evidence on the relationship between competition and price rigidity.

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1 Introduction

Does the unit labour cost affect the persistence of the business cycle? If so, why? The present paper attempts to answer to these two questions theoretically and empirically. Unit labour costs have appeared in a large number of macroeconomic papers, particularly those concerned with the importance of sticky prices (Sbordone, 1998), the Phillips curve (Gali *et al.*, 2001) and monetary policy (Goodfriend and King (2001), and Neiss (2001)). By and large, this literature has used measures of the unit labour cost as a proxy for the real marginal cost, i.e. the inverse of the actual markup of prices over the marginal cost set by monopolistic firms. Yet, this practice is controversial since it requires to impose a constant technology, typically over long periods of time or across countries.[1] In this work we will discuss the problems associated with this interpretation. We will see under which circumstances unit labour costs are likely to be a good proxy for the markup.

In particular we will provide some empirical evidence of a positive correlation between the unit labour cost and persistence of the output gap for a panel of 24 OECD countries. On the basis of some simple models, we will argue that, following the current literature, this evidence points at a positive correlation between the degree of competition and persistence of output deviations from trend. This evidence does not necessarily constitute a puzzle. Since the work of Kimball (1995), it is well known that the degree of competition can reduce the responsiveness of prices to aggregate shock, i.e. competition can increase the "real rigidity" of prices (Ball and Romer (1990) and Romer (1996, ch. 6)). Carlton (1986) provides also some microeconometric support of this claim. He shows indeed that while there is evidence of a positive correlation between concentration of an industry and length of price stickiness (the degree of nominal rigidity), there is also evidence that higher competition implies smaller "jumps" in the prices when prices adjust.

In this paper we will also take the perspective of the current sticky price literature. In the recent years there has been a growing consensus, among researchers, about the importance on nominal rigidities as a propagation mechanism for the business cycle.[2]

Underneath sticky price models lies generally the assumption of imperfect competition. That is, while firms are assumed to have price setting power, part or all of them do not exercise this power efficiently and promptly in response to shocks. While the assumption of imperfect competition in sticky price models was originally imposed mainly for theoretical rigour, recent re-

[1] See Roberts (2001) for a criticism of this practice.

[2] See for example Goodfriend and King (1997).

search has shown that the degree of competition can have important dynamic implications.[3] Here we discuss this role in a simple general equilibrium model with sticky prices. Furthermore, our empirical evidence shows that this role is supported by the data, to the extent that our measure of the markup is correct.

In the logic of the impulse-propagation nature of the business cycle one can see differences in the international fluctuations as due to two causes. On one side the business cycle of two countries could differ because of idiosyncratic shocks: i.e. different impulses. On the other side two economies could respond in different ways to similar shocks: i.e. different propagation mechanism. In this paper we concentrate our attention on the second source of diversity. In particular, we explore the possibility that the degree of competition can affect the propagation mechanism of the business cycle.

We have in mind two fundamental ways in which competition and persistence can be linked. First of all, it is natural to think of a relationship between the degree of competition and the degree of nominal rigidity. From the point of view of state contingent price setting rules, e.g. the so called "menu-cost" models, a higher markup makes the profit function flatter. Other things equal, failing to adjust the price induces smaller losses the flatter is the profit function. For a given cost of adjusting the price, the higher the markup, the less likely the firm will adjust after a shock. On the other side, various authors have pointed out that for a given degree of nominal rigidity, the actual degree of price level inertia (and hence output persistence) depends on the sensitivity of the efficient price to aggregate shocks: the above mentioned degree of real rigidity (Romer, 1996).

In our sample of 24 OECD countries there are strong signs of a *positive* correlation between the unit labour cost and a measure of persistence. From the viewpoint of sticky price models, this result cannot be easily rationalised in terms of the markup-nominal rigidity channel mentioned above. Yet, as we will argue below, even a simple model with a "text-book" upward sloping marginal cost curve would predict exactly this result.

Our findings can have important policy implications. To the extent that deviations of output from its long run trend are inefficient, our results shows that the inefficiency of a higher markup, due to suboptimal level of output in equilibrium, is partially offset by shorter deviations of output form trend. When prices are sticky, very risk-averse agents might be worst off with higher competition.

The rest of the paper is organised as follows. In section 2 we present

[3] See Goodfriend and King (2001), Aloi and Dixon (2001) and Coto and Dixon (1999). The second two articles discuss this point in models with flexible prices without money.

a simple model displaying a negative relationship between the markup and persistence. Section 3 describes the data-set and the empirical methodology. Section 4 reports our empirical results. Finally, section 5 concludes.

2 The theory

In this section we solve a simple closed-economy general equilibrium model with Calvo (1983) price contracts. The purpose of this exercise is to show which factors, under simple assumptions, determine the relationship between the unit labour cost and persistence.

For the sake of our argument we start off by showing some simple algebra borrowed from Kimball (1995). Kimball shows that the degree of real rigidity could be decreasing in the markup. Assuming that firms operates in monopolistically competitive markets, the demand faced by firm i can be described as follows

$$y_i = \left(\frac{p_i^*}{P}\right)^{-\varepsilon} Y \tag{1}$$

where y_i is the demand for good i, p_i^* is its price, P is the aggregate price level, Y stands for total real expenditures and ε is the elasticity of demand.

On the other side, each profit maximizing firm can be thought of as setting its efficient price as a markup over marginal cost, i.e.

$$\frac{p_i^*}{P} = \mu\, \phi\left(y_i, Y\right) \tag{2}$$

where p_i^* is the efficient price, μ is the markup and ϕ is the real marginal cost. For the sake of simplicity, we assume here that the markup is constant and equal to $\frac{\varepsilon}{\varepsilon-1}$. Also we assume that the marginal cost depends only on the aggregate level of output and on the firm's own output.

If we take the log-deviation of equation (1) and (2) around their symmetric equilibrium (i.e. where $p_i^* = P$) and we solve for the equilibrium price we obtain

$$\hat{p}_i^* - \hat{P} = \frac{\Omega}{1 + \varepsilon \frac{\phi_y}{\phi} y_{ss}} \hat{Y} \tag{3}$$

where $\Omega = \frac{\phi_y}{\phi} y_{ss} + \frac{\phi Y}{\phi} Y_{ss}$ is the total elasticity of the marginal cost, $\hat{}$ denotes log-deviations, ss denotes values at their symmetric equilibrium and where we have assumed that the steady state is constant.

The smaller is the coefficient on output in equation (3) the smaller is the sensitivity of the relative efficient price to changes in aggregate demand: i.e. the larger is the *real rigidity* of prices. Under our assumptions the markup affects the degree of real rigidity in a way that depends on the elasticity of the marginal cost with respect to the firm's own output.[4] A textbook upward sloping marginal cost curve would imply a negative relationship between the markup and the degree of real rigidity.[5]

As for the other factors that determine the degree of real rigidity in equation (3), both the marginal cost elasticity with respect to the firm's own output and the elasticity the marginal cost with respect to aggregate output play a very important role.

In particular the real rigidity decreases in the microeconomic part of the marginal cost elasticity when the macroeconomic elasticity is "big enough". To see this let us assume that the macroeconomic elasticity is constant, i.e.

$$\frac{\phi_Y}{\phi}Y = x \tag{4}$$

That is, one component of this elasticity is independent of the microeconomic part. Replacing this in the coefficient of equation (3) and taking the derivative of it with respect to $\frac{\phi_y}{\phi}y$ gives

$$\frac{1-\varepsilon x}{\left(1+\varepsilon\frac{\phi_y}{\phi}y\right)^2} \tag{5}$$

which is positive if[6]

$$x < \frac{1}{\varepsilon} \tag{6}$$

That is, the degree of real rigidity decreases in the microeconomic elasticity of the marginal cost for sufficiently small values of the macroeconomic elasticity. In other words, the firm's marginal revenue must fall with output, by

[4]Kimball (1995) allows for the possibility of a variable markup. Various factors could bring about a variable markup. Most of these factors are discussed in Romer (1996, ch. 6). Lombardo (2001) shows that with intermediate goods in production the steady state markup can affect the degree of real rigidity also with a marginal cost independent of the firm's output. Models with intermediate goods in production (as in Barro and Tenreyro (2000)) tend to generate a positive relationship between the markup and the degree of real rigidity, in contrast with the evidence proposed here.

[5]Note that μ is high when ε is low.

