Interpreting the Procyclical Productivity of Manufacturing Sectors: External Effects or Labor Hoarding?

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Interpreting the Procyclical Productivity of Manufacturing Sectors: External Effects or Labor Hoarding?

This paper investigates whether procyclical productivity is due to cyclical variations in the rate of utilization of labor or to technological externalities. By looking at the relation between sectoral productivity and the level of aggregate activity, empirical evidence is presented to distinguish the two hypotheses. Analysis of two-digit U.S. manufacturing industries shows that sectoral productivity is more closely related to the rate of change of aggregate activity than to its level. This result is consistent with the interpretation that cyclical productivity is due to cyclical variations in the rate of utilization of labor, which responds to expected future industry conditions. Aggregate variables in production-function regressions have therefore the role of forecasting variables for future industry conditions.

THE PROCYCLICAL MOVEMENT of both average labor productivity and total factor productivity is a well-known feature of aggregate fluctuations. That is, hours and employment vary less than proportionally with output over the cycle.[1] Figure 1 illustrates these phenomena for U.S. manufacturing. These empirical facts are puzzling because they seem to contradict the neoclassical assumption of diminishing returns to factors of production.

Indeed, some argue that procyclical productivity indicates the existence of increasing returns to scale in production. These can be internal increasing returns, which require the existence of firms with market power, as in the recent work of Robert Hall (1988, 1991), or external increasing returns as, for example, in the business cycle model of Murphy, Shleifer, and Vishny (1989) or of Baxter and King (1991).

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[1] Most evidence on this phenomenon comes from the U.S. manufacturing industry. For an overview, see Bernanke and Powell (1986). Among the earliest papers describing this phenomenon are Hultgren (1960) and Kuh (1965). See also Sims (1974).

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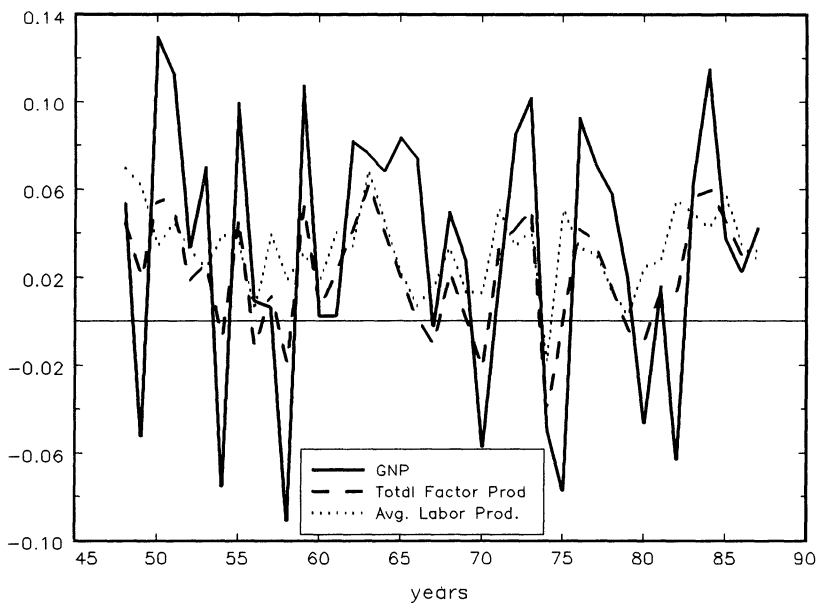

FIG. 1. U.S. Manufacturing: Output and Productivity Growth

Another, older, explanation is "labor hoarding" (Solow 1964). If firms face adjustment costs in hiring and firing workers, they tend to respond to short-run fluctuations in production by adjusting the rate of utilization of the labor force, as opposed to the labor force itself. As a result, a relatively stable labor input may be observed despite large oscillations in output, while the "effort" that workers supply varies over the cycle.

These explanations are not observationally equivalent. An explanation in terms of internal increasing returns implies that a simple production function relation between output and hours in each sector is correctly specified—the problem with the standard measure of growth in total factor productivity (the Solow residuals) is simply its use of the labor share as a measure of the elasticity of output with respect to labor input. On the other hand, in the case of either externalities or labor hoarding, there is an omitted variable problem with any such production function. When there are external increasing returns the relation between output and inputs in a sector is affected by activity in other sectors; in the labor hoarding case, the omitted variable is the variation in the rate of utilization of labor. In terms of econometric estimation, this means that additional variables may be found to enter significantly in production-function-type regressions—direct or indirect measures of the activity that produces the external effect, or any variable that may serve as a proxy for the unobserved variation in labor utilization.

Recent papers by Caballero and Lyons (1990, 1992) and Bartelsman, Caballero, and Lyons (1994) document a difference between the point estimates of the returns-to-scale parameter at the aggregate manufacturing level and that obtained at a two-digit level and interpret such a difference as a measure of an external effect. Furthermore, they show that including aggregate output in sectoral production-function regressions results in a significant coefficient on aggregate output in many sectors, and a substantial reduction in the estimated elasticity of the sector's output with respect to the sector's own inputs.

These results, however, can also be interpreted as evidence of "labor hoarding." Bernanke and Parkinson (1991) suggest a number of reasons why, when there is labor hoarding, cyclical indicators may be correlated with unobserved variations in labor utilization. For example, an industry's cost of adjustment may depend on aggregate labor market conditions; or fluctuations in industry demand due to cyclical conditions may have different persistence properties than those due to idiosyncratic sectoral shocks, so that firms will respond to shocks with different combinations of employment and utilization adjustments.

To explore the possibility that their results are due to unmeasured variations in factor utilization, Caballero and Lyons (1992) include direct proxies for effort in their production-function regressions. They find significant cyclical variations in effort, both own-inputs-related variations and variations unrelated to own-inputs, and conclude that these play a significant role in explaining procyclical productivity. Yet they argue that the effort variations measured by their proxies can explain only about half of the measured external effect, so that some unexplained external effect remains.

In this paper I try to distinguish the explanation of cyclical variations in productivity based on externalities from that based on "labor hoarding" phenomena in a different way. Specifically, I use the alternative theories' different predictions about the dynamic effects of aggregate variables.

In a common interpretation of the externality hypothesis, each sector i's production function is assumed to be of the form

$$Q_{it} = F(K_{it}, L_{it}\Theta_{it}Q_{At}^{\delta_i}) \tag{1}$$

where Q_{it} indicates sector i's output at date t, Q_{At} is aggregate output, K_{it} is sector i's capital stock, L_{it} is sector i's labor input, and Θ_{it} represents an exogenous sectoral productivity factor. If $\delta_i > 0$, aggregate output affects sectoral productivity in a manner analogous to the exogenous productivity shock Θ_{it}.[2]

Now suppose that fluctuations in aggregate output are persistent. It follows from the specification in (1) that the induced effect on sector i's productivity should be equally persistent. In particular, suppose that an innovation in aggregate output at date t implies a *permanent* increase in aggregate output, of k times the initial innovation (for some $k > 0$). Then (1) implies that there should be a *permanent* increase

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[2] Baxter and King (1991) and Cooper and Haltiwanger (1993) are examples of authors who assume production relations of this form, and cite the work of Caballero and Lyons as empirical motivation for such a specification. A common interpretation of such externalities is that they are due to "thick market" effects; reduced marketing costs when others sell a lot may allow resources to be shifted into production.

in sector *i*'s productivity, and that it should be *k* times as large as the initial increase. The "thick market" effects, if present and economy-wide, should operate equally in the long run as in the short run.

