

# External effects in U.S. procyclical productivity

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Received April 1991, final version received October 1991

In this paper we highlight a new dimension of the aggregate procyclical productivity phenomenon. We show that estimates of the degree of returns to scale are larger for manufacturing as a whole than for two-digit industries. Since this difference must be due to factors that are only internalized at the most aggregate level, we term it an external effect. This result rules out explanations based on own-input variation – such as true increasing returns and unmeasured factor utilization tied to own-activity – as the sole explanations for aggregate procyclical productivity. We explore several potential explanations of this external effect.

## 1. Introduction

In recent years there has been a surge of interest on the topic of the procyclicality of measured productivity. The earliest work in this area rejects the assumption that labor is a freely variable factor [Hultgren (1960), Oi (1962), and Okun (1962)], implying that measured hours worked will not accurately reflect true labor input which, in the standard model, produces procyclicality. This labor-hoarding hypothesis provided an intuitive explanation that remained virtually unchallenged for many years.<sup>1</sup>

In the 1980's, two alternatives were emphasized: (i) procyclical productivity shocks and (ii) increasing returns. The first, productivity shocks, provides the

\*We appreciate the helpful comments of an anonymous referee. Richard Baldwin, Jagdish Bhagwati, Jordi Galí, Michael Gavin, Robert Hall, Mohamad Hammour, Glenn Hubbard, David Romer, Paul Romer, Julio Rotemberg, and seminar participants at Dartmouth, Harvard, NYU, SUNY-Buffalo, Wharton, the Board of Governors of the FED, and the NBER conferences on studies of firms and industries and economic growth. We also thank Robert Hall for the use of his data. Ricardo Caballero acknowledges the National Science Foundation for financial support under grant SES-9010443. This paper is a substantially revised version of Caballero and Lyons (1989).

<sup>1</sup>See Fay and Medoff (1985) for a careful accounting of labor-hoarding at the plant level.

foundation for existing real business cycle models. In this setting, positive shocks to production possibilities induce higher marginal labor productivity, generating procyclical labor productivity. The second alternative, addressed recently by Hall (1990), maintains that an important part of the explanation is due to increasing returns to scale at the firm level. These internal increasing returns imply that output increases will entail movement down an average cost curve, producing procyclicality.

With the work concerning alternatives to labor-hoarding has come a number of papers that emphasize the likely relevance of the more traditional hoarding approaches. For example, countering an assertion by Hall that even under labor-hoarding productivity should be acyclical, Rotemberg and Summers (1990) argue that once rationing and price rigidity at higher frequencies are added to the story, the result of hoarding is indeed procyclical productivity. A slightly different tack is taken by Burnside, Eichenbaum, and Rebelo (1990). Their work addresses the premise of authors like Prescott (1986) that productivity shocks alone are driving procyclicality; they find that allowing for labor-hoarding reduces the ability of technology shocks to account for aggregate output fluctuations by about half. Gordon (1990) goes further; he argues that the measured procyclicality results wholly from the interaction of different types of measurement error including excess-capacity and labor-hoarding. He concludes that once these errors are taken into account there is nothing left to explain. Focusing on interwar U.S. manufacturing, Bernanke and Parkinson (1991) argue that procyclicality through this period is strong evidence against the technological shock theory since it is unlikely that the preponderance of cyclical variation was due to technological shocks. With respect to the alternatives, they find mixed evidence for both increasing returns and labor-hoarding. As a final example, Shea (1991) uses accident rates to proxy variations in effort and concludes that this can explain some, but not all, of the cyclical productivity puzzle.

Here, we look at the problem from a different angle. In the first part of the paper we document that estimates of returns to scale are substantially larger for aggregate manufacturing than for two-digit manufacturing. Since this difference must be due to factors that are, at least econometrically, only internalized at the most aggregate level, we term it an 'external effect'. We claim that this is a significant finding since it rules out explanations based on own-input variation as the sole answers for aggregate procyclical productivity. The own-input variation explanations include prominent approaches, such as true increasing returns and unmeasured factor utilization tied to own-activity, the latter being one of the workhorses for aggregate labor-hoarding models [see, e.g., Gordon (1990) and Sbordone (1991)].<sup>2</sup>

<sup>2</sup>In this paper we abstract from the role of procyclical productivity shocks: the empirical section relies on instruments that are taken to be orthogonal to innovations in technology.