[6]It is likely that the firm's marginal cost curve slope is reflected in the aggregate elasticity of the marginal curve. If we assume, for example, that $\frac{\phi_Y}{\phi}Y = x + \theta\frac{\phi_y}{\phi}y$, condition (6) becomes $\frac{x}{(1+\theta)} < \frac{1}{\varepsilon}$, where θ is a constant.

more than its marginal cost curve shifts. Hence we would expect that an upward sloping marginal cost curve induces less persistence, if the marginal cost schedule does not shift too much upon an aggregate shock. This is what would amount to a "flat" aggregate marginal cost curve. Various factors can "flatten" the aggregate marginal cost curve. Basu (1995), Bergin and Feenstra (2000) and Lombardo (2001), among others have shown that intermediate goods in production can have this effect. A very flexible factors of production supply would also contribute in this direction. Sticky wages would also flatten the aggregate marginal cost curve.[7] Lower competition in the goods market will also make condition (6) easier to hold. In the following section we will address this issues in a simulated dynamic general equilibrium model.

A higher degree of real rigidity does not necessarily imply that prices are more sticky. In particular one can think of reasons why the degree of competition affects the length of nominal price contracts. Carlton (1986) provides some microeconometric evidence in this regard. Basic microeconomic theory, for example, suggests that the higher is the markup the flatter is the profit function, and hence the smaller are the efficiency losses associated with setting the wrong price, i.e. not adjusting the price (Romer, 1996, ch.6).

We can therefore think of two channels relating the markup (degree of imperfect competition) and the persistence. We refer to the first as the real rigidity channel: This can likely give rise to a negative relationship between the markup and persistence. The second is the nominal rigidity channel: In this case it is likely that higher competition yields higher flexibility and hence lower persistence. As mentioned in the introduction, Carlton (1986) finds also that there is a positive correlation between the length of (nominal) price rigidity and the size of adjustment when prices are updated (real rigidity). This finding is thus consistent with our story.

2.1 The model

The simple algebra used in the previous section does not reveal what are the general equilibrium implications of different degree of competition and different technologies for persistence. For this reason in this section we solve a general equilibrium model with monopolistic competition and sticky prices. For simplicity, we assume that there is perfect foresight except for a single unexpected shock (to the money stock or to technology). Similar results would be obtained in a fully stochastic model.

[7] As we show in the appendix, degree of competition in the labour market and wage stickiness are not necessarily negatively correlated.

Households We assume that there is an infinite number of households, indexed on the continuous unitary segment, living in a closed economy. These households are all identical.

Each household solves the following problem

$$\max_{C,\frac{M}{P},l} \sum_{s=t}^{\infty} \beta^{t-s} \left[\frac{C_s^{1-\sigma}}{1-\sigma} + \frac{1}{1-\phi} \left(\frac{M_s}{P_s} \right)^{1-\phi} - \frac{\zeta}{1+\zeta} l_s^{\frac{1+\zeta}{\zeta}} \right] \tag{7}$$

subject to the budget constraint

$$P_s C_s + M_s + B_{s+1} = (1+i_s) B_s + M_{s-1} + w_s l_s + \Pi_s + T_s \tag{8}$$

where C is an aggregate of an infinite variety of differentiated goods, i.e.

$$C_j = \left\{ \int_0^1 c_j^{\frac{\varepsilon-1}{\varepsilon}} dj \right\}^{\frac{\varepsilon}{\varepsilon-1}} \tag{9}$$

with c_j denoting the demand for variety j; M denotes the stock of money, l denotes the labour supply, w denotes the nominal wage, i is the nominal interest rate and B is a nominal bond with zero aggregate supply. Since households own firms they receive profits, which we denote by Π. P is the consumption based price index defined further below. The remaining symbols represent preference parameters.

The first order conditions of the household problem are

$$C_{t+1} = \left[\beta (1+i_{t+1}) \frac{P_t}{P_{t+1}} \right]^{\frac{1}{\sigma}} C_t \tag{10}$$

$$\frac{M_t}{P_t} = C^{\sigma\phi} \left(\frac{1+i_{t+1}}{i_{t+1}} \right)^{\phi} \tag{11}$$

$$l_t = \left(\frac{w_t}{P_t} \right)^{\zeta} C^{-\zeta\sigma} \tag{12}$$

Firms We assume that there is an infinite number of firms also indexed on the continuous unitary segment.

Each firm faces the same technology, i.e.

$$y_{j,t} = z_t l_{j,t}^{1-\alpha} - F \tag{13}$$

where y is firm j's output, z is a common productivity shock, l is the labour input, $(1-\alpha)>0$, and F is a overhead cost of production.

This production function, in one factor only, eliminates the possibility that different degree of persistence derive from a different mix of factors. This fact is well documented in the literature on persistence and intermediate goods of production (e.g. Bergin and Feenstra, 2000). If one country, or in one period of time, the economy switches to technologies that employ factors with more sticky prices, the overall persistence of the output gap is enhanced. While we find this source of diversity in persistence very important, we abstract from it for the sake of simplicity.

The introduction of overhead costs yields varying returns to scale so that we can study two different sources of increasing to scale: overhead costs and "returns to labour". This is indeed the type of production function that allows for a textbook U shaped marginal cost curve. We assume that the cost of production is proportional to the steady state (ss) level of output, i.e. $F=(\kappa-1)\,y_{ss}$, where $\kappa\in\left(1,\frac{\mu}{(1-\alpha)}\right)$.[8] In the special case where $\kappa=\frac{\mu}{(1-\alpha)}$, average revenue and average cost are equal in the steady state, so that there are no "pure profits".

Following Calvo (1983) we assume that each firm adjusts its price only at random periods. In particular we assume that $(1-\omega)$ is the probability that in any particular period a firm adjusts its price, where ω is a positive constant smaller than one.

When a typical firm sets its price, there is a chance that the new price will be in force in subsequent periods. That chance being given by the probability ω. Therefore the firm solves the following problem

$$\max_{p_i}\sum_{s=t}^{\infty}\omega^{s-t}\frac{R_{s,t}}{P_s}\Pi_{j,s} \tag{14}$$

where $R_{s,t}=\frac{1}{1+r_t}\frac{1}{1+r_{t+1}}...\frac{1}{1+r_{t+s}}$ for $s\neq t$ and $R_{s,t}=1$ for $s=t$, and where $(1+r_{t+1})=(1+i_{t+1})\frac{P_t}{P_{t+1}}$, is the gross real interest rate.

The solution to this problem, is

$$p_{j,t}=\frac{\sum\limits_{s=t}^{\infty}\omega^{s-t}\frac{R_{s,t}}{P_s}\mu(1-\varepsilon)\ \left(\phi_{j,s}P_s\right)_{j,s}\ y_{j,s}}{\sum\limits_{s=t}^{\infty}\omega^{s-t}\frac{R_{s,t}}{P_s}y_{j,s}\left(1-\varepsilon\right)} \tag{15}$$

[8] The upper bound derives from the assumption of non-negative profits in the steady state. Notice that κ within this range always satisfies the firm Second Order Conditions, namely $\frac{\alpha}{(1-\alpha)\kappa}\frac{\mu}{\mu-1}+1>0$.

The aggregate price of home produced goods takes the following form

$$P_{h,t} = (1-\omega)\sum_{s=0}^{\infty}\omega^s p_{t-s} \tag{16}$$

That is, the aggregate price is the weighted average of all prices set in the past and that still exist.

Each firm must accommodate all the demand for its goods at the set price. The demand function for good i can be derived from the CES aggregator (9), i.e.

$$\hat{y}_j = \hat{c}_j = \varepsilon\left(\hat{P}_t - \hat{p}_{j,t}\right) + \hat{C}_t \tag{17}$$

Given our production function (equation (13)), the log-linearised real marginal cost faced by those firms setting the price in period t is

$$\left.\widehat{\phi}_t\right|_{p_t} = \hat{w}_t - \frac{1}{1-\alpha}\hat{z}_t + \frac{\alpha}{(1-\alpha)\,\kappa}\left.y_t\right|_{p_t} \tag{18}$$

This implies that

$$\left.\widehat{\phi}_{t+1}\right|_{p_t} = \left.\widehat{\phi}_{t+1}\right|_{p_{t+1}} + \frac{\alpha}{(1-\alpha)\,\kappa}\left(\left.y_{t+1}\right|_{p_t} - \left.y_{t+1}\right|_{p_{t+1}}\right) \tag{19}$$

We can then linearise equation (15) around the steady state making use of equation (19) and equation (17), i.e.

$$\hat{p}_{t+1} = \frac{\left(1+\frac{\alpha\varepsilon\omega\beta}{(1-\alpha)\kappa}\right)}{\omega\beta\left(1+\frac{\alpha\varepsilon}{(1-\alpha)\kappa}\right)}\hat{p}_t - \frac{(1-\omega\beta)}{\omega\beta\left(1+\frac{\alpha\varepsilon}{(1-\alpha)\kappa}\right)}\left(\left.\widehat{\phi}_t\right|_{p_t} + \hat{P}_t\right) \tag{20}$$

Similarly we can linearise equation (16) obtaining

$$\hat{P}_t = \omega\hat{P}_{t-1} + (1-\omega)\,\hat{p}_t \tag{21}$$

Money and technology We assume that the monetary authority transfers all the monetary innovations to the households, i.e.

$$M_t - M_{t-1} = T_t \tag{22}$$

We assume also that when such an innovation takes place, it is unforeseen by the agents and is permanent.