A labor hoarding explanation has quite a different implication in this regard. If procyclical productivity is due to labor hoarding, then following a shock that affects measured productivity due to incomplete adjustment of the labor input, one should eventually observe measured productivity return to normal. For even if the shock *permanently* increases sectoral output, the size of the workforce should eventually fully adjust to the new level of production, so that the rate of labor utilization (or effort) can return to normal. Hence, even if an innovation in aggregate output at date *t* implies a permanent increase in both aggregate and sectoral output, the resulting effect on sector *i*'s productivity should be purely *transitory*.

This suggests a simple empirical test. I measure the dynamic response of sectoral productivity to innovations in aggregate output, for individual two-digit U.S. manufacturing industries. I also measure the dynamic response of aggregate output to such an innovation, and show that a large part of the initial increase in output is permanent. I then compare the *long-run* response of sectoral productivity to the initial (contemporaneous) response. If the labor hoarding explanation is correct, and true external effects are absent, there should be zero long-run effects on sectoral productivity. If a direct, external effect on the production function, as indicated in (1), is present, and there are no unmeasured variations in labor utilization, there should be a *positive* long-run effect, and it should be *as large as* the initial response (multiplied by the fraction of the initial increase in Q_{At} that is permanent). If there is a positive long-run effect, but *less* than proportional to the extent that the increase in aggregate output is permanent, some combination of the two types of effects would be needed to explain the contemporaneous response of sectoral productivity.

The proposed approach is, of course, only an indirect test of the labor hoarding hypothesis, since it makes use only of that model's prediction that variations in measured productivity (other than those due to true sectoral productivity shocks) should be purely transitory. However, if one writes a specific model, one can derive additional strong predictions about the way in which aggregate variables should be related to measured sectoral productivity. Specifically, in a model where aggregate variables proxy for the expected future path of sectoral activity, it is possible to derive what should be the dynamic pattern of the aggregate variables and how they should enter the sectoral production-function regression. Hence, I also derive and test the more detailed restrictions upon the form of Caballero-Lyons-style production-function regressions implied by an explicit model of labor hoarding, the one presented in Sbordone (1996). In both approaches, however, as the above discussion shows, the effort variations I consider are not variations tied to the own activity of the sector: quite to the contrary, their nature is purely transitory, while input variations are permanent. I believe therefore that this way of identifying unmeasured factor utilization is more general than the approach based on the use of direct proxies, as, for example, that used in Caballero-Lyons regressions.

The paper proceeds as follows. Section 1 discusses generally the interpretation of production-function regressions, while section 2 presents the test described above, based on estimation of the long-run response of total factor productivity to an innovation in aggregate output. Section 3 develops the implications of the labor hoarding hypothesis formalized as in the model of Sbordone (1993) and tests the specific restrictions implied by that model on a production-function regression that nests external effects and variable labor utilization. Section 4 concludes.

1. THE RELATION BETWEEN AGGREGATE ACTIVITY AND SECTORAL PRODUCTIVITY

A standard neoclassical production function for a sector i of the economy can be written in log differences as

$$\Delta q_i = \epsilon^i_{QK}\Delta k_i + \epsilon^i_{QL}(\Delta l_i + \Delta\theta_i) \tag{2}$$

where lowercase letters denote natural logs, and ϵ^i_{QL}, ϵ^i_{QK} denote the elasticity of output with respect to labor and capital respectively. In the following, I will denote true productivity growth, $\Delta\dot{\theta}_i$, by ϵ_i.

A traditional measure of cyclical variations in total factor productivity is the Solow residual, computed as

$$SR_i = \Delta q_i - s^i_L\Delta l_i - s^i_K\Delta k_i \tag{3}$$

where s^i_L and s^i_K are the share in total revenue of the factor rewards of labor and capital respectively. Under the assumptions of price-taking behavior and constant returns, the elasticity of output with respect to each factor input should equal the corresponding factor share, and the Solow residual is exactly the technology shock ϵ_i scaled by the labor share. This measure, as Figure 1 shows for the manufacturing industry, has a marked procyclical pattern.

Alternatively, one can measure cyclical variations in productivity by estimating equation (2); a coefficient on labor bigger than the labor share implies that the measured Solow residual covaries with the labor input. An estimated elasticity bigger than 1 implies the stronger result of a procyclical average labor productivity. Some of the literature focuses on the latter phenomenon, which again contrasts with the theoretical prediction of countercyclical average labor productivity from models with constant returns and a cycle not driven by technology shocks.

Table 1 shows some evidence for the U.S. manufacturing industry. In the first row, I report the estimate of a simple production-function regression, using annual data on the twenty two-digit sectors of U.S. manufacturing for the period 1947–1988. Output is value-added and the inputs are production workers' hours and net capital stock. (Details relating to data and sources are in the Data Appendix.) To avoid the issue of a small or insignificant coefficient on capital, I follow a standard practice (see, for example, Baxter and King 1991 or Caballero and Lyons 1992) of constructing a weighted average of capital and labor. The results are obtained by a

TABLE 1

PRODUCTION-FUNCTION REGRESSION
CONSTRAINED ESTIMATES-ANNUAL DATA 1950/1986

$\Delta q_{it} = c_i + \beta \Delta x_{it} + \delta \Delta q_{At} + u_{it}$[1]

	SURE	SURE-IV1[2]	SURE-IV2[3]
β	1.09 (.02)	1.12 (.03)	1.07 (.04)
$\ln \lvert\Sigma\rvert$	−132.71	−132.66	−132.72
LR	48.04 (.001)	37.41 (.01)	37.62 (.01)
β	.89 (.03)	.93 (.03)	.95 (.03)
δ	.29 (.02)	.25 (.04)	.17 (.05)
$\ln \lvert\Sigma\rvert$	−133.03	−133.07	−133.05
LR	65.44 (.01)	11.25 (.99)	14.96 (.99)

NOTES: For the estimated coefficients, the numbers in parentheses are standard errors. For the *LR* tests, they indicate marginal significance levels. $\ln |\Sigma|$ is the log determinant of the residual variance-covariance matrix, which is minimized by the system estimation procedure. The likelihood ratio statistic (*LR*) tests the constraint that the coefficients are the same across the sectors. Its computation is explained in Appendix B.

[1] Δy_{it} includes the log difference of variable y in sector i at time t. q_A is, for each sector i, value added of aggregate manufacturing excluding value added of sector i. x indicates a weighted average (by product shares) of hours of production workers and net capital stock.