In the second part of the paper we begin the search for possible explanations for the external effect. To us, the most obvious of the explanations not based on own-input variation is true externalities; we make this our maintained hypothesis through the second part. Given the high frequency nature of our evidence, externalities are unlikely to be of the strict Marshallian type. Most likely, they correspond to transaction or thick-market externalities arising from easier matching between agents during expansions [Diamond (1982)]. Bartelsman, Caballero, and Lyons (1991) provide further evidence pointing in this direction since they find that the volume of transactions between firms and their customers appears to be the key factor in the transmission of short-run external effects.

To others, the explanation of our results lies in variations in effective labor (or effort). As stressed above, however, the constraint on these explanations is that effort variations must not be related purely to own-input variations. One possibility that satisfies this constraint is variations in effort that are directly related to aggregate variables; however, in this case they become indistinguishable from externalities, and perhaps should be referred to as such. There are also adjustment-cost explanations, as in Sims (1974), that include effort as one of the margins firms and workers use to accommodate short-run fluctuations; at least in principle, these variations in effort may not be perfectly correlated with own inputs. We consider this type of effort variation as the main alternative hypothesis in the second part of the paper.

The distinction between own-input returns and external effects has implications beyond helping to rule out own-input-based explanations as the whole story behind aggregate procyclical productivity. Evidence for the latter provides support for models in which business cycles are enhanced by reinforcing cross-effects, as in Baxter and King (1990). In addition, the presence of externality-based increasing social returns to scale provides fertile ground for multiple equilibria.<sup>3</sup>

The rest of the paper is divided into four sections and two appendices. Section 2 lays out the methodology and presents the results for the indexes of own-input returns, at both the aggregate and two-digit levels, and the estimates of the external effect; section 3 addresses further the possible connection between unmeasured utilization and external effects. Section 4 discusses several robustness issues; and section 5 provides our conclusions.

## **2. Own-input variation**

Consider as a starting point the general value-added equation previously emphasized by Hall (1990) which relates growth (log change) in value-added

<sup>3</sup>See Diamond (1982), Cooper and John (1988), and Hammour (1989).

output to a cost-weighted input measure and a residual:<sup>4</sup>

$$dy_i = \gamma [\alpha_{c_i} dl_i + (1 - \alpha_{c_i}) dk_i] + dw_i, \quad (1)$$

where  $\alpha_c$  is the share of labor in total factor costs,  $dl$  is the growth in labor input,  $dk$  is the growth in capital input, and  $i$  is the two-digit sector (constant suppressed).<sup>5</sup> To simplify the notation define:  $dx_i \equiv [\alpha_{c_i} dl_i + (1 - \alpha_{c_i}) dk_i]$ , so

$$dy_i = \gamma dx_i + dw_i. \quad (1')$$

If there is *unmeasured* labor-hoarding, or variations in effort, though  $dl$  is the growth rate of effective labor the econometrician observes only  $dl^m$ , the rate of growth of *measured* hours.<sup>6</sup> Of course the same applies to capital; so we use  $dx_i$  and  $dx_i^m$  to denote effective and measured factor growth, respectively. These two quantities are related by

$$dx_i = dx_i^m + df_i, \quad (2)$$

where  $df$  is (tautologically) the growth rate of per-factor unmeasured utilization or, more vaguely, effort. Typically, in showing the implications of effort fluctuations for short-run increasing returns and procyclical productivity, these fluctuations are related to sector  $i$ 's activity level. To capture this we postulate

$$df_i = \mu(dy_i - a_i), \quad (3)$$

where  $\mu$  is a positive constant and  $a_i$  is some sector-specific constant such that  $E[dy_i - a_i]$  is sector  $i$ 's long-run hoarding.

Replacing eqs. (2) and (3) in eq. (1) yields

$$dy_i = \gamma dx_i + \mu\gamma dy_i + dw_i, \quad (4)$$

<sup>4</sup>In the empirical implementation we expand the model to consider the effect of the large changes in energy prices during the sample.

<sup>5</sup>Some intuition for the cost share weights comes from cost minimization. Consider a slight substitution of  $l$  for  $k$  at the marginal rate of technical substitution (i.e., such that  $dy = 0$ ). Given factor prices, the percent rise in the total labor bill equals  $dl$  and the percent fall in the total capital bill equals  $dk$ . The only way these (typically) different percent changes can result in no change in total cost is to weight them by their corresponding cost shares. Thus,  $[\alpha_{c_i} dl + (1 - \alpha_{c_i}) dk] = 0$  when  $[F_l dl + F_k dk] = 0$ . These two expressions establish a clear link between the cost share and the corresponding marginal product.