As for the technology shock, we will assume that it is unforeseen and temporary.

Equilibrium An equilibrium in our model is given by a path for the variables described above that satisfies the household first order condition, the firm first order condition, the monetary authority budget constraint and such that the economy stays bounded over time.

2.1.1 Numerical results

The aim of this numerical exercise is to give a quantitative example of the relationship between the components of the unit labour cost and the degree of persistence of the output deviation from the steady state under simple assumptions.

The unit labour cost is related in an important way with key parameters of our model. Consider the steady state marginal cost function implied by equation (13), i.e.[9]

$$\phi_{i,ss} = \frac{w_{ss} l_{i,ss}}{(1-\alpha) P_{ss} (y_{i,ss} + F)} \Rightarrow \frac{w_{ss} l_{i,ss}}{P_{ss} y_{i,ss}} = \frac{(1-\alpha)\kappa}{\mu} \tag{23}$$

where $F = (\kappa - 1) y_{ss}$, and where the second relationship makes use of the fact that firms set prices as markups over marginal costs. This equations show that the unit labour cost decreases in the profit margin, that is the gap between the markup μ, and the returns to scale parameter κ and $(1-\alpha)$. In this section we will characterise the relationship between persistence and these components of the unit labour cost.

The numbers given to our parameters are taken from the ballpark of numbers that can be found in any dynamic general equilibrium model. The crucial parameter in this exercise is $(1-\alpha)$, which for simplicity we refer to as the return to labour. As evident from equation (3) the sign of the relationship between the degree of real rigidity and the markup depends on the return to labour. This relationship is instead invariant with respect to κ.

Numerical simulation of our simple model confirms this fact. In particular it shows that there is a positive relationship between the markup and persistence (real rigidity) with increasing returns to labour $((1-\alpha) > 1)$, while this relationship turns negative with decreasing returns to labour $((1-\alpha) < 1)$. There is no relationship when $(1-\alpha) = 0$, that is when there would be constant returns to scale absent overhead costs.

This general equilibrium model confirms our earlier statement that the relationship between persistence and the degree of return to labour depends on the response of marginal costs to aggregate shocks. In our simple model, the latter depends only on the total elasticity of labour supply, i.e. the

[9] We assume stationary productivity shocks.

intertemporal elasticity of substitution, $\frac{1}{\sigma}$ and the elasticity parameter ζ. A very flexible labour supply implies a very flat aggregate marginal cost curve. This in turn brings about a positive relationship between the returns to labour and persistence as table (1) reveals.

The following numbers are used in the exercise: $\phi = 9$, $\beta = 0.96$, $\zeta = 0.5$, $\sigma = 2$ $\omega = 0.5$.

Persistence is measured by the highest, "stable" but not unitary, eigenvalue associated with our linearised dynamic model.[10] This measure of persistence refers therefore to the transition path only.

Table (1) gives a first example of the relationship between our parameters of interest and persistence. The entries of the table are the measure of persistence for different values of the markup, returns to labour and overhead costs.

	$\mu = 1.25$	$\mu = 1.05$	$\mu = 1.25$
No overhead costs	$(\kappa = 1)$: $\zeta = 0.5$, $\sigma = 2$		$(\kappa = 1)$: $\zeta = 2 \cdot 10^6$, $\sigma = 0.05$
$(1-\alpha) = 0.3$	0.6371	0.7772	0.2239
$(1-\alpha) = 0.8$	0.4973	0.6357	0.2731
$(1-\alpha) = 1.01$	0.3843	0.3572	0.4541
$(1-\alpha) = 1.05$	0.3527	0.0514	0.7777
Overhead costs	$(\kappa = \mu)$: $\zeta = 0.5$, $\sigma = 2$		$(\kappa = \mu)$: $\zeta = 2 \cdot 10^6$, $\sigma = 0.05$
$(1-\alpha) = 0.3$	0.6294	0.7758	0.2259
$(1-\alpha) = 0.8$	0.4889	0.6322	0.2828
$(1-\alpha) = 1.01$	0.3923	0.3607	0.4481
$(1-\alpha) = 1.05$	0.3681	0.0939	0.6090

Table 1: Numerical examples

Column 2 and 3 of table (1) show that persistence decreases in the markup when there are decreasing returns to labour, with or without overhead costs. They also show that there is a monotonic relationship between returns to labour and persistence. This is true also when there is an extremely flexible labour supply, as the last column shows, although the sign of the relationship is reversed. In the latter case we cannot compare persistence with different markups since reducing the markup would require a even flatter aggregate marginal cost curve to preserve the positive relationship between returns

[10] In the case of technology shocks we exclude obviously the eigenvalue associated with the shock process.

and persistence. This per se would affect persistence making the comparison meaningless.

To better see the effect of the markup on persistence consider the case where there aren't overhead costs, $(1-\alpha)=0.8$ and $\mu=1.25$. In this case the "half life" of the real effects of the shock is slightly less 12 months, whereas with $\mu=1.05$ the "half life" increases to slightly more than 18 months. Figures (1) shows this particular case, while figure (2) shows persistence with increasing returns to labour. In both cases we have assumed $\kappa=1$.

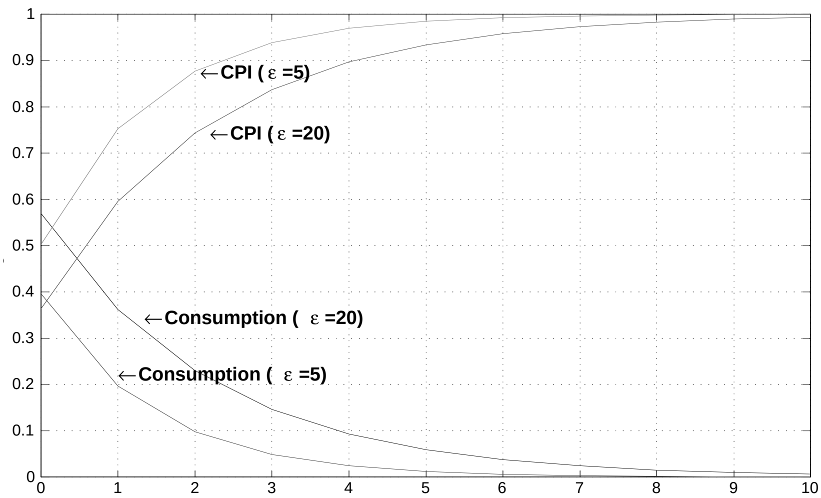

Figure 1: Persistence with $(1-\alpha)=0.8$

Table (1) shows also the effect of increasing returns under two different total elasticities of labour supply.[11] The size of κ does not alter the relationship between persistence and both, the markup and $(1-\alpha)$. Finally persistence increases in κ when $(1-\alpha)>1$ and decreases otherwise.

In this model, the structural persistence, i.e. not belonging to the underlying shock process, is independent of the source of the shock (money or technology). Nevertheless the response of the economy to a technology shock is different from the response of the economy to a nominal shock under other respects, as figure (3) shows. This graph is obtained under a temporary technology shock of the form $\{\hat{z}_{t+1}=0.5\,\hat{z}_t+\nu_{t+1}:\nu_0=1\}$ and no monetary shock.

[11] We found that with $\mu=1.25$, at about $\zeta=5\cdot10^8$ and $\sigma=0.2$ persistence was not affected by the returns to labour. We can therefore conjecture that in a narrow interval of these values the shift in the aggregate marginal cost curve is identical to the elasticity of the marginal revenue. Smaller values for the markup would make it more difficult to generate a positive correlation between the returns to labour and persistence.