[2] IV1 includes the rate of growth of military expenditure and the price of oil current and lagged, and a dummy representing the political party of the President.

[3] IV2 is IV1 plus one lag of aggregate output.

system estimation, where, except for a constant term, the parameters are constrained to be the same for all the sectors. Evidence of procyclical productivity is the estimate of the output elasticity to factor's input which is bigger than 1. The implied labor elasticity is therefore bigger than the labor share.[3]

If one allows for technological externalities, the production function is equation (1) where δ_i is the elasticity of sector i productivity with respect to aggregate output. Including current aggregate output in the regression gives a positive and highly significant estimate of δ. Moreover, the estimate of the return to scale parameter β declines. The results of a simple OLS estimation (column 1) are similar to the estimates obtained by using instrumental variables (columns 2 and 3) in order to handle the potential correlation of regressors with the error term. Because this correlation problem would likely arise if firms make input decisions after having some knowledge of the technology shock—in which case labor, capital, and output may all be contemporaneously correlated with the technology shock component of the error term—I use demand-type instruments, that should be uncorrelated with movements in technology.[4]

The usual caveats about the choice of the instruments apply.[5] Furthermore, the inclusion of aggregate output among the regressors requires, in order to assume or-

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3. Qualitatively similar results are obtained by using industrial production data for output or total hours of work for labor input. The results in Table 1 are very close to those reported in Table 2 of Caballero-Lyons (1992), who cover a slightly shorter time period and construct the input measure using cost shares, as opposed to product shares.

4. See Hall (1988), Bernanke and Parkinson (1991), Caballero and Lyons (1992).

5. Beyond the exogeneity property, one has to care about the relevance of the instruments, because the finite sample behavior of IV estimators is strongly affected by the correlation of the instruments with the variables instrumented. When this correlation is very low, and the number of observations is small, the asymptotic distribution is not a good approximation to the true distribution and, in fact, the central tendency of the IV estimator is biased away from the true value (see Nelson and Startz 1990a and 1990b).

thogonality to the error term in sectoral production function regressions, the additional assumption that technology shocks are uncorrelated across sectors, so that a given sector's technology shock has little correlation with aggregate variables. Although this is a reasonable property of true technology shocks, and is often assumed in econometric estimation of sectoral production functions, it is not uncontroversial. For most of the sectors in manufacturing, however, there is some empirical evidence of the predominance of idiosyncratic shocks.[6] In any case, in the second and third columns of Table 1 both inputs and aggregate hours are instrumented by the demand variables used by Hall (1988).[7]

Overall, these results show a significant contribution of aggregate variables to reducing the procyclicality problem. The question is how to interpret such a contribution.

Suppose firms "hoard" some labor, in the form of varying the rate of utilization of hours worked: then the true production function depends on effective labor, defined as the product of observed hours and unobserved effort ($L_{it} = E_{it}H_{it}$). The equivalent to equation (2) is then

$$\Delta q_i = \epsilon^i_{QK}\Delta k_i + \epsilon^i_{QL}(\Delta h_i + \Delta e_i + \delta_i \Delta q_A + \epsilon_i) \ . \tag{4}$$

Here there are two reasons why measured productivity is procyclical. External economies imply that the parameter δ_i is positive. If aggregate output is positively correlated with the inputs of the sector, OLS estimates of the specification (2), which exclude aggregate output, result in overestimating the output elasticities. The same result obtains if effort is positively correlated with the inputs, and is omitted in the production-function regression.

Solow residuals of equation (4), even maintaining the assumption that the input elasticities correspond to input shares, co-vary with effort and aggregate output:

$$SR_i = s^i_L(\Delta e_i + \delta_i \Delta q_A + \epsilon_i) \ . \tag{5}$$

As discussed in the introduction, however, if the correlation between aggregate variables and the inputs is due to external effects, then the effect of aggregate activity on sectoral productivity should last at least as long as the perturbation to the level of aggregate activity. In the equation above, one can easily see that total factor productivity, computed as the cumulate of the Solow residuals, depends on the cumulate of the changes in aggregate activity. When a change has lasting effects on aggregate activity itself, then it has to have long-lasting effects on sectoral productivity as well. If the effect of the externality is purely contemporaneous, as suggested by the "thick market" story, and as is assumed in the stated specification of

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[6] See Long and Plosser (1987). To take into account a potential simultaneity bias arising from a common aggregate component in the sectoral productivity shocks, I also estimated the system using labor input of the whole manufacturing as the aggregate variable. The results were not qualitatively different.

[7] The instruments include the rate of growth of military expenditure, the world oil price current and lagged, and a dummy representing the political party of the President. The third column includes also one lag of aggregate output.

the production technology, then sectoral productivity should be high for exactly as long as Q_A is high. Alternatively, one might suppose that the effects of an externality occur with a time lag, or persist after the cause has disappeared (as would be expected in the case of knowledge spill-overs). In this case, sectoral productivity should remain high even after Q_A ceases to be high. A simple generalization of equation (4) to allow for spill-overs is therefore

$$\Delta q_i = \epsilon^i_{QK}\Delta k_i + \epsilon^i{}_{\mathrm{QL}}\left(\Delta h_i + \Delta e_i + \sum_{j=0}^{J} \delta_{ij}\Delta q_{A,t-j} + \varepsilon_i\right). \tag{6}$$

When a shock to aggregate activity is persistent, we would expect long-run effects on sectoral productivity. More generally, the perturbation to sectoral productivity should not decay back to trend any faster than aggregate output return to its trend path (if it does). Of course, if the effects of the externality cumulate, productivity might return to trend *more slowly*.

The dynamic implications of variable utilization on productivity are instead quite different. Variations in effort give the firm an additional margin by which to respond to the needs of production. As I describe in more details in section 3 below, one can model the choice of effort by solving a dynamic cost minimization problem for a firm that faces adjustment costs for labor (see Sbordone 1996). In such a model, variations in effort depend on how future growth of hours compares to current growth. The intuition is quite simple: if hours are expected to grow tomorrow more than they were expected to grow today, then effort declines toward its equilibrium value, because firms decide to hire more workers. Contrariwise, if hours growth tomorrow is predicted to be lower than today's, firms would prefer a higher present level of utilization of a smaller number of workers. All the variables that help to predict hours are potentially useful to predict effort, and aggregate variables are among these. However, because effort turns out to be a stationary variable, the effect of aggregate variables on productivity via this information channel is purely transitory in nature.[8]

I look therefore at these dynamic implications in order to discriminate whether the effect of aggregate variables on sectoral productivity is a production externality or derives instead from their informational content for the decision about labor utilization.

My first test is astructural in nature. It is based on the moving average representation of the vector time series composed of sectoral output, sectoral inputs, and aggregate output. Specifically, it evaluates the effect of innovations in aggregate output, by computing and comparing the impulse response function of sectoral productivity and aggregate output.

[8] Technically, as we will see in section 3, because what is relevant is the comparison of the predictions at two different points in time, current and lagged values of aggregate variables enter the production-function regression with coefficients that are, period by period, the same in absolute value, but opposite in sign.