<sup>6</sup>It is important to notice that labor-hoarding, in the sense of holding workers whose wages are higher than their marginal product, is not sufficient for the measurement error story to go through. This type of hoarding introduces problems in the cost shares, but this can easily be shown to have only second-order effects. The real problem arises with unobserved variations in effort, which we discuss here. We return to observed hoarding in section 4.

Table 1  
Aggregate versus two-digit results.<sup>a</sup>

$$dy = \phi dx + \kappa d(\text{energy}) + dv$$

$$dy_i = \theta dx_i + \kappa d(\text{energy})_i + dv_i$$

	IV1( <i>Poil</i> )	IV2( <i>Poil</i> )	IV1( <i>Ener</i> )	IV2( <i>Ener</i> )
$\phi$	1.30 (0.09)	1.26 (0.10)	1.56 (0.59)	1.46 (0.54)
$\theta$	1.15 (0.05)	1.07 (0.04)	1.29 (0.06)	1.22 (0.05)

<sup>a</sup>IV1: instrument set #1, which contains military expenditures, the political party of the president, and the price of oil relative to nondurables and durables manufactures (all in rates of growth) IV2: instrument set #2, which is equal to #1 plus the first lag of military expenditures and the political party of the president (*Poil*): the sectoral relative price of oil is included on the right-hand side (not reported). (*Ener*): the sectoral energy use is included on the right-hand side (not reported). Standard errors in parentheses. All equations include a constant per sector. Annual data: 1959–1984.

and solving for  $dy_i$ , we obtain

$$dy_i = \frac{\gamma}{1 - \mu\gamma} dx_i + \frac{1}{1 - \mu\gamma} dw_i, \quad (5)$$

where constants (and energy corrections) remain suppressed.

Eq. (4) demonstrates that as long as  $\mu$  is positive, productivity will be procyclical even when the technology exhibits constant returns to scale and  $dw_i$  is entirely acyclical. It is eq. (5), however, that more clearly reflects the standard labor-hoarding/capacity-utilization criticism of the increasing returns literature: the estimated returns to scale parameter is upward biased in the presence of hoarding that is related to  $i$ 's activity [see, e.g., Gordon (1990)].

The aggregate version of eq. (5) is obtained by summing over all  $i$ :<sup>7</sup>

$$dy = \frac{\gamma}{1 - \mu\gamma} dx + \frac{1}{1 - \mu\gamma} dw. \quad (5')$$

Eqs. (5) and (5') show that true increasing returns and own-input-related variation in effort predict the same returns to scale estimates at different levels of aggregation. This does not hold in U.S. manufacturing data. Row 1 in table 1 presents the IV results for eq. (1) at the level of aggregate

<sup>7</sup>Of course assuming that the technological and effort coefficients are the same across all sectors is highly unrealistic. This aggregation problem is not responsible for our 'external effects' finding, however. See Caballero and Lyons (1989).

manufacturing, while row 2 presents the estimates obtained with two-digit data.<sup>8</sup> For simplicity, we denote the aggregate returns to scale by  $\phi$ , and the corresponding two-digit estimate by  $\theta$ . Columns 1 and 3 use as instruments military expenditure, the political party of the president, and the price of oil in terms of durables and nondurables manufactures; columns 2 and 4 add the first lag of both military expenditure and the political party of the president to the list of instruments. The first two columns correspond to the specification with the price of oil variable accounting for the energy shocks (see appendix), while the last two columns use a direct measure of sectoral energy use. We emphasize at the outset that use of first differences together with the removal of industry effects imply that the results correspond more closely to business cycle characteristics of the data rather than growth characteristics [see Bartelsman, Caballero, and Lyons (1991)].

The table shows a uniform difference between the point estimates of  $\phi$  and  $\theta$ , which indicates that there is a component that is, at least econometrically, only internalized at the most aggregate level.<sup>9</sup> Accordingly, we refer to this difference as due to an external effect. The simplest explanation for the external effect is a proper externality, which we develop as our null hypothesis in the next subsection.

### 2.1. Externalities

We capture the idea of an externality in the same manner as most of the theoretical models that investigate their effects on neoclassical results: by allowing sectoral productivity to depend on an index of aggregate activity,<sup>10</sup>

$$dw_i = \beta dy + dt_i.$$

Embedding this in eq. (5) yields

$$dy_i = \frac{\gamma}{1 - \mu\gamma} dx_i + \frac{\beta}{1 - \mu\gamma} dy + \frac{1}{1 - \mu\gamma} dt_i, \quad (6)$$

and summing over all sectors yields

$$dy = \frac{\gamma}{1 - \mu\gamma - \beta} dx + \frac{1}{1 - \mu\gamma - \beta} dt. \quad (6')$$

<sup>8</sup>The sample, 1959–1984, is the maximum length that provides consistency across our tables given the data available.