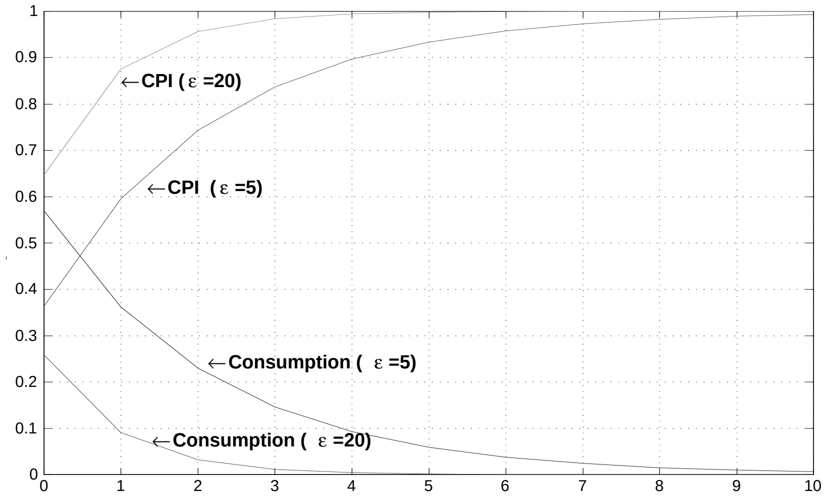

Figure 2: Persistence with $(1-\alpha) = 1.05$

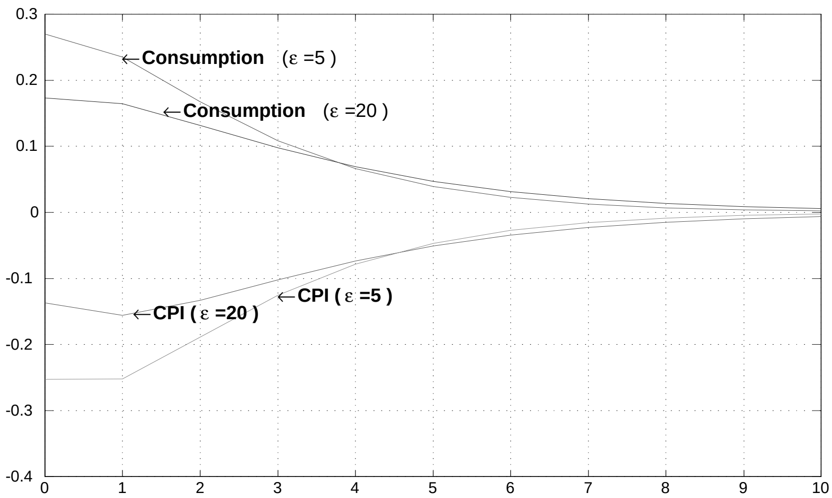

Figure 3: Effects of a transitory productivity shock.

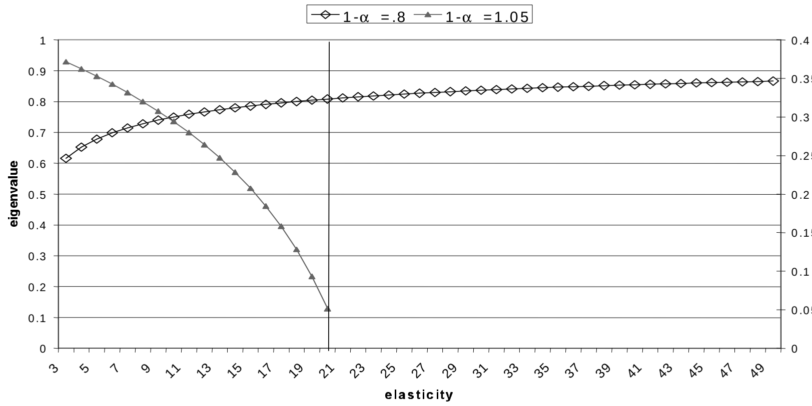

Figure 4: Persistence and demand elasticity at increasing and decreasing returns to scale.

Since an analytical characterization of the response of persistence to the three parameters at hand would be too cumbersome, we carried out some sensitivity analysis. Figure (4) shows the response of persistence for varying values of the elasticity at increasing and decreasing returns to labour and $\kappa = 1$.[12] The vertical line in the graph represents the limit $\varepsilon = \frac{1-\alpha}{\alpha}$, which derives from the second order conditions of profit maximization.

Figure (5) shows the response of persistence to various values of κ

Finally figure (6) describes the relationship between the returns to labour parameter $(1-\alpha)$ and persistence. This graph shows that persistence is a monotonic function of the returns to labour. The first derivative of persistence with respect to returns to labour depends on the elasticity of the marginal cost with respect to aggregate output. The upper limit of the increasing function is a "singularity point" where the equilibrium becomes *indeterminate*. In this simple model, indeterminacy can be easily produced by making the aggregate marginal cost curve sufficiently flat. This point has been recently stressed by Farmer (2000) who discusses the relationship between the real rigidity of sticky price models and indeterminacy. To the extent that more complex models (e.g. with capital) make indeterminacy more difficult to be obtained, a large positive first derivative of the persistence function with respect to the returns to labour will be also more exceptional.

We conjecture therefore that variations in returns to factors across coun-

[12]Increasing κ did not change the result qualitatively.

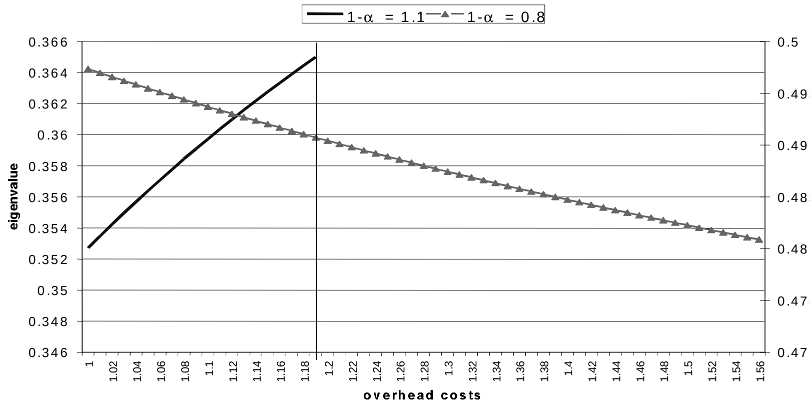

Figure 5: Varying size of overhead costs and persistence

tries would not be the major source of variations in the unit labour cost.

3 The data and the methodology

In this section we carry out a cross-country empirical investigation of the markup-persistence relationship. This study is based on observations for 24 countries drawn from the OECD (Economic Outlook) data-set over the period 1960-1999.[13]

The empirical investigation of the relationship between the markup and the persistence of aggregate output deviations is paved with difficulties. In particular, as we have seen, we must define empirical measures of the desired markup and of the degree of persistence of output.

A vast literature discusses the problems associated with measuring the markup.[14] Equation (2) tells us that the desired markup is identical to the inverse of the real marginal cost, under flexible prices. The fact that prices are not flexible implies that the actual markup may differ from the desired markup at any point in time. Nevertheless we expect that on average the actual markup and the average markup coincide. Therefore, we calculate the

[13] Further details below. The countries are: : Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Japan, Iceland, Ireland, Italy, Mexico, Netherlands, New Zealand, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, United Kingdom and United States

[14] See for example Carlton (1986) and Rotemberg and Woodford (1999).

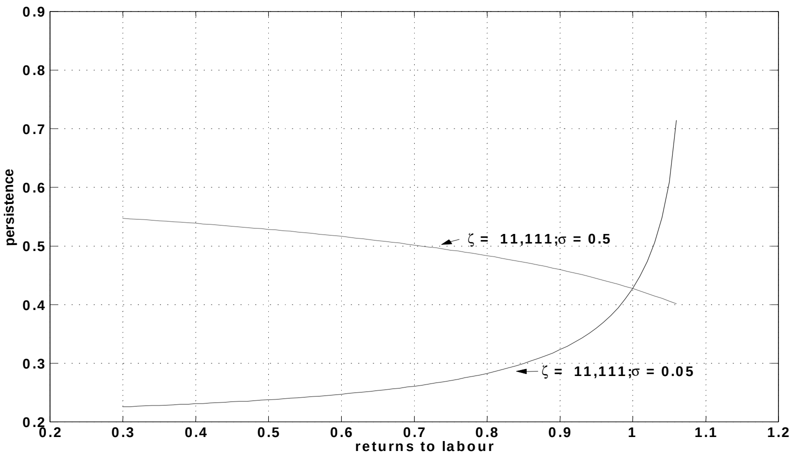

Figure 6: Persistence, returns to labour and macroeconomic elasticity of costs under $\mu = 1.25$.

desired markup as the average over about 40 years of a measure of the actual markup. Rotemberg and Woodford (1999) suggest that the correct measure of the markup should be net of indirect taxes. Therefore we present results using both, the gross of indirect tax markup as well as the net of tax markup. Figure (7) shows the two measures for the 24 countries.

