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Cyclical productivity in a model of labor hoarding

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Abstract

This paper develops a dynamic model of labor hoarding to explain two empirical facts, the cyclical behavior of total factor productivity and the dynamic correlations of sectoral productivity with aggregate variables. The model features convex costs of adjusting the labor force, which induce firms to vary the intensity of labor utilization over the cycle. In particular, cyclical variations in labor 'effort' take place as a response to expected future changes in industry conditions. I test the restrictions imposed by the model for several two-digit manufacturing industries under different assumptions about market structure and returns to scale. Then, using the assumption that aggregate variables carry information about future changes in industry conditions, I simulate the model's dynamic response of hours and productivity to aggregate innovations and compare them to those estimated from the data.

Key words: Total factor productivity; Labor hoarding

JEL classification: E32; D24

1. Introduction

In many industries it is observed that output rises and falls at cyclical frequencies more than can be accounted for by changes in measured capital and labor inputs, assuming constant returns to scale. This *procyclical productivity* is a long-standing puzzle in the empirical study of business cycles. Fig. 1 illustrates the extent of this phenomenon for the manufacturing industry and for 11 of its

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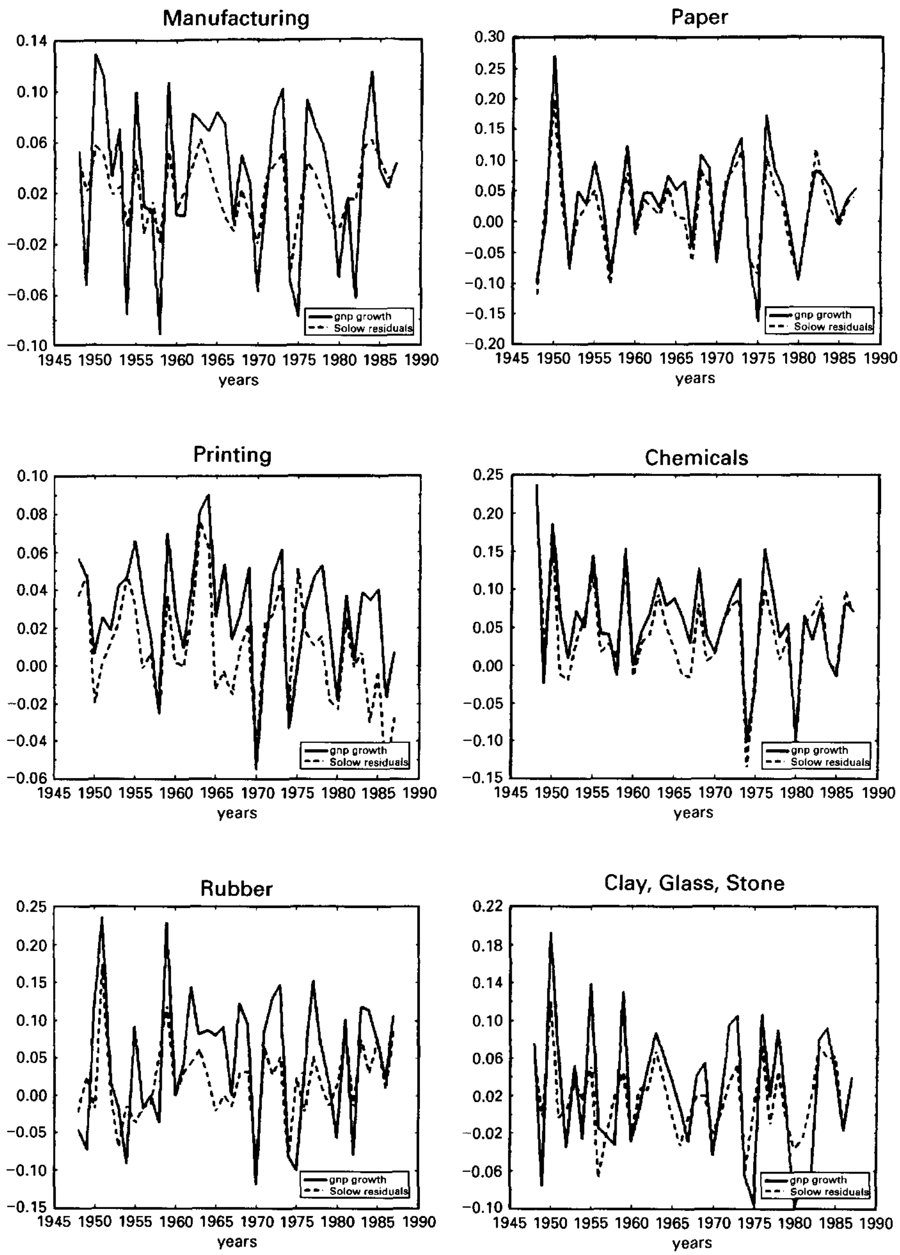

Fig. 1. Output growth and Solow residuals.

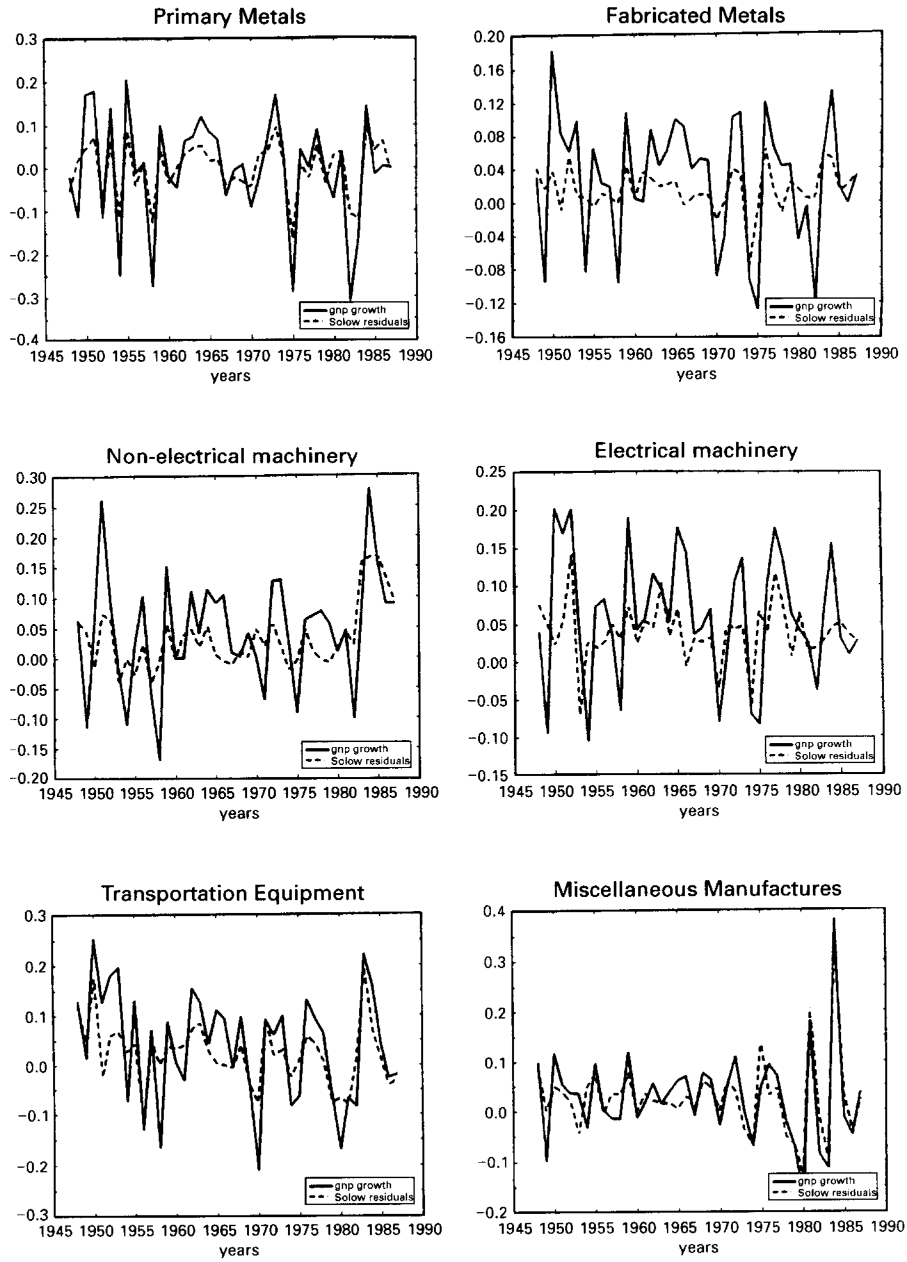

Fig. 1 (continued)

Table 1
Correlation of Solow residuals

Sector	With sectoral output growth	With aggregate gnp growth
	Corr. (s.e.)	Corr. (s.e.)
Manufacturing	0.79 (0.06)	0.71 (0.08)
Paper	0.94 (0.02)	0.38 (0.13)
Printing	0.75 (0.07)	0.08 (0.16)
Chemicals	0.91 (0.03)	0.33 (0.14)
Rubber	0.68 (0.09)	0.36 (0.14)
Clay, Glass, and Stone	0.78 (0.06)	0.46 (0.13)
Primary Metals	0.89 (0.03)	0.64 (0.10)
Fabricated Metals	0.56 (0.11)	0.40 (0.14)
Nonelectrical Machinery	0.56 (0.11)	0.21 (0.15)
Electrical Machinery	0.44 (0.13)	0.23 (0.15)
Transportation Equipment	0.79 (0.06)	0.35 (0.14)
Miscellaneous Manufactures	0.87 (0.04)	0.20 (0.15)

two-digit sectors. The graphs show, for each industry, output growth and Solow residuals, computed as the difference between output growth and the output-share weighted growth of capital and labor. In all sectors there is evidence that the two series move together; correlation coefficients are reported in Table 1.

Macroeconomists have proposed a variety of explanations.[1] Real business cycle theorists interpret the procyclical behavior of measured productivity as indicating actual shocks to technology. Others have argued that it reflects increasing returns, either internal or external to the firm.

This paper reexamines an old explanation, 'labor hoarding' (Solow, 1964). Because it is costly for firms to adjust labor hours, they respond to short-run increases in demand by obtaining increased effort from their workers. Measured productivity then rises with short-run increases in output.

The literature on labor hoarding is a very large one. Most recently, a number of contributions were stimulated by Robert Hall's (1991) challenge to real business theorists' identification of Solow residuals as true technology shocks. However, one of the problems that arise in empirical tests of the labor hoarding hypothesis is the unobservability of effort. Many authors overcome this problem by using other variables as direct proxies, such as overtime hours (Caballero and Lyons, 1992) or the number of hours per employee (Abbott, Griliches, and Hausman, 1988; Eden and Griliches, 1993). In few cases, more direct statistics on labor utilization are used, like in a study for the U.K. by Schor (1987), and a study for the U.S. by Shea (1991), who constructs a series for effort by using accident rates.