<sup>9</sup>The lack of precision of the most aggregate equation in the energy use case impedes carrying the statements about point estimates to statistically meaningful comparisons. This imprecision is removed, however, when we estimate the external effect directly from the panel. See the next subsection.

<sup>10</sup>For a review of work along these lines in International Trade see Helpman (1984).

Table 2  
The external effect.<sup>a</sup>  
 $dy_t = \lambda dx_t + \beta^* dy + \kappa d(\text{energy})_t + d\nu_t$

	IV1( <i>Poil</i> )	IV2( <i>Poil</i> )	IV1( <i>Ener</i> )	IV2( <i>Ener</i> )
$\lambda$	0.87 (0.03)	0.78 (0.03)	0.80 (0.03)	0.75 (0.02)
$\beta^*$	0.32 (0.03)	0.35 (0.02)	0.46 (0.02)	0.49 (0.01)

<sup>a</sup>IV1: instrument set #1, which contains military expenditures, the political party of the president, and the price of oil relative to nondurables and durables manufactures (all in rates of growth). IV2: instrument set #2, which is equal to #1 plus the first lag of military expenditures and the political party of the president. (*Poil*): the sectoral relative price of oil is included on the right-hand side (not reported). (*Ener*): the sectoral energy use is included on the right-hand side (not reported). Standard errors in parentheses. All equations include a constant per sector Annual data. 1959–1984.

It is apparent from these equations that if  $\beta > 0$ , returns to scale will be larger at the aggregate level where the externality has been internalized. This is true even if one excludes the externality component from the disaggregate equations, as we did in table 1. Using hats to denote estimates, it can be shown that

$$\text{plim } \hat{\theta} = \phi \left( 1 - \frac{\beta}{1 - \mu\gamma} (1 - \psi) \right),$$

which is less than  $\phi$  as long as  $\psi$  is less than one, where  $\psi$  is a coefficient summarizing the ratio of (i) the covariance between (the projections of) industry and aggregate inputs and (ii) the variance of (the projection of) industry inputs.<sup>11</sup> In the sample, the average  $\psi$  (across sectors) is about 0.9.

Moreover, denoting the estimate of returns to scale in (6) by  $\lambda$ , one can also write

$$\text{plim } \hat{\theta} = \lambda \left( 1 + \frac{\beta\psi}{1 - \mu\gamma - \beta} \right),$$

which means that a strong implication of positive externalities is the ranking

$$\lambda < \theta < \phi. \tag{7}$$

Table 2 presents estimates of  $\lambda$  and  $\beta/(1 - \mu\gamma) \equiv \beta^*$  for the different sets of instruments and oil/energy proxies. Comparing results from tables 1 and 2

<sup>11</sup> $\hat{\psi} = dx'_i P_z Q_{\widehat{d\rho}_i} P_z dx / dx'_i P_z Q_{\widehat{d\rho}_i} P_z dx_i$ , where  $P_z$  is the instruments projection matrix,  $\widehat{d\rho}_i$  is the projection of the energy proxy (price of oil or energy consumption) onto the instruments, and  $Q_z$  is an orthogonal projection matrix equal to  $I - P_z$ .

shows that the ranking in (7) is *always* satisfied. Moreover, the estimates of  $\beta^*$  in row 2 are always positive and significant. At the very least, the results in this table can be viewed as a more precise quantification of the external effect evinced in table 1.

In summary, the central message from this section is that there exist effects that are not internalized at the two-digit level which play an important part in raising the aggregate returns to scale index insignificantly above one. *Hence, explanations of procyclical productivity based upon either (i) internal increasing returns or (ii) unmeasured utilization tied to own-industry-inputs are at best insufficient.* In the next section we examine a number of different possibilities that tie procyclicality to variables other than own-inputs to determine whether a broader class of unmeasured utilization stories might be at least partially responsible for the external effect.

### 3. Unmeasured utilization and the external effect

Effort and utilization may fluctuate for reasons that are not captured by own-input variation. Shea (1991) shows that accident rates, as proxies for effort, have important explanatory power in production function estimates. Unfortunately, the accident rate data available has a short intersection with our data sample (1973–84). He finds, however, that accident rates are correlated with average overtime hours and the ratio of production to nonproduction workers, which are available for a substantially longer span of time. Accordingly, we use both of these as proxies for effort.