The actual markup, and hence the real marginal cost, are not observable. Here we follow the literature and measure the real marginal cost using the unit labour cost.[15]

By interpreting the (inverse) labour share as the markup, the literature typically imposes a constant return to factors as well as a constat distribution of net of profits income among factors. If these assumptions where incorrect, then typical measures of the real marginal cost and of the markup would be wrong. In particular different unit costs across countries could indicate a different markup as well as different degrees of returns to scale.[16]

To take a stand in the interpretation of the unit labour cost we relay on two assumptions. One is that similar shares of net of profit income accrue to factors of production across countries. The second assumption is that either the reutrns to scale do not vary significantly across countries or that aggregate costs increase sufficiently during expansions. In either case the

[15]See Galí, Gertler (1999), Galí, Gertler and López-Salido (2001), Sbordone (1998), Rotemberg and Woodford (1999), Neiss (2001), among others.

[16]This would be the only possible interpretation if $\mu = \kappa$.

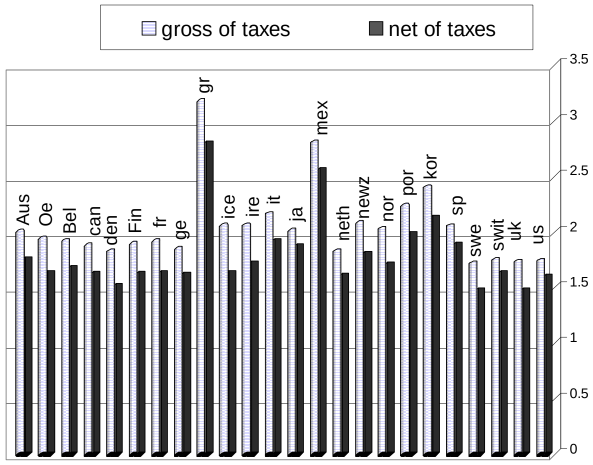

Figure 7: The markup in the 24 OECD countries.

returns to scale would not explain our evidence.

Consequently and in light of our empirical evidence of a positive relationship between unit costs and persistence, interpreting the unit labour cost in terms of $(1-\alpha)$ only, would be in contrast with our theoretical results. This because a higher $(1-\alpha)$ implies lower persistence. It is therefore tempting to interpret the unit labour cost as the (inverse of) pure profits: that is the markup adjusted for returns to scale, which size depends on the degree of competition.

Notice in particular that if aggregate costs are sufficiently increasing during expansions, we do not need to impose a constant return to labour across countries. Say, for example, that we observe a unit labour cost higher in country A, than in country B. This could be due to a higher return to labour in country A than in country B. Ceteris paribus, this would imply a lower persistence in country A, contrary to our evidence. To be consistent with our evidence, this example requires that pure profits in country A are sufficiently smaller than those in country B to offset the gap in technology and produce the observed persistence. If the returns to labour were instead smaller in country A vis-à-vis country B, consistently with the higher persistence, the size of pure profits should be sufficiently smaller in country A to reflect the gap in unit labour cost. This would tell us that more competitive economies have a more persistent business cycle, although the major contributor to this it technology. Notice moreover that the latter example would apply also to an economy with increasing returns to labour. A further requirement here would be that the gap in pure profits necessary to bring about the observed difference in unit labour cost is not such to be in contrast with the observed persistence.[17]

The assumption of decreasing returns to labour would clearly help the interpretation of our evidence. This restriction is indeed not very strong, since it still allows for increasing returns to scale via the overhead cost of production. In this case the marginal cost curve would assume the "U-shape" of undergraduate textbooks. Furthermore, overhead cost are also a plausible rationale for imperfect competition since they constitute barriers to entry.

If we read our results in terms of the real rigidity channel, the interpretation of the labour share as representing mainly the markup is consistent with the finding of Carlton (1986). As mentioned above, Carlton provides microeconometric evidence of a positive relationship between concentration and size of price adjustments. Our evidence suggests that a higher labour share (lower adjusted markup) is associated with higher persistence. Hence, our story would be consistent with the idea that the size of the adjustments is inversely related with the markup (real rigidity channel). In this light, our results suggest that the real rigidity channel is the dominating factor through which the markup affects persistence.

A second problem in our empirical investigation derives from the difficulty of measuring persistence in the output deviation from trend. Besides the well known problems in defining the appropriate trend of a series, there is some degree of freedom in determining the appropriate dynamic process that governs output. Here we partially follow a recent work by Kiley (2000). In his work Kiley provides some cross-country evidence of a negative relationship between inflation and persistence.

Kiley uses three ways of estimating persistence. The first derives from a simple AR(1) process of detrended output. The second derives from a joint estimation of a ARIMA(2,1,0) process for money and a AR(2) process for output. The last is a VAR estimation of a bivariate model in real and nominal output. The last two methods are intended to capture the persistence in output deviation associated with monetary shocks.

Here we estimate persistence in three different ways also. The first is, like in Kiley, an AR(1) process for output. The second is an ADL(1,1) model in output and the interest rate. The latter is intended as a proxy for the monetary process that appears, for example, in the dynamic equation for output in a price staggering model *á la* Taylor (1980).[18] Finally we select the

[17] That is, the elasticity of persistence with respect to the adjusted markup must be smaller than the elasticity of persistence with respect to the returns to labour. If this were not the case, our evidence could not be rationalized with increasing returns.

[18] See for example Romer (1996, ch. 6).

"best" AR(p) model for output, and measure persistence by the smallest root (highest eigenvalue) of the estimated AR(p) model. Chari *et al.* (2000) for example use this procedure to estimate the "contract multiplier" in models of price stickiness. This procedure is methodologically preferable to the two alternative discussed earlier. Nevertheless we have proposed all of them since they are also used in the literature to measure persistence (as for example in Kiley (2000)).

We were not able to obtain VAR based measures of persistence correlated with the markup. Nevertheless, consistently with our theoretical model, we expect competition to affect the persistence of the output gap under any type of shock. At least to the extent that sticky prices constitute a propagation mechanism for that shock.[19]

4 Results

The first measure of persistence is based on a AR(1) model for detrended output fit on each individual country, i.e.

$$y_t = constant + \gamma\, y_{t-1} + u_t$$

where y_t is real output detrended using a Hodrick-Prescott (HP) filter.

Table (2) shows the estimates of the parameter γ. The first column shows the estimate of persistence based on a AR(1) process for all countries. Column 2 and 3 show the t-statistic and the R^2 associated with the AR(1) estimation. Column 6 shows the maximum eigenvalue implied in the AR(p) estimation where p is given in the last column.

Figure (8) shows the scatter plot of the first measure of persistence versus the gross of tax markup.

As a second step we regress these 24 estimates of persistence on our measure of the markup and other control variables. The results are shown in table (3).[20] Note that in this table, as well as in the other regressions in this paper, p-values are reported in parenthesis.

We have considered various possible candidates as control variables. Of these only three gave us interesting results, that is 1999 gross national income per head (World Bank PPP measure), volatility of detrended real output (i.e.

[19]Furthermore, a VAR approach introduces extra degrees of freedom in choosing the appropriate model, i.e. the variables that enter in the system, the identification of the shocks etc.. Following our argument a univariate time series model seems more appropriate.

[20]For all our regressions we have checked and excluded heteroscedasticity. Standard specification tests where also carried out and passed.