My second test is based on a production function regression. I derive and test the restrictions that a specific labor-hoarding model imposes on a production function regression that allows for technological externalities, such as equation (4).

2. DYNAMIC RESPONSE TO AGGREGATE INNOVATIONS

Let $w_t = [q_{At}\, k_{it}\, q_{it}\, l_{it}]'$ be a first-difference stationary vector with moving average representation

$$(1 - L)w_t = \mu + \Phi(L)v_t\,.$$

$\Phi(L) = \Sigma_{j=0}^{\infty}\phi_j L^j$, $\phi_0 = I$, and v_t is a vector of innovations, with $E(v_t) = 0$ and $E(v_t v_s') = \Omega$ for $t = s$, and 0 otherwise. k_i q_i and l_i are respectively capital, output, and hours in sector i while q_A is a measure of aggregate output.[9]

The multivariate Beveridge-Nelson decomposition is

$$(1 - L)w_t = \mu + [\Phi(1) + (1 - L)\Phi^*(L)]v_t$$

where $\Phi_j^* = -\Sigma_{k=j+1}^{\infty}\phi_k$ and $\Phi(1) = \Sigma_{k=0}^{\infty}\phi_k$. The matrix $\Phi(1)$ controls the "persistence" of the series: partitioning $\Phi(1)$ according to the size of the vector, the diagonal elements measure the "size" of the random walk component in each series, while $\Phi_{nj}(1)$ measure the persistence of an innovation in w_j to w_n. The hypothesis that an innovation to q_A is "persistent" but does not permanently affect total factor productivity in sector i implies that $\Phi_{11}(1) \neq 0$ and $\Phi_{31}(1) - s_L^i\Phi_{41}(1) - s_K^i\Phi_{21}(1) = 0$, where Φ_{n1} ($n = 2, 3, 4$) are respectively the long-run responses of capital, output, and labor of sector i to an innovation in aggregate output. Note that total factor productivity (TFP) is defined, for a sector i, as $q_{it} - s_L^i l_{it} - s_K^i k_{it}$, so it is just the cumulate of productivity growth as measured by the Solow residual.

To test this long-run restriction, I recover the matrix $\Phi(L)$ of the moving average representation from the impulse response function to a unit innovation in aggregate production. Figure 2 reports the results of this analysis performed on a number of two-digit sectors of U.S. manufacturing, selected as the ones that display more clearly a significant procyclical behavior of productivity.

The impulse responses are generated by fitting a first-order autoregressive model to the vector w_t. I impose the cointegrating restriction that the sectoral output/capital ratio is a stationary variable.[10] The errors are orthogonalized by a lower triangularization of the residual covariance matrix. Each figure reports the response of aggregate output (the dashed line) and sectoral total factor productivity (the dotted line) to

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[9] The sectors I consider are two-digit sectors of the manufacturing industry and the aggregate is, for each sector, the output of all the rest of manufacturing.

[10] This restriction is imposed to be consistent with the theoretical model discussed in the next section. It is tested by a two-step procedure using a standard augmented Dickey-Fuller test, and passes at usual significance levels. In any case, the impulse response functions generated by an unrestricted VAR are qualitatively the same.

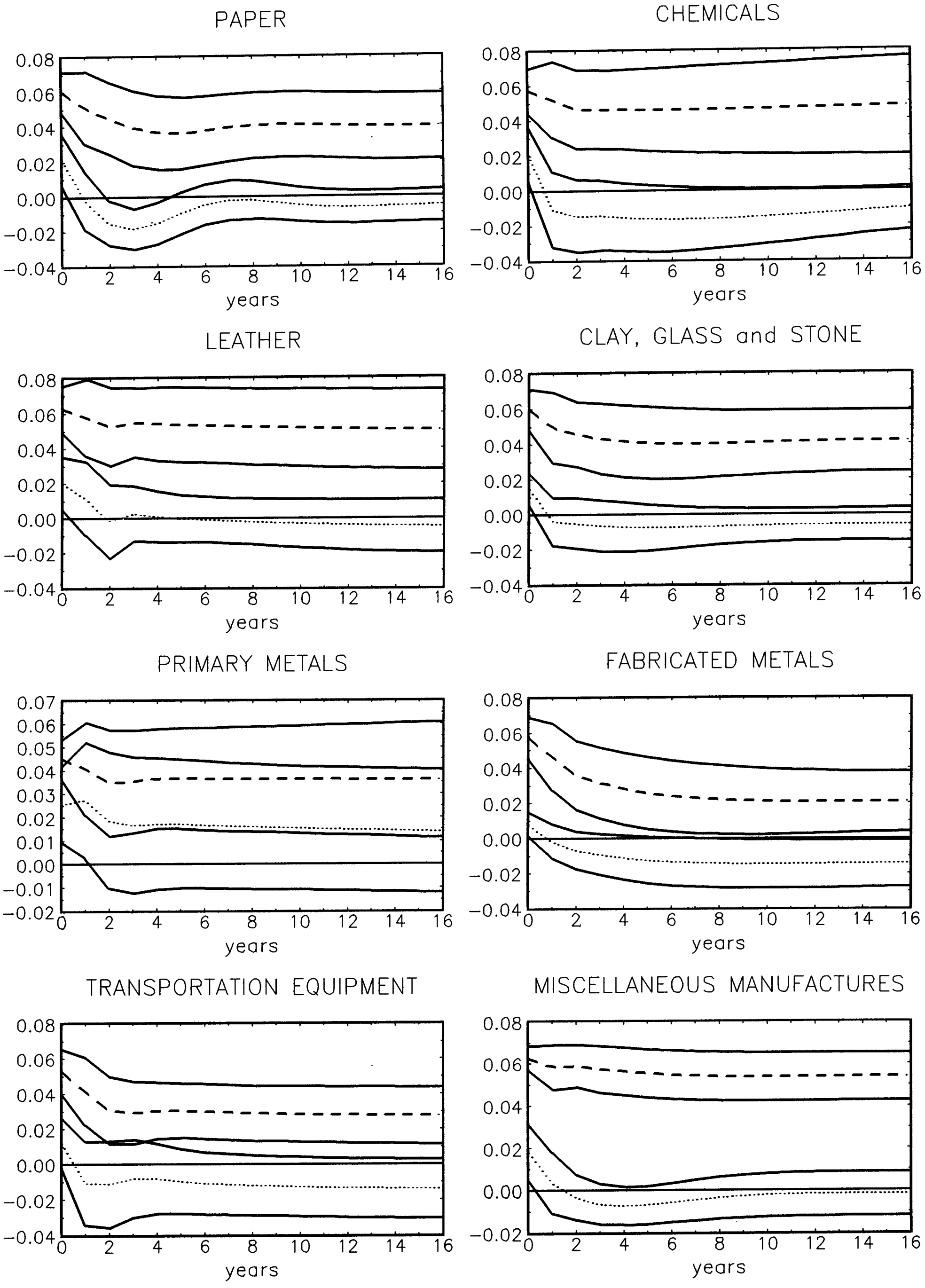

FIG. 2. Dynamic Response to a Unit Innovation in Aggregate Output

a unit innovation in aggregate output. Standard error bands—generated by bootstrapping with one thousand replications—are indicated by the solid lines. In the typical pattern, hours growth in the sector responds positively to a shock in aggregate activity, but in most cases that response turns negative after the first period; total hours therefore grow toward a level higher than the initial level, but below the "peak" response. The response of capital is instead smoothly increasing toward a higher long-run level. As a consequence, total factor productivity, as the pictures show, steadily declines to its original level, after a first-period jump.