[1] Among the most recent contributions, see Abbott, Griliches, and Hausman (1988), Bernanke and Parkinson (1991), Hall (1987, 1989), Gordon (1990), Caballero and Lyons (1990, 1992), Baxter and King (1991), Basu (1996).

In this paper I take a different approach to this measurement issue, by looking directly at the determinants of firms' decision about labor utilization rates. In this respect this work is more in the spirit of Burnside, Eichenbaum, and Rebelo (1993) (BER for short), who look at implications of labor hoarding for business cycle theory. In BER's general equilibrium model the production technology includes labor hoarding, while consumers' utility is decreasing in effort. They use this model to examine how the variance of true technological innovations is reduced by imposing that they are orthogonal to government consumption, and how the ability of technological innovations to account for output volatility is affected. By imposing that, in equilibrium, the return to an extra unit of effort should equal its marginal disutility, BER are able to obtain a time series of effort, given observations of hours, consumption, and output, for given values of other parameters.

I do not work out a general equilibrium model, because my scope is narrower. I construct a dynamic model of labor demand that incorporates costs of adjusting hours and a variable rate of utilization of labor. Effort in my model is deduced from the firm's first-order condition of cost minimization. By assuming a firm's compensation scheme by which wages increase more than proportionally with effort, I accomodate an increasing marginal disutility of effort in consumers' preferences, without having to be specific about their functional form. The advantage of such a procedure is that the results will not depend upon particular assumptions about preferences.

Moreover, while my results contribute well as to the assessment of the importance of technology shocks as a driving force of business cycle,[2] my focus here is more specific. I want to explore first whether there are significant adjustment costs to justify the hypothesis of labor hoarding, and second, whether this form of labor hoarding may provide a propagation mechanism of aggregate shocks by which I can duplicate the observed dynamic response of measured productivity. The aim is to offer an explanation of the procyclical behavior of productivity, and also account for the observed dynamic correlations of aggregate variables with sectoral productivity.

The correlation between aggregate variables and sectoral productivity has been recently pointed out, for manufacturing industries, by Caballero and Lyons (1990, 1992). Column 2 in Table 1 documents this second empirical 'fact'. The correlation of Solow residuals with aggregate output in several manufacturing industries is pretty high. This correlation is of particular interest because it allows one to discriminate among alternative possible explanations of the correlation between sectoral productivity and sectoral output. If one assumes that true technological progress should be uncorrelated across sectors, an association between

[2] I analyze more specifically this issue in Sbordone (1995), where I show how labor hoarding modifies the statistical properties of true technology shocks as compared to those of Solow residuals.

aggregate activity and productivity in an individual sector rules out true shifts in technology as a cause. Furthermore, if aggregate activity continues to predict sectoral productivity when sectoral input growth is controlled for, one can also exclude explanations, such as the hypothesis of internal increasing returns, that imply that measured productivity should vary whenever the scale of sectoral activity changes. While Caballero and Lyons interpret their findings as evidence of external effects of activity in other sectors on the production possibilities in a given sector, here I show that labor hoarding is another possible explanation.

The idea is that aggregate variables may be statistically significant in a sectoral production-function regression not because of any true production externality, but because they act as proxies for an omitted variable in the sectoral production function, sectoral labor utilization. In my model, sectoral output depends upon the *effective* labor input, defined as reported hours times an unmeasured utilization rate. I show that variations in aggregate variables may provide information about this utilization rate beyond what can be inferred from the measured sectoral inputs. The reason is simple. Firms tend to 'hoard' workers when production is temporarily low. This underutilization of workers may take the form of variation in work effort, of the kind reported by Schor (1987), or variations in the number of workers assigned to nonproduction tasks, such as maintenance and training, as in Bean (1989).[3] As a result, expectations about how future output and employment in a sector will compare to present levels are an important determinant of labor utilization. Aggregate variables are relevant to this decision problem because they help to forecast future conditions in the sector. In particular, if a higher growth rate of an aggregate variable forecasts lower growth of sectoral employment in the future, then this aggregate variable should affect measured sectoral productivity positively. For in this case, firms subject to costs of adjusting employment would prefer a higher present level of utilization of a smaller number of workers.

Not only can the model account for the relation between aggregate variables and sectoral productivity, but it can also account, at least roughly, for the dynamic response of sectoral productivity to an innovation in aggregate output or aggregate consumption. In Sbordone (1997) I study the dynamic response of productivity in the two-digit manufacturing industry to fluctuations in the output of the whole manufacturing, and find that permanent increases in aggregate output result in permanent increases in sectoral output, but only a transitory increase in sectoral productivity (with the impact effect largely reversed after the first year). This discrepancy between the time patterns of the response of sectoral output and

[3] Fay and Medoff (1985) evaluate the empirical importance of different forms of 'hoarding' by direct evidence from survey data on manufacturing plants. They find that about 8% of the blue-collar hours paid for by the typical plant during downturn periods were not technically necessary to perform regular production tasks, and at least 4% could be classified as strictly 'hoarded', in the sense that the workers were not performing some otherwise useful task.

productivity again indicates that internal increasing returns alone cannot explain the productivity response. Similarly, the discrepancy between the time patterns of the response of aggregate output and sectoral productivity means that the hypothesis of a simple, contemporaneous external effect of activity in other sectors (as in the model of Baxter and King, 1991) cannot account for it. Here I show that a labor hoarding model can account for this aspect of sectoral productivity variations as well.

The model I present below describes the behavior of an individual industry. To compare my results to the bulk of the empirical literature on procyclical productivity, I perform the empirical analysis on the two-digit sectors of U.S. manufacturing.

The model is evaluated along two dimensions. First, I estimate the first-order condition of the firm's cost minimization problem, test whether the restrictions they impose on the data hold, and whether significant costs of adjusting hours, relative to the cost of increasing labor utilization, are found. Secondly, I evaluate whether the model correctly predicts the measured response of sectoral total factor productivity to aggregate innovations. The model evaluation is based on a simulation exercise, in which some parameters are determined by direct estimation.

The structure of the paper is the following. In Section 2, I describe the model and the strategies for its evaluation; in Section 3, I present the Euler equation estimates and relate the results to previous literature on adjustment costs. Section 4 discusses the simulated response to an aggregate innovation, and Section 5 concludes.

2. The model

Consider a sector i of the economy, in which a representative firm chooses inputs to use in production, while facing each period a stochastic shock to its technology. The labor input L (effective hours) is composed of measured hours H and unobserved effort e: $L = eH$. The production function is

$$Q_{it} = F(K_{it}, e_{it}H_{it}\Theta_{it}), \tag{2.1}$$

where e_{it} is the rate of utilization of labor (effort) and Θ_{it} is a labor-augmenting technological change. While Θ_{it} need not be stationary, I assume that $\gamma^i_{\Theta t} = \Theta_{it}/\Theta_{i,t-1}$ is a stationary variable. F is assumed homogeneous of degree η in K and (eHQ), so I write

$$Q_{it}/K_{it}^{\eta} = f(e_{it}H_{it}\Theta_{it}/K_{it}). \tag{2.2}$$

Firms face technological costs in adjusting the number of workers or of hours. Total labor costs are (for ease of notation, I omit the subscript i from now on)

$$C_t = W_t H_t (g(e_t) + \lambda(H_t/H_{t-1})),$$

where W_t denotes the basic wage level (the one associated to a standard effort level e^s, defined by $g(e^s) = 1$), and $g(\ )$ indicates the proportional increase in the cost of hours that are more fully utilized. The function $\lambda(\ )$ represents the increase in costs associated with rapid adjustment of labor hours. For simplicity, I consider the case of adjustment costs related only to the change of the current level with respect to the previous one. One way to interpret this cost function is as the sum of two components: the first, $(W_t g(e_t))H_t$, represents the cost of H 'productive' hours of work, evaluated at wage $Wg(e)$, which is function of effort. The second, $W_t(\lambda(H_t/H_{t-1})H_t)$, is the cost of 'nonproductive' hours of work λH, evaluated at a standard effort level, that are allocated to hiring/firing decisions.[4]

I assume that $H\lambda(\ )$ is a nonnegative, convex function of H and that $g(\ )$ is a positive and strictly convex function. This compensation scheme is consistent with consumers' increasing marginal disutility of work.[5]

To get the restricted cost function (i.e., the minimum real expenditure on the variable input, conditional on the quantity Q to be produced, the capital K, and the quasi-fixed factor H) I solve Eq. (2.2) for effort, getting

$$e_t = \frac{K_t}{H_t \Theta_t} \varphi(Q_t/K_t^{\eta}), \tag{2.3}$$

where $\varphi(\ )$ is the inverse of $f(\ )$, and substitute this value into the cost function to obtain

$$C(H_t, H_{t-1}, K_t, Q_t, \Theta_t, W_t) = W_t H_t \left[g\left(\frac{K_t}{H_t \Theta_t} \varphi(Q_t/K_t^{\eta}) \right) + \lambda\,(H_t/H_{t-1}) \right].$$

The assumptions made above on the functions g and λ are sufficient for this cost function to be convex in H_t and H_{t-1}.

I determine the optimal sequence $\{H_t\}$ by solving a cost minimization problem for the firm, assuming given the optimal path for output and for the capital stock. This procedure allows me not to specify other elements that may be relevant to the decision about how much capital to install (for example, other adjustment costs affecting capital accumulation), or how much to produce, specifically the price rule that the firm is adopting. This is particularly useful in this context,

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[4] I thank an anonymous referee for helping me to clarify this interpretation.

[5] An alternative way of specifying the cost of adjusting hours would be as just the product $H\lambda$, without multiplying by the wage. The exact expression for some of the parameters of the Euler equation (Eq. (2.11) below) would be slightly different, but that would not affect the theoretical interpretation and the restrictions discussed below.

because I will be able to empirically evaluate the model under two different market structures.