Country	AR(1) coef	t-st.	R^2	obs.	λ	AR(p)
Australia.	0.483	3.37	0.23	39	0.558	2
Austria	0.556	4.07	0.31	39	0.556	1
Belgium	0.540	3.89	0.29	39	0.540	1
Canada	0.605	4.503	0.35	39	0.613	2
Denmark	0.371	2.44	0.14	39	0.371	1
Finland	0.743	6.39	0.52	39	0.807	2
France	0.663	5.14	0.44	39	0.619	2
Germany	0.625	4.80	0.38	39	0.643	2
Greece	0.390	2.36	0.17	29	0.390	1
Iceland	0.636	4.92	0.40	39	0.767	2
Ireland	0.655	4.71	0.37	39	0.613	2
Italy	0.441	3.07	0.20	39	0.597	2
Japan	0.724	6.23	0.51	39	0.724	1
Mexico	0.593	4.46	0.35	39	0.608	2
Netherlands	0.515	3.77	0.28	39	0.515	1
New Zealand	0.570	4.22	0.33	39	0.570	1
Norway	0.613	4.68	0.37	39	0.672	2
Portugal	0.592	4.47	0.35	39	0.624	2
S. Korea	0.513	3.02	0.25	29	0.513	1
Spain	0.702	6.76	0.55	39	0.679	2
Sweden	0.647	5.00	0.40	39	0.717	2
Switzerland	0.634	5.15	0.42	39	0.701	2
UK	0.620	4.80	0.38	39	0.719	2
US	0.533	3.77	0.28	39	0.671	2

Table 2: Time series estimation statistics

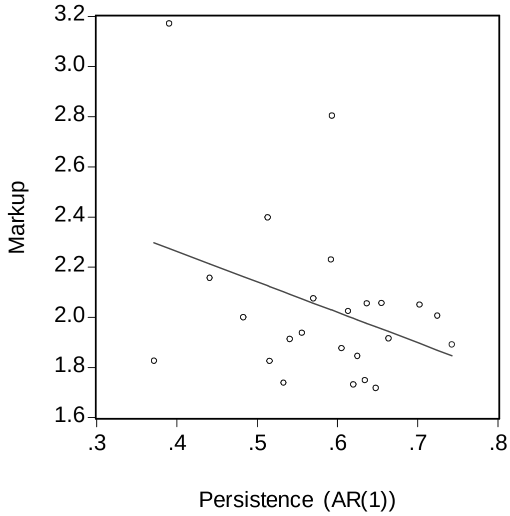

Figure 8: Average adjusted markup vs. persistence

standard deviation of y_t), government expenditures relative to gross domestic product, and inflation.[21]

The rationale for the first variable is that richer countries may have more efficient markets and institutions so that departures from the underlying trend should be short-lived. Markups and income per capita are also correlated. The higher the monopolistic distortion the lower the income per capita. At the same time anti-trust lows might be better designed or better enforced in richer economies, so that a higher income per head is associated with a lower markup. The following simple regression estimation gives evidence of the markup-income per capital relationship.

$$\begin{aligned} \mu_i &= \underset{(0.00)}{10.37} - \underset{(0.00)}{0.86} \, (GNI99) \\ R^2 &= 0.60 \end{aligned} \tag{24}$$

where GNI99 is the log of income per capita.

We interpret the volatility of income as a measure of the degree of uncertainty in the economy. Regressing the markup on volatility alone gives a positive, although insignificant, coefficient estimate.[22] Income volatility is also expected to be positively correlated with income persistence, as time

[21] Other variables considered were capital per worker, degree of openness and the volatility of the exchange rate.

[22] P-value of slope estimate is 0.23.

	measures of the markup							
	Gross	Net	Gross	Net	Gross	Net	Gross	Net
Constant	0.72 (0.00)	0.68 (0.00)	1.33 (0.00)	1.32 (0.00)	2.42 (0.04)	2.31 (0.07)	0.85 (0.00)	0.79 (0.00)
μ	-0.13 (0.02)	-0.12 (0.04)	-0.23 (0.01)	-0.25 (0.01)	-0.19 (0.03)	-0.19 (0.06)	-0.16 (0.04)	-0.14 (0.09)
volatility	5.61 (0.03)	5.30 (0.04)						
GNI99			-0.14 (0.16)	-0.14 (0.20)				
Gov.share					-1.42 (0.03)	-1.50 (0.04)		
Inflation							0.71 (0.21)	0.51 (0.36)
R^2	0.29	0.26	0.20	0.16	0.30	0.27	0.18	0.16

Table 3: Dependent variable: persistence using an AR(1) model

series principles suggest. Yet, the volatility of income depends on the persistence of income as well as on other factors. These factors include the volatility of the underlying shocks. This volatility can be thought of as generating uncertainty.

Galí (1994) provides some evidence that the government expenditure share, (s_g), is negatively correlated with the volatility of income for 22 OECD countries. The interpretation of this fact is that government expenditures can stabilize the business cycle. In our sample, the size of the government share appears also to be negatively correlated with the markup, as the following regression shows[23]

$$\begin{aligned} \mu_i &= \underset{(0.00)}{3.30} - \underset{(0.00)}{5.91} s_{g,i} \\ R^2 &= 0.56 \end{aligned} \tag{25}$$

This result is robust to the inclusion of the other control variables. It appears then that government spending crowds out monopolists, or indeed that it reduces their profit margins.

Kiley (2000) shows that inflation is correlated with persistence, although not for the OECD countries. Neiss (2000, 2001) shows that inflation and the markup are correlated in a sample of 23 OECD countries. For these reasons we control also for inflation.

As the table shows we do not run regressions using combinations of our control variables. When we did so we could not improve the quality of our

[23] The markup in the regression is net of indirect taxes. Using a gross of tax markup does not change the result.

estimates.[24]

Table (3) shows that in all cases the markup is estimated to be negatively correlated with output persistence. In 6 out of 8 cases the estimate is significant at the 5% level while in the other two it is significant at the 10% level. As for the control variables, all but inflation have sign estimates as expected.

Government expenditure appears to be negatively correlated with persistence. This results conforms with findings by Galí (1994): Governments seem able to reduce the persistence of output deviations from equilibrium. Income volatility is positively correlated with persistence, as the theory suggests. The contribution of income per capita is not significant. Nevertheless it shows that the correlation between the markup and persistence is independent of this factor.

Finally, inflation does not appear significant and has a counter-intuitive sign estimate.

Following sticky price models *á la* Calvo (1983) or Taylor (1980), the dynamics of output ensued from the staggering process depends on the unexpected innovation in the money supply, besides other shocks. When the process for money is not a simple Random Walk, the unexpected monetary shock depends on the past evolution of the monetary variable. In the following we try to capture part of this fact by estimating persistence controlling for this monetary component. Specifically we use the (OECD) short run government bon yield to proxy for monetary shocks. Therefore we estimate the following equation

$$\begin{aligned} y_t &= const. + a\ (int.rate_t) + u_t \\ u_t &= \gamma u_{t-1} + \nu_t \end{aligned}$$

where ν is assumed to be $i.i.d.$.[25] The results are reported in table (4).

By and large, controlling for the interest rate in the estimation of persistence does not alter dramatically our results. The markup is still negatively correlated with persistence. It is worth noting that while controlling for volatility of income does not yield significant estimates, controlling for inflation yields significant estimates at 10% level when the markup is measured gross of taxes. Yet the sign of inflation seems still counter-intuitive.

Finally we estimate persistence using an AR(p) model for detrended output. We select p using two criteria jointly. One is the minimum Schwartz Bayesian Criterion (SBC), while the other just looks at the significance of the AR coefficients. The estimated order is reported in the last column of table

[24]The high degree of multicollinearity in regressions with multiple control variables is the likely reason for the poor results.

[25]Similar results were obtained using the change of the interest rate rather than its level.

	measures of the markup							
	Gross	Net	Gross	Net	Gross	Net	Gross	Net
Constant	0.70 (0.00)	0.66 (0.00)	1.45 (0.00)	1.38 (0.00)	3.96 (0.00)	3.72 (0.01)	0.86 (0.00)	0.76 (0.00)
μ	-0.09 (0.20)	-0.07 (0.34)	-0.23 (0.01)	-0.23 (0.03)	-0.24 (0.01)	-0.23 (0.03)	-0.15 (0.06)	-0.12 (0.18)
volatility	3.99 (0.19)	3.65 (0.23)						
GNI99			-0.29 (0.01)	-0.27 (0.02)				
Gov.share					-1.80 (0.01)	-1.77 (0.03)		
Inflation							1.11 (0.08)	0.83 (0.18)
R^2	0.12	0.08	0.31	0.24	0.29	0.23	0.18	0.10

Table 4: Dependent variable: persistence measured using AR(1) model cum interest rate

(2). Only for Norway the SBC was not consistent with the p-value criterion. The p-value for the lag-3 coefficient was significant at the 10% level. In this case we decided on a $p = 2$. The estimated maximum eigenvalue (inverted root) is reported in column 6 of table (2).

Figure (9) shows the scatter plot of the markup (net of tax) v. persistence. The graph suggests that few countries could have a disproportionate effect on our estimates. As in all circumstances where there are few observations it is very costly to throw away some of them. In this case if we are willing to drop all countries with markup smaller than 2.2 and persistence smaller than 4.5 regressing persistence on the markup gives extremely significant results.[26] To avoid the risk of data mining we report the results including all available data, which we find sufficiently robust anyway.

The results of the cross country regression are reported in table (5).