The key results of the graphs can be summarized as follows: First, aggregate output does indeed have a significant degree of persistence—an innovation affects its level far into the future. Second, aggregate output innovations do affect sectoral variables, but the impact on sectors' productivity is short-lived.

The fact that total factor productivity responds to aggregate innovations is evidence that either one or both the phenomena discussed—labor hoarding or external effects—are potentially at work, while it rules out purely internal increasing returns. However, the fact that productivity declines to zero after a permanent shock to aggregate output argues against external increasing returns, at least those of the kind incorporated in the production technology of equation (1). To support the existence of "thick market" effects one would need a more sophisticated hypothesis about the diffusion and the decay of such an effect.

Moreover, the graphs also offer some evidence against the interpretation of the effect of aggregate output as due to a common technology shock, because a permanent innovation to aggregate output does permanently alter sectoral output but not sectoral productivity.

Altogether, these facts seem more consistent with an explanation of the procyclical productivity "puzzle" based on labor hoarding. The next section will motivate the labor-hoarding hypothesis and test more direct predictions of a specific model of labor hoarding.

3. A MORE STRUCTURED PRODUCTION-FUNCTION REGRESSION

As pointed out in section 1, one can study the dynamic implications of aggregate shocks in the context of production function regressions.

In order to discriminate whether aggregate output does in fact measure the extent of a technological externality or, as I claim, it has the role of an information variable for the decisions about the degree of labor utilization, I nest both hypotheses in a generalized production function regression as equation (4). Such equation has an unobservable variable, which is the coefficient of labor utilization. To handle this problem, instead of choosing an observable proxy for effort,[11] I model the optimal

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[11] This is the approach taken, for example, by Caballero and Lyons (1992) and Abbott, Griliches, and Hausman (1988).

choice of effort by using the adjustment cost model of Sbordone (1996), of which I briefly summarize the intuition and steps here. This model provides a structural framework for the production-function regression analysis and allows to test the labor-hoarding hypothesis versus the externality one. It should be noted, however, that the validity of the interpretations proposed does not depend upon this special model.

The model describes a sector i of the economy, where a representative firm chooses inputs to use in production, while facing each period a stochastic shock to its technology. Labor is treated as a quasi-fixed factor, which is costly to adjust in response to changes in the environment. The production technology depends on reported hours and unmeasured effort,

$$Q_{it} = F(K_{it}, e_{it}H_{it}\eta_{it}) \, , \tag{7}$$

where H_{it} is reported hours, e_{it} is the rate of utilization of labor (labor effort), and η_{it} is a composite technology term, defined as $\eta_{it} = \Theta_{it}Q_{At}^{\delta_i}$, so that it includes possible externalities.

Variations in utilization might be due to variations in work effort, of the kind reported by Schor (1987) and Shea (1991); to variations in the number of workers assigned to nonproduction tasks such as maintenance and training, as in the model of Bean (1989); or to variations in the number of workers who are actually redundant, as reported by Fay and Medoff (1985).

One argument to motivate variations in labor utilization is the existence of hiring and firing costs, that make labor somewhat immobile. Firms will then tend to "hoard" workers (that is, under-utilize them in one of the senses listed above) when production is temporarily low. As a result, expectations about how future sectoral output and employment will compare to present levels are an important determinant of labor utilization. Aggregate variables that help to forecast future conditions in the sector accordingly could enter a production-function equation like the one above. In particular, aggregate output should enter with a positive coefficient if a *higher* growth rate of aggregate output forecasts *lower* future growth of sectoral employment, since in this case firms subject to costs of adjusting employment would prefer a higher present level of utilization of a smaller number of workers.

In contrast with the theory of technological externalities, labor hoarding need not imply non-negative coefficients on all lags of aggregate output. In fact, labor-hoarding models typically imply that the sum of the coefficients on all lags should equal zero. The reason is that labor utilization is a stationary variable—it returns to its "normal" level once labor inputs fully adjust to their desired level. Hence if fluctuations in aggregate output contain a permanent component, the long-run effect of aggregate output would have to be zero, in order for a permanent increase in aggregate output to have no permanent effect on labor utilization (the omitted variable in the production function). In other words, while externalities tie total factor productivity of a sector to the level of aggregate output, labor hoarding makes measured total factor productivity depend upon the changes in aggregate output. Once output has stabilized at a new level, no effect persists on sectoral productivity.

The firm's total labor cost is given by

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

(for ease of notation the subscript i is omitted from now on), where W_t denotes a base wage level, $g(\;)$ indicates the proportional increase in the cost of hours that are more fully utilized, and $\lambda(\;)$ represents the increase in costs associated with rapid adjustment of the labor force. $g(\;)$ is assumed positive and strictly convex, and $H\lambda(\;)$ is a non-negative, convex function of H.

A restricted cost function is obtained by solving effort out of the production function and substituting this expression into the cost function. Then the problem of the firm is to choose the sequence $\{H_t\}$ to minimize the expected sum of discounted costs

$$E_t \sum_{j=0}^{\infty} R^j \{C(H_{t+j}, H_{t+j-1}, K_{t+j}, Q_{t+j}, \eta_{t+j}, W_{t+j})\}$$

where R is a real discount factor and E_t denotes expectations conditional on knowledge of all the variables up to time t. The optimal decision rule can be characterized through a log-linear approximation of the first-order condition of this minimization problem around the sector steady-state growth path. This procedure [the details are in Sbordone (1996)] leads to an orthogonality condition that is suitable for empirical analysis. In first differences, it can be written as the following production-function regression:

$$\begin{aligned}\Delta q_t = {} & \pi_0 \Delta h_t - \pi_2 \Delta h_{t-1} - \pi_3(E_t \Delta h_{t+1} - E_{t-1}\Delta h_t) + \pi_4 \Delta k_t \\ & + \pi_5 \Delta w_t + \pi_6 \Delta \eta_t \end{aligned} \tag{8}$$

where lowercase letters denote natural logarithms, and the coefficients π depend upon the parameters of the cost function and of the production function. The most important parameter for our purposes is π_3 which is a cost-of-adjustment parameter, measuring the relative cost of adjusting hours versus effort.[12] Also, because $\Delta\eta_t = \epsilon_t + \delta \Delta q_{At}$, $\pi_6 \delta$ measures the elasticity of sectoral output to aggregate output.[13]

There are two things to note in this equation: It includes a term in the difference between expected future growth of hours and current hours, and its coefficient is negative. This term enters the equation because the production function is specified

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[12] Technically it is the ratio of the curvature of the adjustment function λ and the effort function g.