Abbott, Griliches, and Hausman (1989) address the potential effects of factor utilization in the context of Hall's framework by using average hours per employee as a proxy for both capital and labor utilization rates. They argue that Hall's finding of increasing returns is an artifact of the correlation between his instruments and factor utilization. They find that when this proxy is included in Hall's specification, then internal increasing returns disappear while the capacity measure becomes significant. We also include their variable as a proxy for effort/utilization.

Since our central purpose here is to test whether effort not related to own-input variation can account for the 'external effect', we first use the residual of the three effort proxies projected on own-inputs. Later we use the unprojected variables to identify, via the difference across the two sets of estimates, effort related to own-input variation. In all cases we include sector-specific definitions.

#### 3.1. *Non-own-input-related effort*

Table 3 presents the results using the orthogonal component of each of the three effort proxies, together with the same two instrument sets and proxies



Table 3  
Non-own-input-related effort.<sup>a</sup>

	IV1( <i>Poil</i> )	IV2( <i>Poil</i> )	IV1( <i>Ener</i> )	IV2( <i>Ener</i> )
$\lambda$	1.00 (0.05)	0.92 (0.04)	1.05 (0.05)	0.97 (0.04)
$\beta^*$	0.16 (0.05)	0.19 (0.04)	0.20 (0.05)	0.26 (0.04)
<i>OVT</i>	0.06 (0.02)	0.07 (0.02)	0.14 (0.02)	0.13 (0.02)
<i>AGH</i>	-0.31 (0.09)	-0.27 (0.08)	-0.19 (0.09)	-0.17 (0.07)
<i>PNP</i>	1.30 (0.18)	1.12 (0.15)	0.93 (0.18)	0.93 (0.15)

<sup>a</sup>IV1: instrument set #1, which contains military expenditures, the political party of the president, and the price of oil relative to nondurables and durables manufactures (all in rates of growth). IV2: instrument set #2, which is equal to #1 plus the first lag of military expenditures and the political party of the president. (*Poil*) the sectoral relative price of oil is included on the right-hand side (not reported). (*Ener*): the sectoral energy use is included on the right-hand side (not reported). *OVT*: average overtime hours. *AGH*: average hours per worker. *PNP*: ratio of production to nonproduction workers. Standard errors in parentheses. All equations include a constant per sector. Annual data: 1959–1984.

of oil/energy effects. In every case each of the three measures enters significantly. Overtime hours and the ratio of production to nonproduction employees enter with the expected positive sign; the *AGH* measure, however, enters with a negative sign, though this is difficult to interpret given the fact that all of the measures are proxies for the same sorts of effects. More important are the estimates of  $\beta^*$ : although they are systematically lower than those in table 2, they remain significant in every case. In addition, the estimates of  $\lambda$  are systematically higher, all of them now in the neighborhood of constant returns to scale. The upshot, then, is that effort variations not related to own-inputs appear to be playing a significant role, *but they cannot fully explain our measured external effects.*<sup>12</sup>

### 3.2. Own-input-related effort

While including the orthogonal component of each proxy provides a measure of the effect of unmeasured utilization which is *not* tied to own-inputs, including them outright provides a means of capturing their total effect. The difference between the two sets of results provides a means of capturing the effects of variations of unmeasured utilization that *is* tied to

<sup>12</sup>This is consistent with Shea's (1991) conclusion that effort seems to be procyclical but unable to account fully for the observed cyclical pattern of productivity.

Table 4  
Own-input-related effort.<sup>a</sup>

	IV1( <i>Poil</i> )	IV2( <i>Poil</i> )	IV1( <i>Ener</i> )	IV2( <i>Ener</i> )
$\Delta\lambda$	0.13	0.17	0.28	0.30
$\mu$	(0.15)	(0.25)	(0.35)	(0.46)
$\Delta\beta^*$	0.07	0.06	0.07	0.06
$\mu$	(0.78)	(0.50)	(0.51)	(0.31)

<sup>a</sup>IV1: instrument set #1, which contains military expenditures, the political party of the president, and the price of oil relative to nondurables and durables manufactures (all in rates of growth). IV2: instrument set #2, which is equal to #1 plus the first lag of military expenditures and the political party of the president. (*Poil*): the sectoral relative price of oil is included on the right-hand side (not reported). (*Ener*): the sectoral energy use is included on the right-hand side (not reported). All equations include a constant per sector. Annual data: 1959–1984.