The firm chooses the sequence $\{H_t\}$ to minimize the expected sum of discounted costs

$$\mathrm{E}_t \sum_{j=0}^{\infty} R^j \{C(H_{t+j}, H_{t+j-1}, K_{t+j}, Q_{t+j}, \Theta_{t+j}, W_{t+j})\},$$

where R represents a real discount factor ($R = 1/(1+r)$, and $0 < R < 1$) and E_t denotes expectations conditional on knowledge of all the variables up to time t. The Euler equation for this problem is

$$C_1(H_t, H_{t-1}, K_t, Q_t, \Theta_t, W_t) + R\mathrm{E}_t\,[C_2(H_{t+1}, H_t, K_{t+1}, Q_{t+1}, \Theta_{t+1}, W_{t+1})] = 0, \tag{2.4}$$

for all t. To find a stationary solution, I transform the variables in order to eliminate the sources of nonstationarity (which are in the H, K, and Q processes). Defining the variables

$$x_t = Q_t/K_t^{\eta}, \quad \gamma_{ht} = H_t/H_{t-1}, \quad \gamma_{kt} = K_t/K_{t-1}, \quad \gamma_{\Theta t} = \Theta_t/\Theta_{t-1},$$
$$\omega_t = W_t/\Theta_t, \quad \kappa_t = K_t/H_t\Theta_t,$$

I rewrite the problem as follows. The firm chooses processes $\{\gamma_{ht}, \kappa_t\}$ to minimize the expected sum of discounted costs (per unit of initial capital)

$$\mathrm{E}_t \sum_{j=0}^{\infty} \left[R^j \prod_{s=1}^{j} \gamma_{k(t+s)}\right] \tilde{C}(\gamma_{ht+j}, \kappa_{t+j}, x_{t+j}, \omega_{t+j}),$$

where $\tilde{C}(\gamma_h, \kappa, x, \omega) \equiv (\omega/\kappa)[g(\kappa\varphi(x)) + \lambda(\gamma_h)]$, subject to the evolution equation

$$\kappa_t = \frac{1}{\gamma_{ht}}\left(\frac{\kappa_{t-1}\gamma_{kt}}{\gamma_{\Theta t}}\right), \tag{2.5}$$

and taking as given stationary stochastic processes for the evolution of the variables $\{\gamma_{\Theta t}, x_t, \gamma_{kt}, \omega_t\}$. The optimal choice of (γ_{ht}, κ_t) will then be a function of $(\kappa_{t-1}, \gamma_{\Theta t}, x_t, \gamma_{kt}, \omega_t)$ and the conditional probability distribution at time t for the future values of $(\gamma_{\Theta t+j}, x_{t+j}, \gamma_{kt+j}, \omega_{t+j})$ for all $j \geqslant 1$. Given the assumption of stationarity for the driving processes $\{\gamma_{\Theta t}, x_t, \gamma_{kt}, \omega_t\}$, it follows that $\{\gamma_{ht}, \kappa_t\}$ will be stationary stochastic processes as well. These will satisfy an Euler equation of the form

$$\begin{aligned}&\omega_t[g(\kappa_t\varphi(x_t)) + \lambda(\gamma_{ht}) - [\kappa_t\varphi(x_t)]\,g'(\kappa_t\varphi(x_t)) + \gamma_{ht}\lambda'(\gamma_{ht})]\\ &-R\mathrm{E}_t[\omega_{t+1}\gamma_{\theta t+1}(\gamma_{ht+1})^2\,\lambda'(\gamma_{ht+1})] = 0.\end{aligned} \tag{2.6}$$

Assuming that all information at time t about both current and expected future values of the variables $\{\gamma_{\Theta t+j}, x_{t+j}, \gamma_{kt+j}, \omega_{t+j}\}$ can be summarized by a finite vector of state variables z_t (which includes among its elements $\gamma_{\Theta t}, x_t, \gamma_{kt}, \omega_t$), and furthermore that $\{z_t\}$ is a stationary Markov process, the optimal decision rules have the form

$$\gamma_{ht} = \Gamma_h(\kappa_{t-1}, z_t), \qquad \kappa_t = \Psi(\kappa_{t-1}, z_t).$$

These functions, together with the process $\{z_t\}$, describe the evolution of the complete set of stationary variables of the model. Note that stationary processes for $\{\kappa_t, x_t\}$ imply stationary fluctuations in effort, since

$$e_t = \kappa_t\, \varphi(x_t). \tag{2.7}$$

I characterize these decision rules by taking a log-linear approximation for the functions Γ_h and Ψ in the neighborhood of a constant vector (κ^*, z^*) such that the unconditional mean of log z_t is log z^*, and $\kappa^* = \Psi(\kappa^*, z^*)$. If the fluctuations in the variables $\log z_t$ around their mean values are sufficiently small, the log-linear decision rules will provide an adequate approximation to the equilibrium dynamics.

To guarantee that a solution for κ^* exists, I make the following assumptions about the functions g – the cost of increasing effort – and the adjustment cost function λ (detailed proof is given in Appendix A):

(i) $g(e)$ goes to infinity as some finite upper bound for e is approached, which implies that $eg'(e)/g(e)$ is a monotonically increasing function, varying between 0 and $+\infty$ as e varies between zero and its upper bound.

(ii) $\lambda(\gamma_h^*)$ and $\lambda'(\gamma_h^*)$ are both equal to 0. This assumption means that adjustment costs reach their minimum value of zero when hours growth is at the steady state rate.

To characterize the decision rules, I first assume that the Markov process for the state variables log z_t is a linear autoregressive process of the form

$$\hat{z}_{t+1} = V\hat{z}_t + v_{t+1}, \tag{2.8}$$

where $\hat{z}_t$ denotes $\log(z_t/z^*)$, and $\{v_t\}$ is a vector white noise process. (I will from now on consistently use a hat to denote the percentage deviation of a variable from its steady state value.)

Then, I obtain a similar log-linear form for the evolution equations for $\{\gamma_{ht}, \kappa_t\}$ by a log-linearization of the Euler equation (2.6) and the evolution equation for κ (2.5) around the steady state solution. These are, respectively,[6]

$$\alpha_0\hat{\omega}_t - \alpha_1\hat{x}_t + \alpha_2\hat{\gamma}_{ht} - \alpha_4\hat{\kappa}_t - \alpha_3 \mathrm{E}_t\hat{\gamma}_{ht+1} = 0 \tag{2.9}$$

[6] Note that in the derivation of Eq.(2.9) the terms in $\mathrm{E}_t\hat{\omega}_{t+1}$ and $\mathrm{E}_t\hat{\gamma}_{\Theta t+1}$ cancel because their coefficients depend upon $\lambda(\gamma_h^*)$ and $\lambda'(\gamma_h^*)$, which I assumed to be 0.

and

$$\hat{\kappa}_t = \hat{\kappa}_{t-1} + \hat{\gamma}_{kt} - \hat{\gamma}_{ht} - \hat{\gamma}_{\Theta t}, \tag{2.10}$$

where the coefficients α are defined by

$$\alpha_0 = g(\kappa^*\varphi(x^*)) - [\kappa^*\varphi(x^*)]g'(\kappa^*\varphi(x^*)),$$

$$\alpha_1 = x^*\varphi'(x^*)/\varphi(x^*)[\kappa^*\varphi(x^*)]^2 g''(\kappa^*\varphi(x^*)),$$

$$\alpha_2 = (\gamma_h^*)^2\lambda''(\gamma_h^*),$$

$$\alpha_3 = [R\ \gamma_k^*](\gamma_h^*)^2\lambda''(\gamma_h^*),$$

$$\alpha_4 = [\kappa^*\varphi(x^*)]^2 g''(\kappa^*\varphi(x^*)). \tag{2.11}$$

Finally, I solve Eqs. (2.9) and (2.10) for the evolution of $(\hat{\gamma}_{ht}, \hat{\kappa}_t)$, taking as given the evolution of the vector $\hat{z}_t$ (Eq. (2.8)) and initial values $(\hat{\kappa}_{-1}, \hat{z}_0)'$. Specifically, defining $\hat{y}_{t+1} = [\hat{\gamma}_{ht+1}, \hat{\kappa}_t, \hat{z}_{t+1}]'$, I write the system of Eqs. (2.9), (2.10), and (2.8) compactly as

$$A\mathrm{E}_t\,\hat{y}_{t+1} = B\hat{y}_t\,. \tag{2.12}$$

Given $(\hat{\kappa}_{t-1}, \hat{z}_t)'$, I solve for $\hat{\gamma}_{ht}$ and $\hat{\kappa}_t$ as functions of $(\hat{\kappa}_{t-1}, \hat{z}_t)$: these solutions are the linear approximations to the functions Γ_h and Ψ. (Details of these derivations are given in Appendix A.)

Before turning to the implications of these solutions, it is useful to reinterpret the Euler equation (2.9) as follows. A log-linearization of the effort equation (2.7), $e_t = \kappa_t\,\varphi(x_t)$, gives

$$\hat{e}_t = \hat{\kappa}_t + x^*\frac{\varphi'(x^*)}{\varphi(x^*)}\,\hat{x}_t = \hat{\kappa}_t + \frac{\alpha_1}{\alpha_4}\hat{x}_t\,. \tag{2.13}$$

This expression can be substituted in the Euler equation (2.9) to obtain

$$\alpha_0\hat{\omega}_t - \alpha_4\hat{e}_t + \alpha_2\hat{\gamma}_{ht} - \alpha_3\mathrm{E}_t\hat{\gamma}_{ht+1} = 0\,.$$

Using the fact[7] that $\alpha_0=0$ and α_2 is approximately equal to α_3, this equation gives the behavior of effort in terms of the expected deviation of future hours growth from current growth,

$$\hat{e}_t \cong -\frac{\alpha_3}{\alpha_4}(\mathrm{E}_t\hat{\gamma}_{ht+1} - \hat{\gamma}_{ht})\,. \tag{2.14}$$

This interpretation shows that current deviations in effort are negatively related to how expected future growth of hours compares to present. The intuition is

[7] $\alpha_0=0$ results from the fact that the steady state level of effort is at the point of unitary elasticity of the function g (see Appendix A), while $\alpha_2 \approx \alpha_3$ if the growth rate of capital is sufficiently small and the discount factor approximately equal to 1.

that when the growth of hours next period is expected to be bigger than current growth, firms start to increase labor today (the marginal cost of increasing labor is lower today, taking into account the reduction of future adjustment costs), so decreasing effort. The slow response of labor to cyclical variations, due to costs of adjustment, generates an immediate response of effort. This interpretation also stresses that the crucial parameter in the model is the relative cost of adjusting hours versus effort (α_3/α_4 is a scaled ratio of the curvature of the adjustment cost function to that of the cost of effort). The next section provides an empirical estimate of this cost.

Next, I consider the implications of the derived solution for the co-movements of the observable stationary variables,

$$v_t = [\gamma_{ht}, x_t, \gamma_{kt}, \gamma_{At}]\,,$$

where by $\{\gamma_{At}\}$ I denote a vector of stationary aggregate variables which belong to the vector z_t, and therefore provide information about the future evolution of the variables $\{x_{t+j}, \gamma_{kt+j}, \omega_{t+j}\}$. Note that neither γ_Θ nor κ_t are among the observables.[8] This means that I cannot directly conduct tests on the functions Γ_h and Ψ.