[13] Note that π_6 is the elasticity of output to effective labor.

in effective hours, and therefore it includes a term for effort.[14] Equation (8) could be, in fact, interpreted as a log linearization of the production function (7) into which has been substituted a solution for the unobservable effort in terms of past observable hours and expected future growth of hours; this interpretation makes it clear how the inclusion of effort as an additional unmeasured input results in the dynamics of the production-function regression. It also explains the negative sign in front of the coefficient π_3, because current effort is negatively related to how expected future growth of hours compares to current growth. The intuition is that when output and hours are expected to grow next period more than they were expected for the current period, firms start to increase labor today (the marginal cost of increasing labor is lower today, taking into account the reduction of future adjustment costs), thus decreasing effort today. The slow response of labor to cyclical variations, due to costs of adjustment, generates a counterbalancing response of effort, which is the variable factor.

In this framework, while aggregate variables enter the equation because of a technological externality, they may be correlated with the productivity of individual sectors through an additional channel, that does not depend at all on external effects. This is because aggregate variables help to forecast future labor growth. Under this hypothesis, a solution for expected future growth of hours involves lags of the rate of growth of aggregate output, as well as lagged values of the other inputs, where the number of lags will depend on the specification of the process for the forcing variables, which include aggregate output. The solution of the model is an optimal decision rule for hours that depends on the capital stock and on the evolution of a vector of state variables that summarize all the information at time t. Specifically, assuming that the vector of state variables includes the sectoral technology shock ϵ, the sectoral capital/output ratio $q - k$, the growth of sectoral capital Δk and the growth of aggregate output Δq_A, and furthermore that it follows a stationary first-order autoregressive process, the optimal solution for hours can be written as

$$E_t \Delta h_{t+1} = const + \mu_1 (k_{t-1} - h_{t-1} - \eta_{t-1}) + \mu_2 \epsilon_t + \mu_3 (q_t - k_t) \\ + \mu_4 \Delta k_t + \mu_5 \Delta q_{At}$$

involving only one lag of aggregate output q_A.

Computing $E_{t-1}\Delta h_t$, and substituting the difference $(E_t \Delta h_{t+1} - E_{t-1}\Delta h_t)$ in equation (8) gives a production function regression where output depends on current and past values of the inputs and also on current and past values of the aggregate variable:

$$\Delta q_t = \vartheta_1 \Delta h_t + \vartheta_2 \Delta h_{t-1} + \vartheta_3 \Delta k_t + \vartheta_4 \Delta k_{t-1} + \vartheta_5 (\Delta q_{At} - \Delta q_{At-1}) \\ + \vartheta_6 \epsilon_t + \vartheta_7 \epsilon_{t-1} + \vartheta_8 \Delta q_{At} \tag{9}$$

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[14] The fact that only one lead and one lag of hours are included depends on the specification of the adjustment cost as a function only of H_t/H_{t-1}.

The coefficients ϑ are nonlinear combinations of the structural parameters of the model and of the forecasting equation for hours. They summarize the restrictions that the labor hoarding hypothesis imposes on the equation.

Two special cases are interesting as null hypotheses:

1. According to the Baxter-King model, with a contemporaneous external effect and no labor hoarding, one should have $\vartheta_2 = \vartheta_4 = \vartheta_5 = \vartheta_7 = 0$ (they all depend on the "adjustment cost" parameter π_3, which is zero in the case of no hoarding), and $\vartheta_8 > 0$. If one allows the external effect to occur with a lag, but continues to assume no labor hoarding, all of these should still hold, except that $\vartheta_5 \neq 0$. If both the contemporaneous and lagged effects are positive, one should have $\vartheta_5 < 0$, $\vartheta_8 > 0$.

2. According to the Sbordone (1996) labor-hoarding model, with no external effects, one should have $\vartheta_8 = 0$, while $\vartheta_5 > 0$. As a consequence, aggregate variables enter the equation in a difference term because they are correlated with the expected future labor growth of a sector. There is no "level" effect of aggregate output on sectoral productivity. Lagged hours and capital also enter the equation: the sign of their coefficients depends on the relative magnitude of the coefficients of the forecasting equation of hours. Finally, an additional prediction for this case is that the coefficients on current and lagged inputs sum to the returns to scale parameter.

In the more general case, that both effects are present, all of the coefficients may be nonzero. However, ϑ_8 will quite generally measure the cumulative external effect, and a positive ϑ_5 will indicate the presence of labor hoarding. (In the case that the external effect is purely contemporaneous, ϑ_5 will measure the significance of labor hoarding as a contribution to procyclical productivity.)

A significance test on the individual parameters ϑ will assess the existence of labor hoarding, while a test on the sum of the coefficients of aggregate variables will assess the existence of technological externalities. Furthermore, one can also test the hypothesis that there are internal increasing returns by testing whether one can reject the hypothesis that the sum of coefficients on current and lagged inputs is 1.

This more structured context shows also that aggregate variables do not simply proxy the information contained in the past values of sectoral inputs. They should add explanatory power once the own-input dynamics are accounted for.

To discriminate among these cases, I estimate the following unrestricted form of (9):

$$\Delta q_t = \vartheta_1 \Delta h_t + \vartheta_2 \Delta h_{t-1} + \vartheta_3 \Delta k_t + \vartheta_4 \Delta k_{t-1} + \sum_{j=0}^{J} d_j \Delta q_{A,t-j} + u_t . \qquad (10)$$

Here $D(1) \equiv \Sigma_j d_j$ is a measure of the long-run effect of any perturbation to aggregate output; given that labor hoarding implies only a transitory effect of aggregate output perturbations, that should be an appropriate measure of the cumulative external effect.

If one allows generalized external effects, in the form of possible spillovers as in equation (6), under no labor hoarding, aggregate output should enter the production function with a non-negative coefficient at all lags (including zero). If the external effect is purely contemporaneous, all lags greater than zero will have a zero coefficient; if, on the other hand, some of the external effects occur with a delay, then lagged aggregate output may enter with a positive coefficient as well. But no lags should enter with negative coefficient.

To sum up, under the null of no externalities, the labor-hoarding hypothesis predicts that $D(1) = 0$. If instead the short-run effect of aggregate output is entirely due to externalities (there is no labor hoarding), one should actually expect $D(1) \geq D(0) \equiv d_0$. I therefore test first whether the coefficients d_j are individually significantly different from zero and in which direction; if the contemporaneous coefficient is positive, but the lagged coefficients are statistically significant and negative, the long-run effect would not be bigger than the short-run effect, and the pure externality hypothesis would be rejected. Then I test whether $D(1)$ is significantly different from zero. If it is, the pure labor-hoarding hypothesis would be rejected.