own-inputs, summarized by the parameter  $\mu$  in section 2.1. As demonstrated, the presence of own-input-related variations in effort would affect both the estimates of  $\lambda$  and the estimates of  $\beta^*$ , in general biasing them upward. Hence, one would expect the differences in the estimates to be positive if these effects are in fact present. Table 4 presents the differences. The first row corresponds to the difference in the estimated  $\lambda$ 's (or  $\lambda - \gamma$ ). The second row corresponds to the difference in the estimated  $\beta^*$ 's (or  $\beta^* - \beta$ ), the external effect parameters. As the theory predicts, both sets of estimates do come down, providing evidence for unmeasured variations in utilization tied to own-activity; it is straightforward to calculate the implied  $\mu$ 's, which appear in parentheses. These are quite large, especially when recovered from the externality coefficient, suggesting that effort is highly cyclical; the caveat is that the  $\mu$ 's are recovered from ratios of coefficients that are very sensitive to the point estimates.<sup>13</sup>

#### 4. Some further considerations

##### 4.1. First-stage $R^2$ 's

Although first stage  $R^2$ 's are irrelevant in very large samples, this is not the case in samples of the size studied here. Nelson and Startz (1988) show that very low first-stage  $R^2$ 's can lead to large small-sample biases of IV estimators. Although their results are derived for single regressors and instruments, they indicate that the problems can be even more severe for more complex systems. Table 5 shows that first-stage  $R^2$ 's for the main regressors are on

<sup>13</sup>The externality remains highly significant in all cases in which the proxies for effort are included outright, except for IV1(*Poil*) where it is marginally significant at the 7% level

Table 5  
Average first-stage  $R^2$ .<sup>a</sup>

<i>Poil/Psec</i>	$d\lambda$	$d x_t$	<i>Energy</i>	<i>OVT</i>
0.94	0.82	0.51	0.24	0.55
<i>AGH</i>	<i>PNP</i>	<i>OVT0</i>	<i>AGHO</i>	<i>PNPO</i>
0.31	0.52	0.33	0.20	0.31

<sup>a</sup>*Poil/Psec*: price of oil over the sector value-added deflator (all variables in rates of growth). *Energy*: energy consumption. *OVT*: average overtime hours. *AGH*: average hours per employee. *PNP*: ratio of production to nonproduction workers. The extension *O* means the residuals from the orthogonal projection of the respective variable onto  $d x_t$ . The  $R^2$ 's are computed from the regressions of the above variables onto instrument set #1, which contains military expenditures, the political party of the president, and the price of oil relative to nondurables and durables manufactures. All equations include a constant. Annual data 1959–1984.

average above 0.2, which is clearly above the single regressor threshold value in Nelson and Startz. Again, however, it is difficult to assess the relevance of this threshold for our framework. Nevertheless, we should point out that these  $R^2$ 's are obtained with the smallest set of regressors (instruments) and that the estimates of external effects are even larger when estimated using SUR instead of 3SLS.

#### 4.2. Adjustment costs and dynamics

In deriving our main estimating equation (appendix A) we assume that the dynamic optimization problem of a firm can be well approximated by a sequence of (annual) frictionless static problems. Yet, in reality there is likely to be some degree of *observed* excess-capacity and labor-hoarding due to adjustment costs, a point stressed by Morrison (1988). We sketch here an argument as to why relaxing the assumption of a sequence of static problems to allow for observed labor-hoarding and excess-capacity is not likely to yield substantial biases. The complete argument is presented in Caballero and Lyons (1989).

Suppose that the first-order conditions for labor and capital use implied by the static optimization problem are not always satisfied, and need not even be satisfied on average. Algebraic manipulation of these conditions, with a wedge included to account for the deviations, demonstrates that observed excess-capacity and labor-hoarding affect the model only if the degrees to which each is present do not move proportionally. In the case where they do not move proportionally, bias is introduced but its magnitude is small: under conservative assumptions and extreme deviations from proportional movement it is possible to show that biases in the estimation of  $\lambda$  are on the order of 3%.

### 4.3. Classical measurement error

An important issue is whether classical measurement error can generate a spurious external effect; that is, factors of production may be reported with errors or imputed to the wrong industries. Here, we sketch an argument that this is implausible as a complete explanation of our findings. The detailed argument is presented in Caballero and Lyons (1991).