I can, however, test certain implications of the model about innovations in the aggregate variables, if I make further assumptions about the process $\{\hat{z}_t\}$. Specifically, I now assume:

(i) that the evolution of the aggregate variables is independent of sector-specific shocks (in particular, of sectoral technology shocks), so that I can write

$$\hat{\gamma}_{At} = W(L)\hat{\gamma}_{At-1} + \nu_{At}\,,$$

where $W(L)$ is a finite-order matrix lag polynomial, and the vector white noise ν_{At} is independent of the sectoral shocks;

(ii) that sectoral technology Θ_t follows a logarithmic random walk, so that I can write

$$\hat{\gamma}_{\Theta t} = \nu_{\Theta t}\,,$$

where $\nu_{\Theta t}$ is a white noise variable, independent of ν_{At} and also independent of (κ_{t-1}, z_{t-1}).

With these assumptions, I try to assess whether this model is able to explain the procyclical behavior of productivity observed in the data. Specifically, I try to see if the model is able to replicate the dynamic response of sectoral variables to

[8] I cannot take the sectoral Solow residuals to be a measure of γ_Θ because such a measure neglects the existence of variations in labor effort. Furthermore, as it is discussed below, I do not necessarily wish to assume that firms are competitive, so that factor shares in total revenues need not represent production function elasticities as it is assumed in the construction of Solow residuals.

aggregate innovations, so that one can argue that the mechanism of labor hoarding and varying labor utilization works as an important propagation mechanism of aggregate perturbations. The results of this experiment are discussed in Section 4.

3. Euler equation estimation

Table 2 presents estimates of the Euler equation (2.9), with a test of the moment conditions and the restrictions imposed on the parameters, for a panel of 11 two-digit sectors of the manufacturing industry.[9] These estimates are a first test of the model, specifically of the importance of adjustment costs. Because the restriction that all sectors share the same parameters is not rejected at standard significance levels, I report in the table only results of estimates obtained by imposing that restriction. Some of the estimated parameters are also used in the simulation excercise that follows.

I estimate a differenced form of Eq. (2.9). This transformation is motivated by the need to work with observable variables, while in Eq. (2.9) both $\hat{\omega}_t$ and $\hat{\kappa}_t$ are ratios to the unobservable technology process Θ_t. In log levels, Eq. (2.9) is (lower-case letters indicate natural logarithms)

$$\alpha_0 w_t - \alpha_0\theta_t - \alpha_1 q_t + \alpha_1\eta k_t + \alpha_2(h_t - h_{t-1}) - \alpha_4 k_t$$
$$+\alpha_4 h_t + \alpha_4\theta_t - \alpha_3 \mathrm{E}_t(h_{t+1} - h_t) + c_0 = 0\,,$$

where the constant term c_0 includes all the steady state values. Dividing through α_1 and taking first differences, I obtain an equation in the rate of growth of output, capital, hours, wages, and technology

$$\Delta q_t - \pi_0\Delta h_t + \pi_2\Delta h_{t-1} + \pi_3(\mathrm{E}_t\Delta h_{t+1} - \mathrm{E}_{t-1}\Delta h_t)$$
$$-\pi_4\Delta k_t - \pi_5\Delta w_t - \pi_6\Delta\theta_t = 0\,, \tag{3.1}$$

where $\pi_0 = (\alpha_2 + \alpha_4)/\alpha_1$, $\pi_2 = \alpha_2/\alpha_1$, $\pi_3 = \alpha_3/\alpha_1$, $\pi_4 = \eta - \alpha_4/\alpha_1$, $\pi_5 = \alpha_0/\alpha_1$, $\pi_6 = (\alpha_4 - \alpha_0)/\alpha_1$. By assumption $\Delta\theta_t = \delta + v_{\theta t}$, and it is stationary. Using the fact that $\Delta h_t = \mathrm{E}_{t-1}\Delta h_t + v_{ht}$ and setting $\pi_1 = \pi_0 + \pi_3$, I write the estimating equation as

$$\mathrm{E}_{t-1}(\Delta q_t - \pi_1\Delta h_t + \pi_2\Delta h_{t-1} + \pi_3\Delta h_{t+1} - \pi_4\Delta k_t - \pi_5\Delta w_t - \pi_6\delta)$$
$$= \mathrm{E}_{t-1}\pi_6(v_{ht} + v_{\theta t}) = 0\,.$$

I perform the estimation by an overidentified linear GMM procedure, where the instruments are all dated time $t-1$ and earlier. The particular parameter of

[9] Appendix B contains a description of the data used. I chose to analyze only those sectors where the two phenomena I am investigating – the cyclical behavior of productivity and the correlation of productivity with aggregate variables – are particularly strong, as the graphs in Fig. 1 and the correlations in Table 1 show.

Table 2
Euler equation estimates: Panel regression, 11 manufacturing sectors, annual data 1950/1988[a]
$\Delta q_t = d + \pi_1 \Delta h_t - \pi_2 \Delta h_{t-1} - \pi_3 E_t \Delta h_{t+1} + \pi_4 \Delta k_t + \pi_5 \Delta w_t + u_t$[b]

CRS (η=1)	π_1	$\pi_2=\pi_3$	μ	J test [p-value][c]	D test [p-value][d]
Model 1					
Perfect competition	1.075	0.177	1	0.11	0.02
($\pi_4 = 1 - s_H$)	(0.02)	(0.01)			
Model 2					
Max mark-up	1.158	0.079	1.39	0.13	0.12
(π_4=0)	(0.02)	(0.01)			
Model 3					
Interm. mark-up	1.117	0.128	1.19	0.16	0.12
($\pi_4 = avg(0, 1 - s_H)$)	(0.02)	(0.01)			
Non-CRS	π_1	$\pi_2=\pi_3$	μ	J test [p-value]	D test [p-value]
Model 4					
No pure profits	1.005	0.233	0.75	0.24	0.03
(μ/η=1)	(0.03)	(0.02)			
Model 5					
Max pure profits	1.062	0.167	1.01	0.41	0.52
($\mu/\eta=1/s_H$)	(0.03)	(0.02)			

[a]GMM estimation. Instruments are two lags of hours in the sector, lagged capital, two lags of hours in the manufacturing industry (excluding the sector itself), lagged wages, and two lags of aggregate consumption. In all rows it is imposed that the coefficient on wages is zero, that $\pi_2 = \pi_3$, and that $\pi_1 - (\pi_2 + \pi_3) + \pi_4 = \eta$. An additional restriction, on π_4 or on μ/η, distinguishes the different models. Standard errors are reported in parentheses.

[b]Δx_{it} indicates the log difference of variable x in sector i at time t. q is industrial production, h is total hours of production workers, k is net capital stock in constant dollars, w is real wage.

[c]The statistic J is distributed as a chi-square with 87 degrees of freedom. It tests for the overidentifying restrictions.

[d]The statistic D, constructed as the difference between the J statistic of the restricted model and that of the unrestricted (not reported here), is distributed as a chi-square with 54 degrees of freedom. It tests simultaneously the restriction that the parameters are the same across sectors and the restrictions specific to each model.

interest is π_3, which measures the cost of adjusting hours relative to the cost of increasing labor utilization. The estimates are obtained under three restrictions on the parameters π imposed by the model. First, as pointed out before (Footnote 7), because the steady state level of effort is at the point of unitary elasticity of the function g, the parameter $\alpha_0 = 0$, and therefore $\pi_5 = 0$.[10] Second, when the rate

[10] This restriction is driven by the form of the cost function, where the wage enters multiplicatively.

of growth of capital is sufficiently small, and the discount factor approximately equal to one, α_2 is approximately equal to α_3. Third, the ratio $\alpha_4/\alpha_1 = \eta\tilde{s}_H$, where $\tilde{s}_H$ is the share of labor in total costs ($\tilde{s}_H = wH/(wH + rK)$).[11] This makes the parameter $\pi_4 = \eta - \alpha_4/\alpha_1 = \eta - \eta\tilde{s}_H = \eta\tilde{s}_K$, where $\tilde{s}_K$ is the share of capital in total costs ($\tilde{s}_K = rK/(wH + rK)$). Finally, the definition of the πs implies that $\pi_1 + \pi_4 - (\pi_2 + \pi_3) = \eta$.

In the estimation below I therefore impose and jointly test the restrictions that $\pi_5 (= \alpha_0/\alpha_1) = 0$, $\pi_2 (= \alpha_2/\alpha_1) = \pi_3 (= \alpha_3/\alpha_1)$, and that $\pi_1 - (\pi_2 + \pi_3) + \pi_4 = \eta$. To impose the last constraint, I consider in turn the case of constant returns to scale ($\eta = 1$), and the case of nonconstant returns ($\eta \neq 1$).

The results under the hypothesis of constant returns are reported in the first three rows of Table 1, where each one corresponds to a different hypothesis about the market structure. Row 1 has results for the perfect competition case, where the coefficient of capital, π_4, is equal to $1 - s_H$, while the second and third rows allow some degree of market power.[12] In the model of row 2 the mark up coefficient μ (defined as P/MC) takes its maximum value of $1/s_H$, obtained by imposing $\pi_4 = 0$. In row 3, I impose π_4 to be equal to the average of the two boundary values, 0 and $(1 - s_H)$.

For the case in which η is different from 1 (models 4 and 5), I impose that $[\pi_1 - (\pi_2 + \pi_3)](1 - (\mu/\eta)s_H) = \pi_4((\mu/\eta)s_H)$ and consider the two boundary values for the level of pure profits (the ratio μ/η).[13]

For profits to be non negative, $\mu/\eta \geqslant 1$. For the return on capital to be non negative, μ/η is bounded from above by the inverse of the labor share. I therefore perform the estimation assuming in turn for μ/η the values 1 and $1/s_H$. The results are reported respectively in rows 4 and 5.

For each different model specification, the table reports the estimated value of the relevant parameters, together with the statistic J, which tests the overidentifying restrictions, and the statistic D, which tests the joint restrictions on the parameters.[14]

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[11] This last equality follows from the definition of α_4/α_1, and it is derived in Appendix A.

[12] There is some empirical evidence of a quite large degree of market power in several sectors of the manufacturing industry (see Hall, 1988; Domowitz, Hubbard, and Peterson, 1988). Hall's estimates, for example, show a particularly high mark-up for sectors like Papers, Chemicals, and Primary Metals.

[13] The constraint that I impose is just another way of writing the constraint on the sum of the π's. To obtain it, I first use $\pi_4 = \eta\tilde{s}_K$ to rewrite the constraint as $[\pi_1 - (\pi_2 + \pi_3)]\tilde{s}_K = \pi_4\tilde{s}_H$. Then, noting that $\mu[(wH + rK)/Q] = \eta(f/(Q/K^\eta)) = \eta$, I use the relation between shares in total revenue and shares in total costs $\tilde{s}_K = rK/(wH + rK) = (\mu/\eta)(rK/Q) = (\mu/\eta)s_K$ and $\tilde{s}_H = wH/(wH + rK) = (\mu/\eta)(wH/Q) = (\mu/\eta)s_H$ to rewrite π_4 as $\pi_4 = \mu s_K = \eta - \mu s_H$.