Table 2 presents estimates of equation (10) and a test of the two implied restrictions, with the same set of data used in Table 1, namely pooled data for the two-digit sectors of the manufacturing, spanning the period 1947–1988. q, h, and k are respectively value added, production workers hours, and capital stock for the sectors, while q_A is value added for the whole manufacturing, excluding each sector in turn. The first column is a pure SURE estimation, while columns two and three contain instrumental variable estimates.[15] Almost all the coefficients are significant at the standard confidence level. The current value of aggregate value added enters the regression with a positive, significant coefficient, and two lags enter with negative and significant coefficient. Their absolute size is bigger in the third set of estimates.[16]

The coefficients on lagged own inputs are significant and with the expected sign. Also, because the coefficients on current hours and capital do not represent factor shares, one can rationalize the negative estimate of the coefficient on capital.[17]

The chi-square statistics reported in the bottom rows test respectively the restriction about $D(1)$, and the restriction about the returns to scale. The restriction that the coefficients on aggregate value added sum to zero is not rejected in any type of estimation. The restriction that the inputs' coefficients sum to one, although rejected in the pure SURE estimate, passes in both the instrumented estimates. Together, the two restrictions also pass in both IV estimates (chi-square statistic on the bottom row).

To summarize, the key element of the model that drives the regression results is

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[15] The instruments are similar to those used in Table 1, and detailed in the notes to the table. Because the error term includes a lagged term of the sectoral technology shock, to handle the potential correlation of inputs and aggregate output with the technology, in column 3 the instruments include only two period lags of inputs and aggregate output.

[16] Although the present formulation of the model brings in only one lag, one can easily obtain that two (or more) lags matter by including another lag in the adjustment cost function, or in the forecasting equation for hours.

[17] A negative coefficient will obtain, for example, when hours growth responds more to the previous period growth of capital than to the previous period output/capital ratio, in the presence of a sufficiently high adjustment cost.

TABLE 2

PRODUCTION-FUNCTION REGRESSION: TEST OF MODEL'S RESTRICTIONS
CONSTRAINED SYSTEM ESTIMATION, ANNUAL DATA 1950/1986

$$\Delta q_{it} = \theta_1 \Delta h_{it} + \theta_2 \Delta h_{it} + \theta_3 \Delta k_{it} + \theta_4 \Delta k_{it-1} + \Sigma_j d_j \Delta q_{At-j} + u_{it}{}^*$$

	SURE	SURE-IV1[1]	SURE-IV2[2]
θ_1	.849 (.02)	.926 (.04)	.808 (.05)
θ_2	.052 (.02)	.082 (.03)	.211 (.04)
θ_3	−.144 (.05)	−.326 (.11)	−.295 (.13)
θ_4	.025 (.05)	.248 (.09)	.243 (.12)
d_0	.135 (.03)	.126 (.03)	.301 (.06)
d_1	−.101 (.03)	−.118 (.03)	−.232 (.06)
d_2	−.048 (.02)	−.061 (.02)	−.064 (.02)
$\ln \lvert\Sigma\rvert$	−133.78	−133.38	−132.33
$\chi_1^2\ [\Sigma_{j=0}^2 d_j = 0]$	3.142 (s. lev. = .08)	0.811 (s. lev. = .37)	0.004 (s. lev. = .95)
$\chi_1^2\ [\Sigma_{j=1}^4 \theta_j = 1]$	27.72 (s. lev. = .00)	2.839 (s. lev. = .09)	0.372 (s. lev. = .54)
$\chi_2^2\ [\Sigma_{j=0}^2 d_j = 0$ and $\Sigma_{j=1}^4 \theta_j = 1]$	30.86 (s. lev. = .00)	3.650 (s. lev. = .16)	0.376 (s. lev. = .83)

NOTES: When not otherwise indicated, in parentheses are reported standard errors. $\ln \lvert\Sigma\rvert$ indicates the log determinant of the residual covariance matrix, which is minimized by the estimation procedure.

*Δx_{it} indicates the log difference of variable x in sector i at time t. q_A is, for each sector i, value added of aggregate manufacturing excluding value added of sector i. h indicates hours of production workers. k is net capital stock.

[1] IV1 includes the rate of growth of military expenditure and the price of oil, current and lagged, a dummy representing the political party of the President, and one lag of aggregate capital and hours.

[2] IV2 is IV1, but with capital, output and hours lagged two periods.

that output growth depends on how future hours growth compares to present growth through the parameter π_3; aggregate output is used to forecast such future variations. The parameter π_3, in the model, depends specifically upon the curvature of the adjustment cost function. In the absence of adjustment costs, this coefficient is equal to zero, eliminating the dynamics in the production function and its dependence on aggregate variables, except for what would arise from a pure externality effect. The intuition for this result is that the dynamic implications of the model come exclusively from the movement of effort, and without adjustment costs there is no cyclical variation of effort.

Finally, the labor-hoarding model implies that variations of effort are purely transitory, as argued earlier. Therefore any shock to aggregate variables, no matter how persistent, should affect sectors' productivity only transitorily. The empirical analysis agrees with this prediction of the model as well.

4. CONCLUSION

Aggregate variables have a persistent component yet do not show a persistent effect on the productivity of individual sectors. I argue in this paper that cyclical variations in labor utilization are able to generate exactly the type of response we saw in the data. I show that a simple model of labor hoarding generated by adjustment costs, together with the hypothesis that aggregate conditions are forecasting variables for the activity of individual sectors, implies a specification of the production function regression that includes distributed lags of aggregate output, whose coefficients sum to zero. This prediction is confirmed by the empirical evidence. Estimation of a sectoral production technology gives a positive, impact effect of aggregate output on sectoral productivity, but significant lagged negative effects, so that the long-run response of productivity is lower than the short-run one and, moreover, it is not statistically significant. These empirical results tend to confirm the conclusions of Rotemberg and Summers (1990) and Burnside, Eichenbaum, and Rebelo (1993), who—although in different contexts and under different assumptions—also assign a role to labor hoarding in generating procyclical factor productivity.

These results are not easily reconciled with a view that the relation between aggregate activity and sectoral productivity is due to a direct external effect upon the sectoral production technology, as many authors have recently proposed. Of course, the range of possible hypotheses involving "external effects" is very large, and it is impossible to address all of them. But at least the simplest version of that hypothesis, as it is formulated in the production function used here, can be clearly rejected, while a labor-hoarding model appears to offer a simple alternative that furthermore makes a number of quite specific predictions that appear to be reasonably consistent with the evidence.

APPENDIX A: DATA DESCRIPTION AND SOURCES

Data on industrial value added are from the NIPA as published in the *Survey of Current Business* (July issue); the capital stock (K) is net constant dollar fixed private capital, as published in the *Survey of Current Business* (August issue).

Data are for the following two-digit manufacturing industries (the SIC code is in square brackets): Food [20], Tobacco [21], Textile [22], Apparel [23], Paper [26], Printing and Publishing [27], Chemical [28], Petroleum [29], Rubber and Plastic [30], Leather [31], Lumber [24], Furniture and Fixtures [25], Clay, Glass and Stone [32], Primary Metals [33], Fabricated Metals [34], Nonelectrical Machinery [35], Electrical Machinery [36], Transportation Equipment [37], Instruments [38], and Miscellaneous Manufactures [39].