It is not difficult to show that even if the correlation between instruments and measurement errors is positive, it does not follow that estimation would unambiguously yield a positive coefficient for  $\beta^*$  in the absence of external effects. To be on the safe side, consider the case in which  $\beta^*$  is in fact upward-biased and no external effects are present. It is possible to further discriminate between the two hypotheses by studying the implication of measurement error for the spread between aggregate and industry-level estimates  $\hat{\phi} - \hat{\theta}$ , and contrasting this with our findings in table 1. Straightforward steps show that the aggregate measurement error left after projecting on the instruments would have to account for more than half of the covariance between the observed variables and the instruments in order to generate the estimated difference  $\hat{\phi} - \hat{\theta}$ .

## 5. Conclusion

The paper proceeded in two stages. In the first we highlighted a new dimension of the aggregate procyclical productivity phenomenon: the role of external effects. We showed that estimates of returns to scale are much larger for manufacturing as a whole than for two-digit industries. That is, there exist factors which are only internalized at the aggregate level. We also showed that there exists a strong reduced-form relationship between industry productivity and aggregate activity. An important implication of these results is that they permit one to rule out explanations such as true increasing returns and unmeasured factor utilization tied to own-activity as complete explanations for aggregate procyclical productivity.

The second stage was more tentative. In this stage we tried to explain the external effect. We began by posing true externalities as our maintained hypothesis. In particular, our preferred interpretation of the results includes thick-market externalities, which is supported by the findings of Bartelsman, Caballero, and Lyons (1991). We explored other alternatives based primarily on effort variation, resulting possibly from labor-hoarding, excess-capacity, or both. We do find some evidence of unmeasured effort variation, both that which is related to own-activity and that which is independent of it. In the end, unmeasured effort variation accounts for about half of the measured external effect.

There is evidence that the phenomenon described in this paper is widespread. Caballero and Lyons (1990) apply a method similar to the one

developed here to European manufacturing at the two-digit level. The bottom line there is very similar to that in the U.S.: The external effects coefficients ( $\beta^*$ 's) for the four countries covered by the study are all very significant. In the country for which we had the most reliable data, West Germany, our estimate of  $\beta^*$  was in the same range (0.26). Additionally, as in the U.S., there is no evidence of internal increasing returns on average in Europe, though there is strong support for the presence of *increasing social returns*.

**Appendix A: Derivation of eq. (1)**

Consider a compound function (not gross production) of value-added and energy:

$$Q = Q(K, L, E, V, O),$$

where  $K$ ,  $L$ ,  $E$ ,  $V$ , and  $O$  are capital, labor, an external effect index, a productivity index, and energy (summarized by oil), respectively. (Time subscripts are suppressed throughout.) Accordingly, define value-added,  $Y$ , as the maximized function

$$Y \equiv \max_O \frac{P_Q Q - P_O O}{P},$$

where  $P$ ,  $P_Q$ , and  $P_O$  represent the prices of value added, the compound, and energy, respectively. We can then write:

$$Y = F(K, L, E, V; P/P_O).$$

Let  $F$  be homogeneous of degree  $\gamma$  in capital and labor,<sup>14</sup> of degree one in the productivity index, of degree one in the external effects index,<sup>15</sup> and of degree  $\kappa$  in  $e^p$ , where  $p \equiv \log(P/P_O)$ . Letting  $x = \log X$  and  $F_x = \partial F / \partial X$ , we get the following equation:

$$\begin{aligned} dy = & \left( \frac{F_K K}{Y} \right) dk + \left( \frac{F_L L}{Y} \right) dl + \left( \frac{F_{(P/P_O)} (P/P_O)}{Y} \right) dp \\ & + \left( \frac{F_E E}{Y} \right) de + \left( \frac{F_V V}{Y} \right) dV. \end{aligned} \tag{A.1}$$

<sup>14</sup>Note that if  $Q$  is homogeneous of degree  $\eta$  in capital and labor and  $\theta$  in energy,  $\gamma = \eta / (1 - \theta)$ .

<sup>15</sup>This is just a normalization. Since  $E$  and  $V$  are simply indexes, homogeneity of degree one imposes no constraint.