[14] This statistic, constructed as the difference between the J statistic of the restricted model and the J statistic of the corresponding unrestricted model, is analogous to the test based on the difference between the restricted and unrestricted sum of the squared residuals (see Newey and West, 1987, for the discussion of this statistic). It tests simultaneously the restriction that all the parameters are the same across sectors and the within-sector parameter restrictions discussed above.

Looking first at the case of constant returns, the adjustment cost parameter is estimated quite precisely in all the models, and it is significant both in the case of perfect competition, and in the case of mark-up pricing, although its size is decreasing in the amount of mark-up allowed. However, the restrictions imposed by the perfect competition model appear to be rejected. The models with mark-up pricing pass instead both tests, and the implied mark-up range between 1.2 and 1.4.

When I relax the assumption of constant returns, I again reject the restrictions imposed by the hypothesis of perfect competition, but I do not reject models with mark-up pricing. However, while the size of the adjustment cost is slightly bigger than that obtained in the corresponding models with constant returns, the estimate of the returns to scale parameter, about 0.75, certainly rules out the hypothesis of increasing returns. Finally, as in the constant returns case, the size of the adjustment cost parameter is inversely proportional to the allowed degree of departure from competition, being the highest in the case of zero pure profits.

As a whole, these results suggest that, for the group of sectors considered, the theoretical framework of adjustment costs and variable rate of utilization for labor is a sensible mechanism to model the dynamics of labor demand. Whether one wants to depart or not from the constant returns case, a model with a moderate degree of market power fits the data reasonably well.

The finding of positive labor adjustment costs in manufacturing is in line with many previous studies (for a survey see Nickell, 1989). By using a convex cost of changing hours from one period to the next, this model is similar to those estimated, for example, by Pindyck and Rotemberg (1983), Sargent (1978), Shapiro (1986), and Sims (1974). However, here the introduction of a labor utilization variable modifies the form of the production function, and the projection of the labor utilization rate onto the space of variables known at the time of decision making introduces dynamic elements into the predicted relation between output and measured inputs. Moreover, I am able to test whether there are significant costs of adjusting hours relative to the cost of increasing labor utilization without choosing a specific functional form for the cost function.

The lag structure of the estimated equation depends on the specification of the adjustment cost. Were the costs associated to adjusting hours spread over more than one period, that equation would have a longer lag structure.

With this first assessment of the model, I now proceed to explore whether it may also be the case that aggregate variables act as a proxy for the unobserved rate of utilization of labor in the industry sectors. For this exercise I simulate the model as described below, using in turn the estimated values for the structural parameters α_3/α_1 and α_4/α_1 that I just described. Because the hypothesis of perfect competition was rejected by the data, I report the simulation results only for the three cases in which some mark-up is allowed (models 2, 3, and 5).

4. Simulation of the model

In this section I investigate whether the dynamic responses of sectoral hours and productivity to an aggregate shock, generated by the model, trace those estimated by fitting a simple vector autoregressive process to the data. As aggregate variable I chose aggregate gnp, which has good forecasting power for sectoral activity.[15] However, in order to isolate a permanent shock, I control for the transitory component of aggregate output by defining the aggregate variables block of my forecasting vector – the component indicated by γ_A in the model of Section 2 – as a vector including aggregate gnp and the ratio of aggregate consumption of nondurables and services to gnp.[16] As the discussion in the introduction showed, the model of this paper implies that there should be no long-run response to persistent aggregate shocks. To recall, the model is built upon the hypothesis that fluctuations in the rate of utilization of labor are the main factor driving the cyclical behavior of total factor productivity and are the channel through which shocks to aggregate activity affect productivity.[17]

Figs. 2.1–2.9 show the results of the analysis performed on the two-digit sectors of the manufacturing industry analyzed in the previous section.

I first fit for each sector a VAR(1) to a five-dimensional vector including aggregate output, the aggregate consumption/output ratio, and capital, hours, and output of the sector. In the estimation I impose the cointegrating restriction that the capital/output ratio in the sector is a stationary variable, which is consistent with the hypothesis of constant returns to scale. Aggregate output, capital, and hours in the sectors are modeled as I(1) processes.[18] The vector of variables y_{it} is therefore defined as $y_{it} = [\Delta y_t,\ c_t - y_t,\ q_{it} - k_{it},\ \Delta k_{it},\ \Delta h_{it}]'$, where lowercase letters denote natural logarithms, and $(\Delta y,\ c - y)'$ correspond to the vector γ_A described in the model. I also impose that the block of the two aggregate variables is not affected by past sectoral variables.

From the estimated VAR, I compute the dynamic response of aggregate output and of capital, hours, and output/capital ratio in each sector to an innovation in aggregate output. For this exercise, I orthogonalize the errors by a lower triangularization of the residual covariance matrix: this orthogonalization implies that

[15] On average across the sectors, one can reject the hypothesis that gnp does not affect sectoral activity with the standard 95% confidence.

[16] The consumption/output ratio has proved to be a powerful forecaster of long-horizon growth of gnp. In particular, a bivariate VAR with output growth and consumption/output ratio allows a meaningful decomposition of transitory and permanent components of output (see, among others, Cochrane, 1994).

[17] As a first approximation, I assume that the time interval in the model is a year, so that the generated time series are annual observations: this allows a direct comparison with the dynamic pattern estimated on annual data (the only frequency available for sectoral data on capital and value added).

[18] Standard unit root tests are conducted to justify the specification of the model in first differences; a two-step cointegration test is also conducted to test for the stationarity of the output/capital ratio.

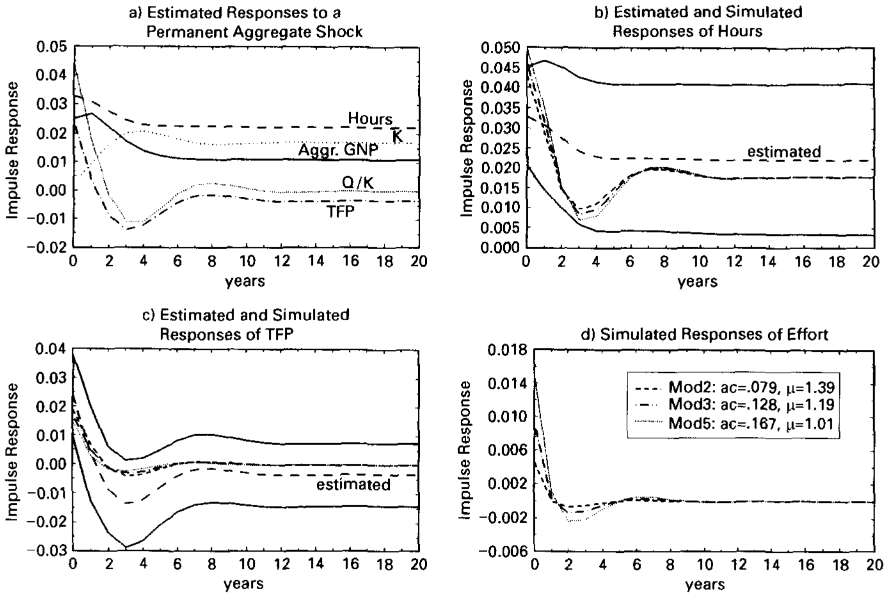

Fig. 2.1. Paper.

Fig. 2. Graph a) plots the cumulative responses of aggregate gnp (solid line), sectoral hours (dashed line), capital (dotted line), output/capital ratio (closely spaced dots), and total factor productivity (TFP, dashes and dots line); graphs b) and c) plot respectively the response of hours and total factor productivity estimated from the data (the dashed line) and those predicted by the 3 models chosen, whose respective parametrization are indicated in the box of graph d). Graph d) plots the responses of effort predicted by the same 3 models.

innovations in gnp measure a permanent aggregate shock, and it also reflects the hypothesis that aggregate shocks are exogenous with respect to sectoral activity. In each figure the upper left corner graph (part a) plots the cumulative responses of aggregate gnp (solid line), sectoral hours (dashed line), sectoral capital (dotted line) and sectoral output/capital ratio (closely spaced dots), together with the implied response of sectoral total factor productivity (TFP, dashes and dots line) – which is the cumulate of productivity growth as measured by the Solow residuals.

These figures show that a positive shock to gnp, that has permanent effects on gnp,[19] also has a significant and positive persistent effect on both capital and hours. It also affects total factor productivity (although in few sectors I cannot exclude that the impact is not significantly different from zero). The effect on productivity, however, is very short-lived. Productivity tends to return to its

[19] Although small, the long-run response of gnp to the shock remains significantly different from zero at the horizon of 20 years (its standard error is about 0.003).

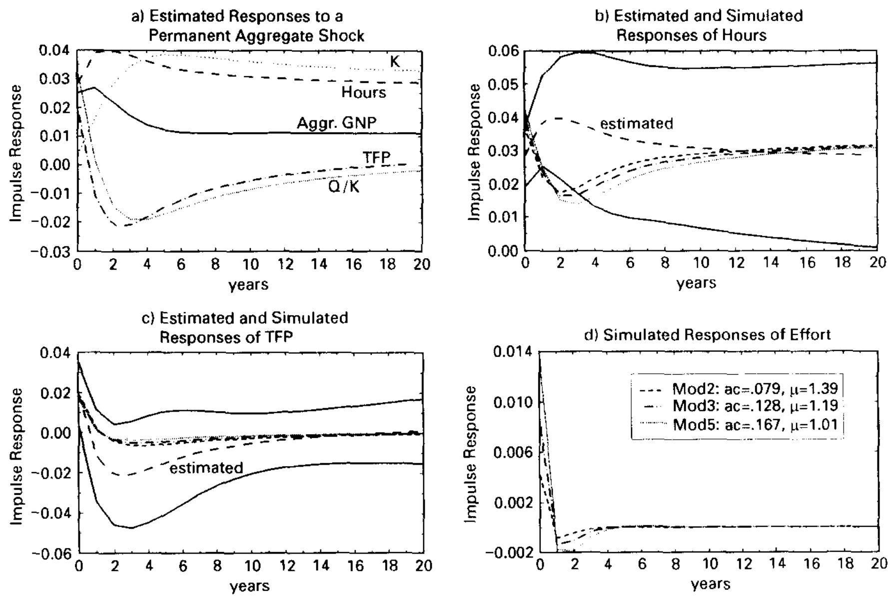

Fig. 2.2. Chemicals.