Data on employment and average weekly hours of production workers are from *Employment, Hours and Earnings, United States, 1909–1984*, vol. 1, by U.S. Dept. of Labor, Bureau of Labor Statistics, March 1985; update to 1988 is from *Supplement to Employment and Earnings*, August 1989. The product of the two series makes total hours of production workers. Total hours by full-time and part-time workers, total labor compensation, and the value-added deflator are from NIPA, as published in the *Survey of Current Business* (July issue). To construct sectoral data for total hours worked, I follow the procedure in Shapiro (1987) and distribute one-digit totals to two-digit industries according to year-by-year shares in total employment. The labor share is computed as the average ratio of total labor compensation to nominal value added.

APPENDIX B: COMPUTATION OF THE *LR* STATISTIC IN TABLE 1

Defining $L_{N,p,T-q} = \det(\Sigma_r)/\det(\Sigma_u)$, where the subscripts r and u stands respectively for *r*estricted and *u*nrestricted, the statistic $LR = K \log L_{N,p,T-q}$ under the null is asymptotically distributed as a χ^2_{pN}. The constant K is equal to $T - q - 0.5(N - p + 1)$, where T is the number of observations, q is the number of parameters estimated, N the number of equations and p the number of parameters restricted (pN is therefore the total number of restrictions). Letting $l_{N,p,T-q}(\alpha)$ be the α-significance point for $L_{N,p,T-q}$, and defining $C_{N,p,T-q+1}(\alpha) = Kl_{N,p,T-q}(\alpha)/\chi^2_{pN}(\alpha)$, the test is conducted by computing the LR statistic defined above and rejecting the null at the level α if $LR > C_{N,p,T-q+1}(\alpha)\ \chi^2_{pN}(\alpha)$. Since $C_{N,p,T-q+1}(\alpha) > 1$, the restrictions cannot be rejected if the statistic $LR < \chi^2_{pN}(\alpha)$. The proportional error in approximating the statistic by a χ^2_{pN} is equal to $(C_{N,p,T-q+1} - 1)$. This error increases slowly with N and p (see Anderson 1984, p. 298 ff.). In the cases considered here this error is about the order of 2 percent, even for a chosen significance level of .001.

LITERATURE CITED

Abbott, Thomas A. III, Zvi Griliches, and Jerry Hausman. "Short-Run Movements in Productivity: Market Power versus Capacity Utilization." Manuscript, 1988.

Bartelsman, Eric J., Ricardo J. Caballero, and Richard K. Lyons. "Customer- and Supplier-Driven Externalities." *American Economic Review* 84 (1994), 1075–84.

Baxter, Marianne, and Robert G. King. "Productive Externalities and Business Cycles." Institute for Empirical Macroeconomics, Discussion Paper 53, 1991.

Bean, Charles R. "Endogenous Growth and the Procyclical Behavior of Productivity." *European Economic Review* 34 (1989), 355–63.

Bernanke, Ben S., and Martin L. Parkinson. "Procyclical Labor Productivity and Competing Theories of the Business Cycle: Some Evidence from Interwar U.S. Manufacturing Industries." *Journal of Political Economy* 99 (1991), 439–69.

Bernanke, Ben S., and James L. Powell. "The Cyclical Behavior of Industrial Labor Markets: A Comparison of the Prewar and Postwar Eras." In *The American Business Cycle: Continuity and Change*, edited by Robert J. Gordon. University of Chicago Press, 1986.

Braun, Anton R., and Charles L. Evans. "Seasonal Solow Residuals and Christmas: A Case for Labor Hoarding and Increasing Returns." University of Virginia Discussion Paper no. 227, 1991.

Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo. "Labor Hoarding and the Business Cycle." *Journal of Political Economy* (1993), 245–73.

Caballero, Ricardo J., and Richard K. Lyons. "Internal versus External Economies in European Manufacturing." *European Economic Review* 34 (1990), 805–30.

______. "External Effects in U.S. Procyclical Productivity." *Journal of Monetary Economics* 29 (1992), 209–25.

Cooper, Russell, and John Haltiwanger. "Macroeconomic Implications of Production Bunching: Factor Demand Linkages." *Journal of Monetary Economics* 30 (1992), 107–28.

______. "Evidence on Macroeconomic Complementarities." National Bureau of Economic Research Working paper no. 4577, 1993.

Fay, Jon A., and James Medoff. "Labor and Output over the Business Cycle: Some Direct Evidence." *American Economic Review* 75 (1985), 638–55.

Hall, Robert E. "The Relation between Price and Marginal Cost in U.S. Industry." *Journal of Political Economy* 96 (1988), 921–47.

______. "Invariance Properties of Solow's Productivity Residual." In *Growth/Productivity/Unemployment*, edited by P. A. Diamond. M.I.T. Press, 1991.

Hultgren, Thor. "Changes in Labor Cost during Cycles in Production and Business." National Bureau of Economic Research Occasional Paper 74, 1960.

Kuh, Edwin. "Cyclical and Secular Labor Productivity in United States Manufacturing." *Review of Economics and Statistics* 47 (1965), 1–12.

Long, John, and Charles Plosser. "Sectoral versus Aggregate Shocks in the Business Cycle." *American Economic Review* 77 (1987), *Papers & Proceedings*, 333–36.

Murphy, Kevin M., Andrei Shleifer, and Robert W. Vishny. "Building Blocks of Market-Clearing Business Cycle Models." *National Bureau of Economic Research Macroeconomic Annual* (1989), 247–87.

Nelson, Charles R., and Richard Startz. "The Distribution of the Instrumental Variable Estimator and Its *t*-Ratio When the Instrument is a Poor One." *Journal of Business* (1990), S25–S140. (a)

______. "Some Further Results on the Exact Small Sample Properties of the Instrumental Variable Estimator." *Econometrica* 58 (1990), 967–76. (b)

Rotemberg, Julio J., and Larry Summers. "Labor Hoarding, Inflexible Prices, and Procyclical Productivity." *Quarterly Journal of Economics* 105 (1990), 851–74.

Sbordone, Argia M. "Cyclical Productivity in a Model of Labor Hoarding." *Journal of Monetary Economics* 38 (1996).

Schor, Juliet B. "Does Work Intensity Respond to Macroeconomic Variables? Evidence from British Manufacturing, 1970–1986." Manuscript, Harvard University, 1987.

Shapiro, Matthew D. "Measuring Market Power in U.S. Industry." National Bureau of Economic Research Working Paper no. 2212, 1987.

Shea, John. "Accident Rates, Labor Effort, and the Business Cycle." Mimeo, University of Wisconsin, 1991.

Sims, Christopher A. "Output and Labor Input in Manufacturing." *Brookings Papers on Economic Activity* (1974), 695–735.

Solow, Robert M. Draft of the Presidential Address to the Econometric Society on the Short-Run Relation between Employment and Output, 1964.