Given the homogeneity properties of  $F(\cdot, \cdot, \cdot)$ , we have

$$\gamma = \left( \frac{F_K K}{Y} \right) + \left( \frac{F_L L}{Y} \right), \quad \kappa = \left( \frac{F_{(P/P_0)}(P/P_0)}{Y} \right),$$

and

$$1 = \left( \frac{F_E E}{Y} \right) = \left( \frac{F_V V}{Y} \right).$$

Replacing these conditions in (A.1) yields

$$dy = \gamma dk + \left( \frac{F_L L}{Y} \right) (dl - dk) + \kappa dp + de + dv. \quad (\text{A.2})$$

Under the very strong assumption that conditions faced by firms are such that their dynamic optimization problem can be well approximated by a sequence of frictionless static problems, it is possible to obtain a simple expression for  $(F_L L/Y)$  since the first-order condition with respect to labor of a profit-maximizing firm with some degree of monopoly power in the goods but not in the factor markets is

$$P \left( \frac{\eta - 1}{\eta} \right) F_L = W,$$

where  $W$  and  $\eta$  are the wage and elasticity of demand (absolute value), respectively.<sup>16</sup>

A firm with monopoly power will set its price such that  $P/MC = \eta/(\eta - 1)$ , where  $MC$  denotes marginal cost. Defining the markup coefficient as  $\rho \equiv P/MC$  yields

$$\left( \frac{F_L L}{Y} \right) = \rho \alpha_l, \quad (\text{A.3})$$

where  $\alpha_l \equiv WL/PY$  is a share of labor in value added.

Replacing (A.3) in (A.2) results in

$$dy = \gamma dk + \rho \alpha_l (dl - dk) + \kappa dp + de + dv. \quad (\text{A.4})$$

<sup>16</sup>The distinction between final goods price and value-added price in the determination of the markup is not important for the purposes of this paper.

But from homogeneity, we have

$$\frac{PY}{WL + rP_K K} = \frac{\rho}{\gamma}, \quad (\text{A.5})$$

where  $r$  and  $P_K$  are the real (rental) cost of capital and price of capital, respectively.

If  $\alpha_c$  denotes labor's share in total factor costs, eq. (A.5) implies

$$\alpha_c = \alpha_l \frac{\gamma}{\rho},$$

hence

$$dy = \gamma[\alpha_c dl + (1 - \alpha_c) dk] + \kappa dp + dw, \quad (\text{A.6})$$

where  $dw \equiv de + dt$ , which represent the change in the external effect and in productivity.

Our alternative route is to simply approximate any possible complementarity between energy and value-added by adding sectoral energy consumption on the right-hand side.

## Appendix B: Data

The basic data used are the same as those used in Hall (1990) and were obtained from Hall. They cover the twenty two-digit manufacturing industries and include:  $Y$  = real value-added in 1982 dollars [*U.S. National Income and Product Accounts* (NIPA)],  $K$  = net real capital stock [Bureau of Economic Analysis],  $N$  = hours of work of all employees [NIPA], and  $W$  = total compensation divided by  $N$ .

The instruments we use to correct for the correlation between regressors and productivity shocks are based on those used by Ramey (1991) and Hall (1987). They include (1) the rate of growth of real military purchases of goods and services, (2) the log difference of the relative price of oil in terms of durables, (3) the log difference of the relative price of oil in terms of nondurables, and (4) a dummy variable with the value of one when the president is a Democrat and zero when Republican. Our instrument set #1 includes contemporaneous values of each of the four. Instrument set #2 adds the first lag of both the growth of real military purchases and the political party of the president.

We construct the rental price of capital as Hall did, following Hall and Jorgenson (1967). The rental price is determined as

$$r = (\rho + \delta) \frac{1 - c - \tau d}{1 - \tau} p_k,$$

where  $\rho$  is the firm's real cost of funds, measured as the dividend yield of the S&P 500;  $\delta$  is the economic rate of depreciation, set to 0.127 [see Jorgenson and Sullivan (1981)];  $c$  is the effective rate of the investment tax credit [ibid];  $d$  is the present discounted value of tax deductions for depreciation [ibid]; and  $p_k$  is the deflator for business fixed investment [NIPA].

The standard argument in support of using the dividend yield as the real cost of funds begins with the observation that most investment in the U.S. is financed through equity in the form of retained earnings. As long as the dividend yield is a good measure of the cost of equity, its use is justified. Of course, stocks differ substantially in the share of their total yield that comes from dividends versus capital gains. The argument is that on balance the dividend yield is an accurate measure. The principal alternative is to derive an estimated real rate from some measure of expected or realized inflation and a nominal rate of interest. Caballero and Lyons (1990) find that the results in this context are robust to the choice of these measures.

The source for the series on sectoral energy use is the Bureau of the Census Annual Survey of Manufactures. The source for sectoral overtime hours and the breakdown between production and nonproduction workers is the Bureau of Labor Statistics Employment and Earnings Survey. The number of employees series were obtained from CITIBASE.

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