These results show that there is strong evidence of a negative correlation between our measure of competition and persistence.[27] In particular in all cases the coefficient estimate for the markup is significant at the 10% level. Income per head does not appear to help estimating the persistence-markup correlation. Volatility and government expenditures enter strongly significantly and with the expected sign. Surprisingly inflation does also enter significantly (at 5% s.l.) but with a positive sign. Taking this result literally we should conclude that the higher is inflation the more persistent are the

[26]The outliers would be Mexico, Greece, Netherlands and Denmark.

[27]Using more than one control for equation reduces the significance of the controls but leaves the markup strongly significant.

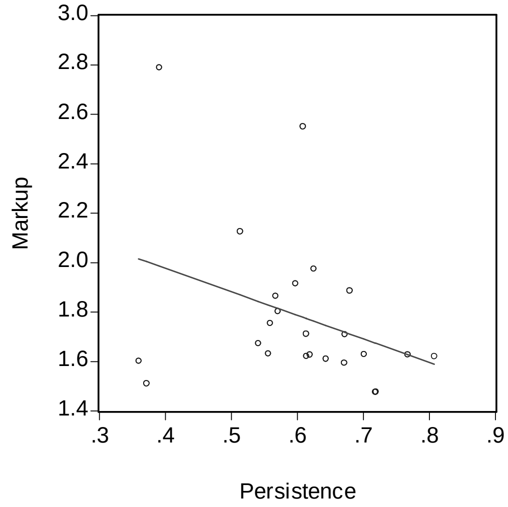

Figure 9: Markup versus persistence estimated with an AR(p) model

deviations of output from trend. This would be in contrast to Lucas (1972) claim that the responsiveness of prices is proportional to inflation. Kiley (2000) also offers new evidence in support of this reasonable claim.

We can think of two factors that could bring about our result on inflation. The first is that inflation could be a proxy of something missing from our regression. Indeed inflation and volatility are strongly correlated, as the following shows

$$\begin{aligned} \sigma_{y,i} &= \underset{(0.00)}{0.02} + \underset{(0.00)}{0.09}\pi_i \\ R^2 &= 0.32 \end{aligned} \tag{26}$$

where $\sigma_{y,i}$ is the standard deviation of income of country i and π_i is the average inflation rate of country i. Using both, inflation and volatility in our regression of persistence on the markup yields insignificant coefficients on the two control variables, while the markup enters significantly. It is therefore unclear whether inflation is simply a proxy for volatility.[28]

The second factor that could drive this result is that the causal relation between persistence and inflation could be read from the former to the latter, specially at low levels of inflation . One possibility is that higher persistence of output deviation might induce the central bank to inflate in order to generate more employment. This logic would derive from a Barro-Gordon (1983)

[28]In other words, the multicollinearity is stronger than the explanatory power of the two control variables.

	measures of the markup						
	Gross[a]	Gross[a]	Gross[a]	Gross	Net	Gross	Net
Constant	0.84 (0.00)	0.76 (0.00)	2.00 (0.00)	1.50 (0.00)	1.56 (0.00)	0.99 (0.00)	0.91 (0.00)
μ	− 0.12 (0.100)	−0.16 (0.02)	−0.18 (0.09)	−0.27 (0.01)	−0.32 (0.00)	−0.25 (0.01)	−0.23 (0.01)
volatility		7.16 (0.00)					
GNI99			−0.10 (0.41)				
Gov.share				−1.70 (0.03)	−1.96 (0.02)		
Inflation						1.49 (0.02)	1.25 (0.050)
R^2	0.12	0.33	0.15	0.30	0.33	0.32	0.27

Table 5: Dependent variable: persistence measured using AR(p)

[a]Gross and Net markups give virtually identical resutls

type of central bank. The other possibility is that the positive correlation between persistence and inflation just reflects the positive correlation between volatility of output and inflation, as equation (26) shows. A possible story behind this would then be that, in front of a volatile economy, the central bank is more prone to use money for anti-cyclical purposes, with the consequence of generating higher inflation.

We consider these results as robust indication of a *negative* correlation between persistence of deviations of output from trend and the degree of competition, measured by the (adjusted) markup.

5 Conclusion

In this paper we have tried to address the following question: Do economies with different unit labour costs display a different degree of persistence of the output gap?

Our empirical evidence have shown that this is indeed the case among 24 OECD countries. We have also argued that by interpreting the unit labour cost as the real marginal cost, as suggested by a large empirical literature, our evidence points at a positive correlation between competition and persistence.

We have discussed to which extent using the unit labour cost as a proxy of the degree of competition is correct. We concluded with a caveat for the interpretation of the related empirical literature in general and for our evidence in particular. That is, the unit labour cost can be a good proxy for the degree of competition only under the assumption of not negligible resource constraints for the aggregate economy at business cycle frequency and of almost-constant factors shares of net of profit income, across country and across time.

Under this "proviso" we interpreted our evidence as reflecting a positive correlation between competition and persistence.

The motivation of our investigation stems from the sticky price literature that is gaining growing importance in modern macroeconomics. Much of this literature rests on the assumption that firms operate in monopolistically competitive markets. That is, firms are assumed to have price setting power. This assumption serves as a necessary condition for sticky price environments: Firms *decide* not to adjust their prices. Nevertheless, the assumed degree of competition will affect the actual degree of price stickiness in these models. The theory suggests that this will be the case for two main reasons. First higher competition implies larger losses the further the set price is from its optimum (infinite losses in perfect competition). For a given cost of adjusting the price, higher competition implies smaller nominal rigidity of prices. A second reason is that the degree of competition will determine the vertical distance between the marginal revenue curve of the firm and its marginal cost curve: Given a shock to the economy, with an increasing marginal cost curve the distance between the old profit maximising price and the new one is decreasing in the degree of competition. These two theoretical predictions have been supported by Carlton (1986) with microeconometric evidence.

In our empirical analysis we were faced by a second type of difficulty, i.e. the measure of persistence. This problem is two-sided. On one side we need to define a trend for output. Here, absent better alternatives, we follow the literature by using a Hodrick-Prescott filter. On the other side the measure of persistence depends on the estimated model. Here we adopt a univariate time series method to estimate the dynamic equation of detrended output (as in Chari et al. (2000)). An alternative would have been to estimate a VAR (as in Kiley (2000)). Yet, our theoretical model suggests that the degree of competition is likely to affect persistence under monetary as well as productivity shocks in the same way. Furthermore a multivariate approach requires extra assumptions regarding the variables used and the identification of the shocks. We don't think that this would help us in our task vis-à-vis the univariate approach.

Finally an important issue is whether wage rigidities would alter our results dramatically. The relative importance of price stickiness versus wage stickiness has been the object of a long lasting debate in economics. This debate has been recently revived by the literature on the Phillips curve and on optimal monetary policy.[29] To the extent that wages are allocative our analysis holds. Firms do still decide to be on their marginal product curve in the factor market. If long run contracts are in place in the labour market, much of our analysis would not carry over. Yet, this problem would be shared with the majority of modern macroeconomic models. Hence, while this is a crucial question, no one has been able so far to give a definite answer to it.

When wages are allocative but sticky, the theoretical implication of our model would apply to the relationship between degree of competition in the labour market and persistence. This fact is sketched in the appendix. We find this an interesting possibility, which deserves to be addressed empirically in future research.

A Appendix

A.1 Monopolistic labour market

We assume here that the labour market is characterised by monopolistic competition. For simplicity we model the market as populated by a large number of "types" of workers, which services are purchased by a "non-profit" union. The latter sells an aggregate of these labour services to firms. If we denote with θ the degree of substitutability between types of workers, the aggregate of worker's services supplied by the union is

$$L = \left(\int_0^1 l_i^\theta \right)^{\frac{1}{\theta}}$$

The demand for a specific type i of workers is therefore

$$l_i = \left(\frac{w_i}{W} \right)^{-\varepsilon} L \tag{27}$$

where $\varepsilon = \frac{1}{1-\theta}$

We assume that each household supply one type of labour. The amount of labour supplied is chosen in order to maximize a utility function in consumption and labour, denoted by $U(C_i, l_i)$.

Since each household faces a downward sloping demand function for its labour services, the first order condition of utility maximization is

$$\frac{w_i}{P} = \mu_w \xi (C_i, l_i) \tag{28}$$

[29]See for example Galì *et al.* (2001), Erceg *et al.* (2000) and Goodfriend and King (2001) and the literature cited therein.

where $\mu_w = \frac{\varepsilon}{\varepsilon - 1}$ is the markup of the real wage over the household's marginal cost of supplying labour, and where $\xi(C_i, l_i) = \frac{-U_{l_i}}{U_{C_i}}$, so that, under standard assumptions, $\xi_C > 0$ and $\xi_l > 0$.