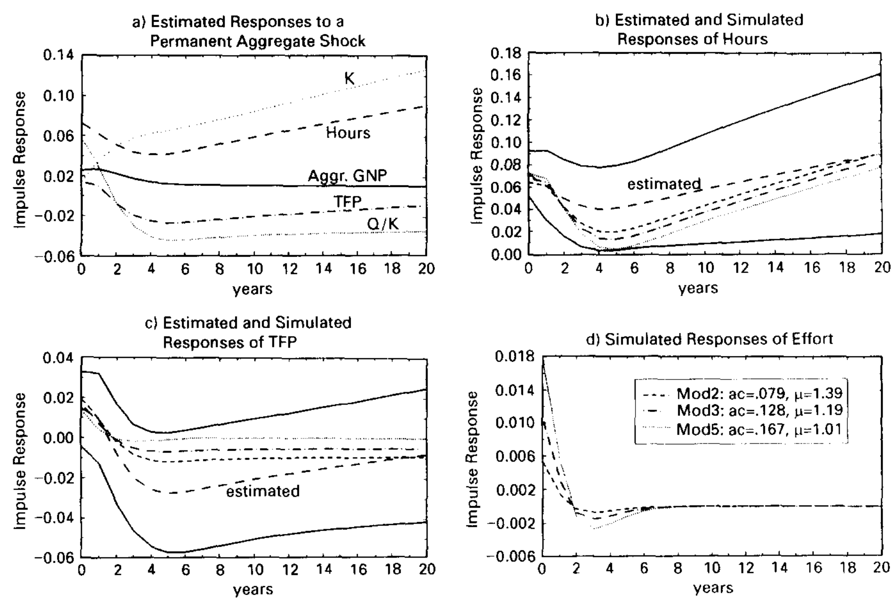

Fig. 2.3. Rubber and Plastic.

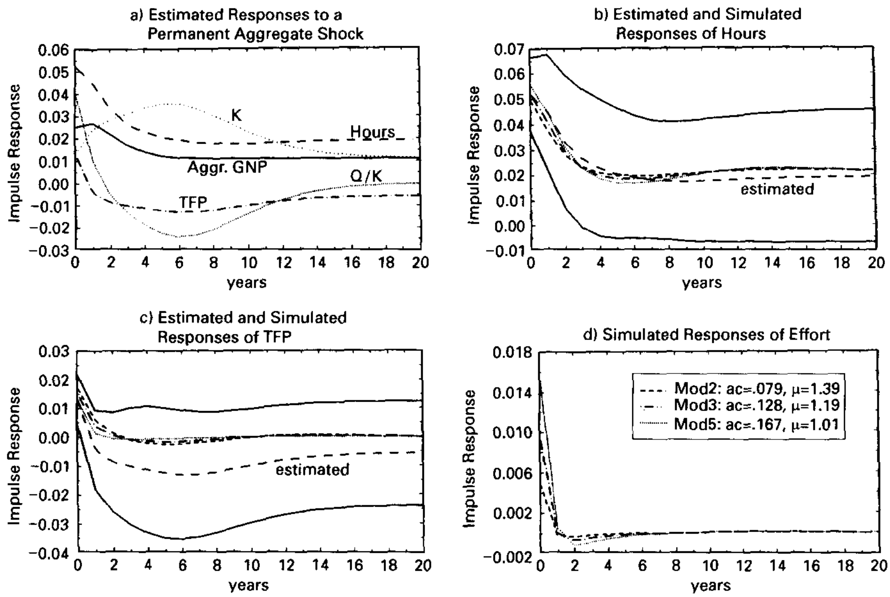

Fig. 2.4. Clay, Glass, and Stone.

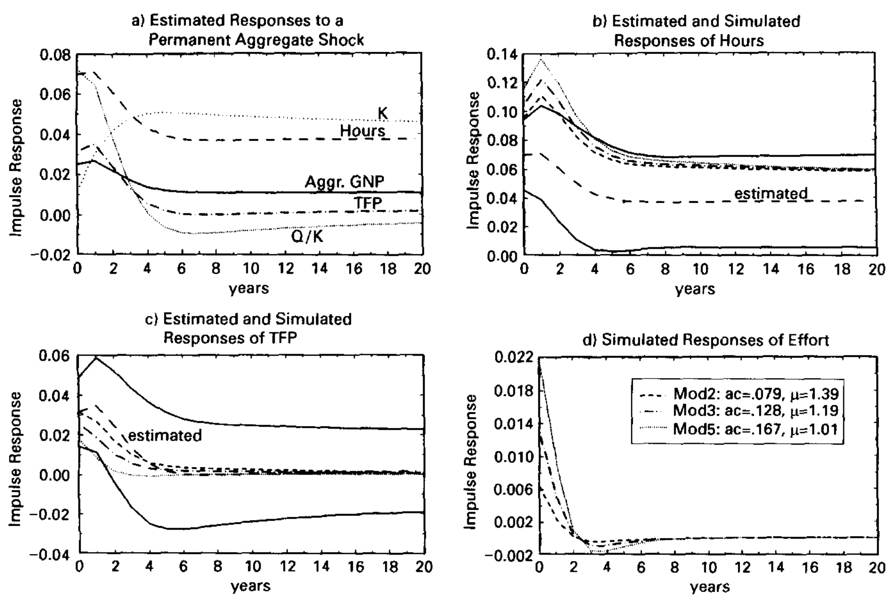

Fig. 2.5. Primary Metals.

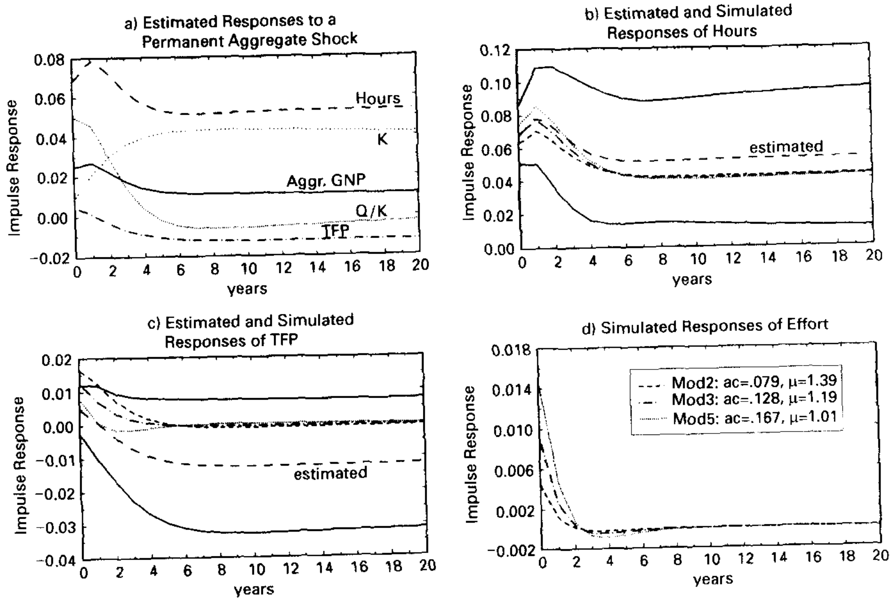

Fig. 2.6. Fabricated Metals.

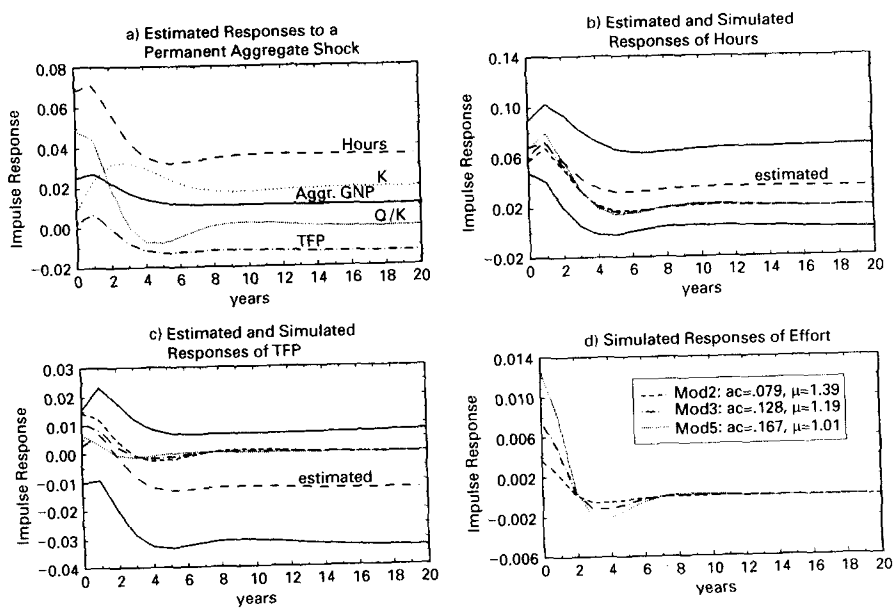

Fig. 2.7. Electrical Machinery.

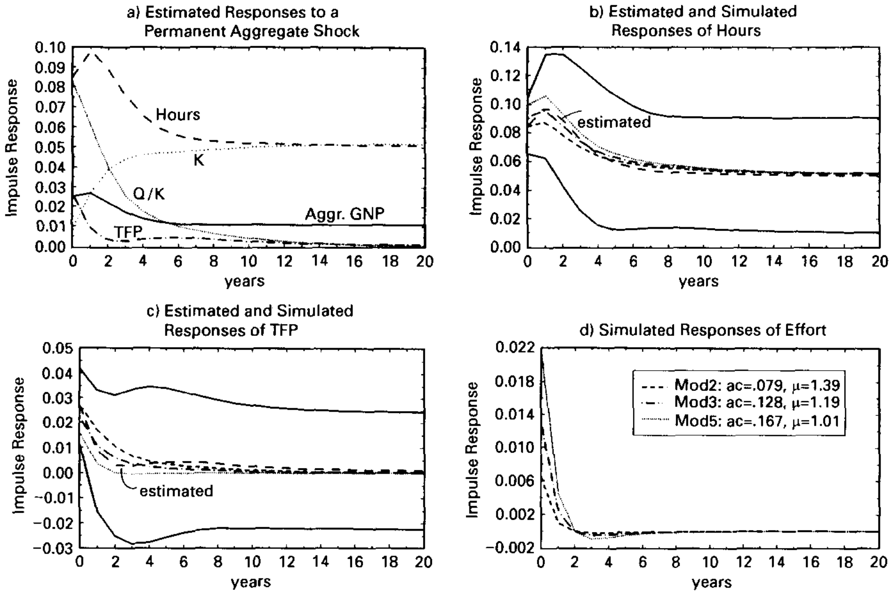

Fig. 2.8. Transportation Equipment.