Households renegotiate their wages with the trade union at fixed intervals of time in a staggered fashion (*á la* Taylor). For simplicity we assume that households can be grouped in two cohorts. The members of the first cohort set their wages for two periods at dates *t*, *t+2*, *t+4* ... etc. while the members of the second cohort set wages at dates *t+1*, *t+3*, ... etc.

To simplify further the model we assume also that the trade union operates as a sort of mutual insurance that allows its members to maintain the same consumption level across cohorts.[30] This consumption level is determined by the aggregate state of the economy and, ultimately, by the aggregate real balances, i.e.

$$C_i = C = Y = \frac{M}{P}$$

On the production side we can assume that aggregate output is *proportional* to aggregate labour so that $C = L$

A.1.1 Optimal real wage and aggregate shocks

Expressing variables as log-deviations around the symmetric steady state we can rewrite equation (28) as

$$\hat{w}_i - \hat{P} = \Omega^l \hat{L} + \frac{\xi_l}{\xi_{ss}} L_{ss} \left(\hat{l}_i - \hat{L} \right) \tag{29}$$

where ^ denotes the variable in log-deviation terms, *ss* stands for symmetric steady state, $\Omega^l = \frac{\xi_l l_{ss} + \xi_L L_{ss}}{\xi_{ss}}$ is the total elasticity of the marginal cost of labour supply and ξ_x denotes the first derivative of ξ with respect to x. To derive equation (29) we have also assumed that the wage-markup μ_w is constant.

To simplify the analysis we assume that final goods prices are flexible and are set by firms as a markup over the marginal cost. Therefore the (aggregate) price is proportional to the aggregate wage index, i.e.

$$\hat{P} = \hat{W}$$

[30] Alternatively one can think of each household as being equally represented in both cohorts, so that household consumption is independent of the wage rate of a specific cohort.

Combining equation (29) with the log-deviation of equation (27) gives, after some algebra

$$\hat{w}_i - \hat{P} = \frac{\Omega^l}{\varepsilon\left[\frac{1}{\varepsilon} + \frac{\xi_l}{\xi} L_{ss}\right]}\hat{L} \tag{30}$$

The term $\frac{\Omega^l}{\varepsilon\left[\frac{1}{\varepsilon} + \frac{\xi_l}{\xi} L_{ss}\right]}$ measures the elasticity of the optimal real wage with respect to aggregate shocks. As long as households dislike to work, $\frac{\xi_l}{\xi} > 0$ so that a higher degree of competition in the labour market (a lower wage-markup) implies a lower elasticity of the real wage and hence a higher "real rigidity".

Due to the wage-staggering structure of the economy the aggregate price level in each period is given by

$$\hat{P}_t = \hat{W}_t = \frac{1}{2}\left(\hat{x}_t + \hat{x}_{t-1}\right)$$

where $\hat{x}$ is the price set by either cohort of workers holding for two consecutive periods. In analogy with firms' behaviour in price-staggering models, here workers set the real wage for the two consecutive periods in order to maximize their utility over these two periods. To simplify our analysis we impose a zero discount rate to the second period utility of the household.[31] This implies that the aggregate price can be written as

$$\hat{P} = \frac{1}{2}\left(\hat{w}_t + \hat{w}_{t-1}\right) \tag{31}$$

Finally, substituting equation (30) in equation (31) yields after some algebra

$$Y_t = \frac{1-\Psi^l}{1+\Psi^l}Y_{t-1} + \frac{1}{1+\Psi^l}\left(M_t - M_{t-1}\right) \tag{32}$$

where $\Psi^l = \frac{\Omega^l}{\varepsilon\left[\frac{1}{\varepsilon} + \frac{\xi_l}{\xi} L_{ss}\right]}$.

The recursive equation (32) implies that the real effects of a monetary shock are more persistent the lower (higher) is the wage-markup (labour demand elasticity ε).

[31] The main results would carry over to the more general case of a non-zero discount rate.

A.2 Imperfect labour market with non linear production function

In this appendix we modify our simple model to allow for changes in labour productivity. We do this by imposing a non linear production function, i.e.

$$Y_t = A_t L_t^{1-\alpha}$$

Where A_t measures technology shocks and $(1-\alpha)$ measures the returns to labour.

The labour demand equation (27) expressed in log deviation becomes now

$$\hat{w}_t - \hat{W}_t = -\frac{1}{\varepsilon}\left(\hat{l}_t - \frac{1}{1-\alpha}\left(\hat{Y}_t - \hat{A}_t\right)\right) \tag{33}$$

We assume that firms set prices efficiently (as a markup over the marginal cost) then given or production function we have that

$$\hat{P}_t = \hat{W}_t - \widehat{MPL}_t$$

where $\widehat{MPL}$ is the log-deviation of the marginal product of labour. That is

$$\hat{P}_t = \hat{W}_t - \hat{Y}_t + \hat{L}_t$$

If we use this relationship in equation (33) we can rewrite the inverse demand for labour as

$$\hat{w}_t - \hat{P}_t = -\frac{1}{\varepsilon}\hat{l}_t + \left[\frac{1-\varepsilon\alpha}{\varepsilon(1-\alpha)}\right]\hat{Y}_t - \frac{1-\varepsilon}{\varepsilon(1-\alpha)}\hat{A}_t \tag{34}$$

The supply of labour is still given by[32]

$$\hat{w}_t - \hat{P}_t = \Omega^l \hat{Y}_t + \frac{\xi_l}{\xi_{ss}} l_{ss}\left(\hat{l}_t - \hat{Y}_t\right) \tag{35}$$

Isolating $\hat{l}_t$ from equation (35) and substituting it into equation (34) gives, after some algebra

$$\hat{w}_t - \hat{P}_t = \Phi_1 \hat{Y}_t - \Phi_2 \hat{A}_t \tag{36}$$

where

$$\Phi_1 \equiv \frac{\frac{1-\varepsilon\alpha}{1-\alpha} + \Omega^l \frac{\xi_{ss}}{\xi_l l_{ss}}}{\varepsilon + \frac{\xi_{ss}}{\xi_l l_{ss}}} \tag{37}$$

[32]Note that now $C_{ss} = Y_{ss} \neq L_{ss}$.

and

$$\Phi_2 \equiv \frac{\varepsilon - 1}{(1-\alpha)\left(\varepsilon + \frac{\xi_{ss}}{\xi_l l_{ss}}\right)}$$

We still assume that workers are grouped in cohorts setting wages in a staggered fashion. This implies that, given our production function, we have

$$\hat{P}_t + \widehat{MPL}_t = \hat{W}_t = \frac{1}{2}\left(\hat{w}_t + \hat{w}_{t-1}\right) \tag{38}$$

Using equation (36) in equation (38), together with the assumption that $\hat{Y} = \hat{M} - \hat{P}$, and rearranging terms, gives[33]

$$\hat{Y}_t = \frac{1-\Phi_1}{\frac{2}{1-\alpha} + \Phi_1 - 1}\hat{Y}_{t-1} + \frac{1}{\frac{2}{1-\alpha} + \Phi_1 - 1}\left(\hat{M}_t - \hat{M}_{t-1}\right) + \frac{\Phi_2}{\frac{2}{1-\alpha} + \Phi_1 - 1}\left(\hat{A}_t + \hat{A}_{t-1}\right) \tag{39}$$

It is easy to show that also in this case the persistence of output deviation from the steady state is decreasing (increasing) in the desired wage-markup (elasticity ε), provided that $\alpha \in (0,1)$. To see this consider the coefficient Φ_1 given by the definition (37) above. As long as returns to labour are not increasing, Φ_1 can be interpreted as the product of a downward sloping straight line in ε (the numerator) and an hyperbola in ε (inverse of denominator): hence Φ_1 is decreasing in ε.[34] In the case of increasing returns to labour ($\alpha < 0$), the straight line (numerator) becomes upward sloping. Therefore, Φ_1 is decreasing in ε only for sufficiently small values of ε.[35]

This result shows that output persistence is decreasing in the wage-markup even if we allow for a variable marginal productivity of labour.

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[33] One can easily verify that equation (39) reduces to equation (32) if constant returns to labour are assumed together with $A = 1$. Here we also assume that $\Phi_1 \in (0,1)$ so that the output path does not oscillate.

[34] Here we are assuming that the elasticity of the marginal cost of supplying labour is independent of ε. This is for instance the case with a additively separable utility function.

[35] That is Φ_1 will be decreasing in ε up to the point where the hyperbola has the same slope of the straight line.

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