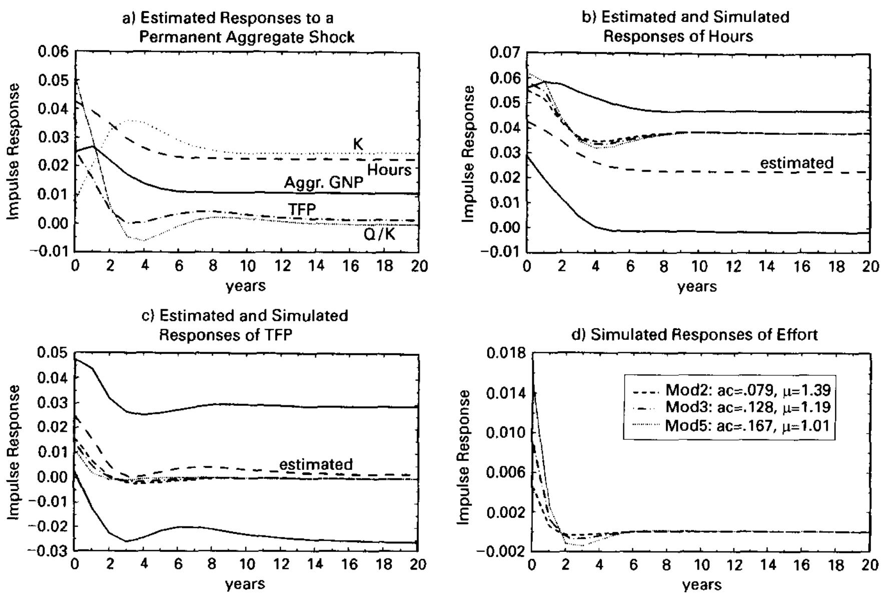

Fig. 2.9. Miscellaneous Manufactures.

steady state value of zero within at most two periods from the shock. The impact effect has the highest coefficient in all the sectors but primary metals, where the response peaks instead at lag 1.

These are the 'facts' that I want the model to be able to explain. According to the model, the behavior of productivity reflects short-run variation in effort. As a consequence, variations in productivity should be larger in sectors with higher adjustment costs[20] and for which aggregate variables have higher forecasting power.[21] I turn therefore to discuss the model implications of a unit shock to aggregate output.

To simulate the model response to a shock, I do the following. For each sector i I estimate the matrix V in the system

$$\hat{z}_{it+1} = V\hat{z}_{it} + v_{it+1}\,,$$

in which the vector $\hat{z}_{it}$ is defined as $(\hat{x}_{it},\ \hat{\gamma}^i_{kt},\ \hat{\gamma}_{At})$, and compute the impact response of the variables in $\hat{z}$ to a unit innovation in gnp, the first component of $\hat{\gamma}_A$. Then I take the model solution for $\hat{\gamma}^i_{ht}$ as a function of $(\hat{\kappa}_{it-1},\ \hat{z}_{it})$[22] substitute it in the Euler equation (2.9) and in the evolution equation for $\hat{\kappa}$ (2.10) and compute $\hat{\gamma}^i_{ht+1}$ and all future values for 20 periods. I call $\hat{\gamma}^i_{ht+j}$ $(j = 1,\ldots,20)$ the 'simulated' response of hours in the model to a unit innovation in $\hat{\gamma}_A$. The response of capital and output is computed analogously. From these responses I construct the simulated TFP as the cumulate of the Solow residuals.

The evaluation of the model is then based on a comparison of the impulse response derived from the VAR fitted to the data and the one computed from the model solution.

To focus on the ability of the model to replicate the behavior of hours and productivity, I graph in parts b) and c) of the figures the responses, respectively, of hours and productivity. In each of these graphs, the dashed line is the response generated from the estimated VAR, while the other three lines – corresponding respectively to model 2 (small dashes), model 3 (dashes and dots), and model 5 (closely spaced dots) – are the responses simulated by the model under the three different parametrizations discussed above, each implying some degree of imperfect competition. Using the relation between the α parameters of the matrix $A^{-1}B$ and the πs of the estimated Euler equations ($\alpha_3/\alpha_1 = \pi_3$ and $\alpha_4/\alpha_1 = 1-\pi_4$), each simulation uses the estimated values of the adjustment cost and the elasticity of supply to effective labor reported in Table 2 for the specific model. Graph d) shows the response of effort. The legend in this graph displays the value of the

[20] A sector-by-sector estimate of the adjustment cost model (not reported in the current draft) indicates that these are Chemicals, Paper, and Primary Metals.

[21] The most sensitive sectors to the aggregate variables included here are Chemicals, Clay, Glass and Stones, Primary Metals, and Fabricated Metals.

[22] This is just solution (A.2) of Appendix A. I assigned to the structural parameters of the matrix $A^{-1}B$ the values estimated for the Euler equation.

mark-up μ and of the adjustment cost π_3 that characterize each parametrization. Finally, the thick lines in the graphs b) and c) are two standard error bands around the estimated values of hours and productivity.[23]

The performance of the model is assessed by its ability to generate impulse responses that are 'close' to the estimated response, in the sense of being within two standard error bands. The ability to trace the pattern of data varies moderately across the sectors. The response of total factor productivity is reproduced pretty closely for most of the sectors, while there is some mismatch in the short-run response of hours (slightly overstated in papers and primary metals, and with a different shape in chemicals). The response of 'effort' notably depends on the market structure. As (2.3) says, $\hat{e}_t = \hat{\kappa}_t + x^*(\varphi'(x*)/\varphi(x*)\hat{x}_t = \hat{\kappa}_t + (1/\mu s_H)\hat{x}_t$, so that the cyclical behavior of effort is decreasing in the degree of mark-up. The last two graphs of each picture summarize the trade-off implicit in the model's explanation of the productivity behavior. Total factor productivity is measured here as[24] $TFP = \mu s_H \hat{e}_t - (\mu - 1)s_H\hat{\kappa}_t$. If $\mu = 1$, its cyclical behavior is totally driven by effort. With $\mu > 1$ however, since the response of $\hat{\kappa}_t$ is typically 'countercyclical', total factor productivity has a pronounced cyclical pattern even when the response of effort is small, and more so depending on the size of μ.

Before concluding I want to point out how to translate these results – specifically the transitory response of measured sectoral *TFP* to aggregate innovations – into a traditional production – function regression framework.

Let $\mathrm{E}_t\,\hat{y}_{t+1} = P[\hat{\kappa}_{t-1}, \hat{z}_t]'$ be the solution for the whole vector $\hat{y}$, and denote by $P_{1.} = \{p_{1j}\}$ the first row of the matrix P. Then $\mathrm{E}_t\hat{y}_{ht+1} = P_{1.}[\hat{\kappa}_{t-1}, \hat{z}_t]'$.

This solution can be used to recover the term in expected future hours that appears in Eq. (3.1):

$$\begin{aligned}\mathrm{E}_t\Delta h_{t+1} - \mathrm{E}_{t-1}\Delta h_t = {} & (p_{14} - p_{13})\Delta k_t + (p_{11} - p_{14})\Delta k_{t-1} - p_{11}\Delta h_{t-1} \\ & + p_{13}\Delta q_t + p_{15}(\Delta a_t - \Delta a_{t-1}) + p_{12}\Delta\theta_t \\ & -(p_{11} + p_{12})\Delta\theta_{t-1}\,. \end{aligned} \tag{4.1}$$

Substituting this expression back in Eq. (3.1) we get a production function that depends on current and past values of the inputs and also on current and past values of the aggregate variable

$$\begin{aligned}\Delta q_t = {} & \vartheta_1\Delta h_t + \vartheta_2\Delta h_{t-1} + \vartheta_3\Delta k_t + \vartheta_4\Delta k_{t-1} + \vartheta_5(\Delta a_t - \Delta a_{t-1}) \\ & + \vartheta_6(1 + \rho L)\Delta\theta_t\,, \end{aligned} \tag{4.2}$$

where the parameters ϑ_i are combinations of the structural parameters and of the parameters of the forcing process z.

[23] The standard errors are computed with bootstrapping on 1000 simulations.

[24] This definition does not include the technology term because of the assumed independence of that term from aggregate gnp, which is the only perturbation considered here.

Eq. (4.1) shows that aggregate variables are correlated with the expected future labor growth because they are good forecasting variables. This channel brings them into the production-function regression (4.2) with a specific pattern of coefficients: coefficients on consecutive lags are the same but have opposite sign, so that the effect in each period vanishes in the next. As I show in Sbordone (1997), this is a testable implication in the regression analysis context. I argue there that my empirical results do not support the interpretation of aggregate variables as a measure of external increasing returns, as in models like Baxter and King (1991), because they have no long-run effect on the *level* of sectoral productivity.

Moreover, in the absence of adjustment costs, the parameters ϑ_2, ϑ_4, and ϑ_5 in (4.2) are all zero, because they are functions of α_2 and α_3 which are both equal to zero. Therefore there is no dynamics in the production function regression and no dependence on aggregate variables. The intuition for this result is that all the dynamic implications of the model come from the movement of effort (see Eq. (2.14)). With no adjustment costs there is no cyclical variation of effort (e_t is always equal to its equilibrium value e^*) and, as a result, there is no movement in Solow residuals beyond pure variations in technology.

5. Conclusion

In this paper I construct a model of labor demand under the hypothesis that firms, facing costs of adjusting hours of work, respond to cyclical movements in activity by varying the rate of utilization of their workforce. The purpose of the model is to rationalize the observed procyclical movements in total factor productivity, giving at the same time an interpretation of the empirical results about the effects of variations in aggregate activity upon sectoral productivity. This interpretation stresses the information content of aggregate variables for the decisions in individual sectors about labor inputs.

The model performs reasonably well. First, it gives a significant estimate of adjustment costs, and its implied restrictions are not rejected by the data. Second, variations in labor utilization as a response to aggregate innovations generate short run dynamics in total factor productivity close to that displayed by actual data. These results support the evidence of Fay and Medoff (1985) at plant level, and agree with the conclusions of other authors (Rotemberg and Summers, 1990; Burnside, Eichenbaum, and Rebelo, 1993) who stress the importance of labor hoarding in explaining the cyclical behavior of productivity, on the basis of evidence independent of that considered here.

While I have used the term 'effort' to refer to the variable utilization margin that is omitted in a standard production function in terms of measured inputs, nothing about the structure of my theoretical or econometric model requires that the omitted variable be given this interpretation. Thus the plausibility of my conclusions, considered more generally, does not depend upon a claim that variations in work effort is the most important such margin available to producers (in addition to varying measured capital and labor inputs). The literature has suggested several other kinds of omitted variables that may also be important, and these other hypotheses are also consistent with the basic structure proposed here.

For example, other authors have proposed a variety of reasons why total man-hours may not be a proper measure of the effective labor input. Bils and Cho (1994) assume that increases in the number of employees and increases in the hours worked per employee affect output differently, while Hansen and Sargent (1988) assume that increases in straight time hours and increases in overtime hours have different effects. In these models, cyclical shifts in the composition of total man-hours are predicted, due to differential adjustment costs associated with the two margins, and the composition variable is essentially an omitted variable in the standard aggregate production function (relating output to man-hours), like the 'utilization rate' in the present model. Thus the qualitative implications of models of those types are quite similar to those of the model presented here. The difference is primarily that those models suggest a particular measurable aspect of the labor input that could be used to eliminate the omitted variable problem, while the model presented here is more general, and does not commit itself to any particular source of utilization variations; as a consequence, it must also use a more indirect estimation strategy to deal with the omitted variable problem.

The dynamic effects considered in this paper could be generated as well by a model where what changes in response to increases in demand is instead the utilization rate of capital. If direct observations on capital utilization are not available, this coefficient may be solved for in terms of observables in the same way I do for labor in this paper. Although disentangling the two mechanisms may be worth investigating,[25] if one makes the reasonable assumption of complementarity between bodies and machines (a more intensive utilization of machines requires more human effort),[26] a model with variable utilization of both capital and labor probably has qualitative properties much like the simpler model of labor hoarding considered here.

As another example, a recent paper by Basu (1995) proposes that cyclical variations in measured productivity result from changes in the relative use of intermediate versus primary inputs in the production function. In Basu's model, the cyclical change in input composition results from changes in the relative price

[25] This route has been taken in two recent papers by Burnside and Eichenbaum (1994) and Burnside, Eichenbaum, and Rebelo (1995), the first by estimating an implicit rate of utilization for capital, the second by proxying it with data on electricity consumption. Both find that the inclusion of capital utilization accounts for a significant part of measured cyclical productivity variations.

[26] The complementarity assumption is made, for example, by Abbott et al. (1988), who use hours per employee as a proxy for both capital and labor utilization. Shapiro (1993) uses a direct measure of the workweek of capital, from an unpublished panel of observations at plant level, to show that a variable workweek of capital solves the puzzle of procyclical total factor productivity.

of intermediate versus primary inputs, due to cyclical variations in mark-ups. In such a model, value added production functions may exhibit procyclical measured productivity and spurious dependence of sectoral output upon aggregate variables. It is easy to see that such an explanation is perfectly compatible with the one proposed here. My utilization variations can be interpreted as referring to variations in the share of materials inputs,[27] which affects the relation between value added and primary input usage if there is imperfect competition. The function $g(e)$ is in this case replaced by the price of materials inputs relative to labor. Under this interpretation of my model, a change in the relative composition of the inputs used in production can result from the existence of adjustment costs for hours, and would not require (as in Basu's model) any change in their relative unit cost. In this way, this input composition effect could also generate the pattern of dynamic correlations of aggregate activity and sectoral productivity that I studied here. Note that this would not be the case in Basu's model, where the change in input composition depends upon a change in the relative prices of materials and labor; in that case, there would be no reason for a persistent shock to aggregate activity to result only in a transitory effect on sectoral productivity.

The crucial contribution of the present analysis is not in the identification of a particular type of substitution between different margins in production, but in identifying the mechanism through which such substitution occurs. The key element of the proposed explanation is the existence of adjustment costs for the labor input, and the empirical analysis confirms the existence, in U.S. manufacturing, of a significant positive cost of this kind. In this sense, the model involves labor hoarding even if the utilization margin refers to a different input in production.

Appendix A: Proofs

A.1. Existence of a steady state vector (γ_h^*, κ^*).

Consider the case of constant (steady state) values for γ_k, γ_Θ, x, and ω, respectively indicated by γ_k^*, γ_Θ^*, x^*, and ω^*. In this case there exists a steady-state solution in which γ_h and κ are constant as well (given appropriate initial conditions). I denote these constant values respectively by γ_h^* and κ^*. The existence of a constant solution for κ may be verified from the Euler equation. In particular, the Euler equation gives

$$\omega^*[g(\kappa^*\varphi(x^*)) + \lambda(\gamma_h^*) - [\kappa^*\varphi(x^*)]g'(\kappa^*\varphi(x^*)) + \gamma_h^*\ \lambda'(\gamma_h^*)]$$
$$-R[\omega^*\gamma_\Theta^*(\gamma_h^*)^2\,\lambda'(\gamma_h^*)] = 0$$

[27] Elsewhere Basu gave exactly this interpretation to the materials share (see Basu, 1996).

or

$$[\kappa^*\varphi(x^*)]g'(\kappa^*\varphi(x^*)) = g(\kappa^*\varphi(x^*)) + \lambda(\gamma_h^*) + \gamma_h^*\lambda'(\gamma_h^*)[1 - R\gamma_\theta^*\gamma_h^*].$$

Therefore κ^* must satisfy

$$[\kappa^*\varphi(x^*)]\frac{g'}{g}(\kappa^*\varphi(x^*)) = 1 + \frac{\lambda(\gamma_h^*)}{g(\kappa^*\varphi(x^*))} + \frac{\gamma_h^*\ \lambda'(\gamma_h^*)}{g(\kappa^*\varphi(x^*))}[1 - R\ \gamma_k^*], \tag{A.1}$$

where I substituted $\gamma_k^* = \gamma_h^*\gamma_\Theta^*$ in the last square brackets. Assumption i) in the text guarantees that a unique positive solution for κ^* exists as long as we assume values for γ_Θ^* and γ_k^* that make the right-hand side of this equation positive. By assumption ii) – $\lambda(\gamma_h^*)$ and $\lambda'(\gamma_h^*)$ are both equal to 0 – the solution for κ^* implies that the steady state level of effort is at the point of unitary elasticity of the function g, i.e., at the level e^* that minimizes $g(e)/e$, as would be optimal in the absence of adjustment costs. The existence of a constant value for κ, κ^* implies that $\gamma_k = \gamma_\Theta\gamma_h$. Hence γ_h^* is indeed constant, and $\gamma_h^* = \gamma_k^*/\gamma_\Theta^*$.

A.2. Log-linear approximation to the functions Γ_h and Ψ

Consider now the case of small, stationary fluctuations in the variables log z_t around their mean values log z^*. The complete system of equations is

$$A\mathrm{E}_t\hat{y}_{t+1} = B\hat{y}_t,$$

where $\hat{y}_{t+1} = [\hat{\gamma}_{ht+1}, \hat{\kappa}_t, \hat{z}_{t+1}]'$. Given $(\hat{\kappa}_{t-1}, \hat{z}_t)'$, we want to solve for $\hat{\gamma}_{ht}$ as a function of $(\hat{\kappa}_{t-1}, \hat{z}_t)$ such that the vector lies in the subspace spanned by the right eigenvectors of $A^{-1}B$ with eigenvalues that are less than one in modulus.

A unique linear solution exists, because the matrix $A^{-1}B$ has exactly one eigenvalue with modulus greater than one. To see this, let the upper left 2× 2 blocks of the matrices A and B be denoted N and M respectively, say,

$$A = \begin{bmatrix} N & 0 \\ 0 & I \end{bmatrix} \quad \text{and} \quad B = \begin{bmatrix} M & S \\ 0 & V \end{bmatrix}.$$

Then the eigenvalues of $A^{-1}B$ are just the two eigenvalues of $N^{-1}M$ and the eigenvalues of V. The process $\hat{z}_t$ is by assumption stable, so the eigenvalues of V are of modulus less than one. $N^{-1}M$ has one eigenvalue of modulus less than one and one with modulus greater than one, because of the following inequalities:

$$\mathrm{tr}(N^{-1}M) - \det(N^{-1}M) = \frac{\alpha_3 + \alpha_4}{\alpha_3} > 1,$$

$$\mathrm{tr}(N^{-1}M) + \det(N^{-1}M) = \frac{2\alpha_2 + \alpha_3 + \alpha_4}{\alpha_3} > -1.$$

(These inequalities follow from $\alpha_2, \alpha_3, \alpha_4 > 0$.) Thus $A^{-1}B$ has exactly one eigenvalue with modulus greater than one. Denoting by $\mathbf{e}'$ the associated left eigenvector, the solution can be found by setting

$$\mathbf{e}'[\hat{\gamma}_{ht}, \hat{\kappa}_{t-1}, \hat{z}_t] = 0\,. \tag{A.2}$$

Solving this equation for $\hat{\gamma}_{ht}$ as a linear function of $(\hat{\kappa}_{t-1}, \hat{z}_t)$, I obtain a log-linear approximation to the function Γ_h. Substituting this solution into (2.10), I obtain $\hat{\kappa}_t$ as a linear function of $(\hat{\kappa}_{t-1}, \hat{z}_t)$ as well, which provides a log-linear approximation to the function Ψ.

A.3. $\alpha_4/\alpha_1 = \eta\tilde{s}_H$

From the definition of the structural parameters in expression (2.11) $\alpha_4/\alpha_1 = [x^*\varphi'(x^*)/\varphi(x^*)]^{-1}$ and from Eq. (2.3) we have that $\varphi(x) = eH\Theta/K$. Therefore

$$x^*\frac{\varphi'(x^*)}{\varphi(x^*)} = \left[\frac{d\log(Q/K^\eta)}{d\log(eH\Theta/K)}\right]^{-1} = \left[\frac{(eH\Theta/K)f'}{Q/K^\eta}\right]^{-1}, \tag{A.3}$$

where the second inequality follows from Eq. (2.2). The value of the numerator can be derived from the condition that the cost-minimizing choice of (K, H) satisfy $\partial Q/\partial K = \mu r$ and $\partial Q/\partial H = \mu w$ for some $\mu > 0$. From the definition of f, these two conditions are respectively $\eta K^{\eta-1}f - K^\eta f'(eH\Theta/K^2) = \mu r$ and $K^\eta f'(e\Theta/K) = \mu w$ so that, multiplying the first by K and the second by H, we get

$$\eta K^\eta f - K^\eta f'\left(\frac{eH\Theta}{K}\right) = \mu r K\,,$$

$$K^\eta f'\left(\frac{eH\Theta}{K}\right) = \mu w H\,.$$

These two expressions allow to derive the value of the elasticity of supply to effective labor in (A.3). The ratio $(eH\Theta/K)f'/\eta(Q/K^\eta) = \mu wH/(\mu wH + \mu rK) = \tilde{s}_H$, so the ratio $\alpha_4/\alpha_1 = \eta\tilde{s}_H$.

Appendix B: Data description and sources

All data used are annual series from 1947 to 1988. Industrial production data are from the Federal Reserve Bulletin, published by the Board of Governors of the Federal Reserve System. Data on industry value added are from the NIPA as published in the Survey of Current Business (July issue); the capital stock is net constant dollar fixed private capital, as published in the Survey of Current Business (August issue). Total hours of production workers are constructed as the product of employment and average weekly hours of production workers;

real wage is average hourly earnings deflated by the industry gnp deflator. All labor data are from 'Employment, Hours, and Earnings' by U.S. Department of Labor, Bureau of Labor Statistics. The labor share is computed as the average of total labor compensation over nominal GNP, both from the NIPA, as published in the Survey of Current Business (July issue). Aggregate GNP and aggregate consumption of nondurables and services are measured in constant 82 dollars, from CITIBASE.

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