

Customer- and Supplier-Driven Externalities

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The purpose of this paper is to provide empirical evidence helpful for distinguishing different types of externalities. We pursue this by extending the production-function framework of Robert E. Hall (1990) and Caballero and Lyons (1990, 1992) to exploit two key dimensions of the data: disaggregate input-output relationships and differences between estimates emphasizing time-series versus cross-sectional aspects of the data.

We obtain three main results. First, from the “within” estimates (using annual data), which emphasize the time-series properties common across sectors, we find a strong reduced-form relationship between industry productivity and the activity level (input growth) of *customers*. In sharp contrast, *supplier* activity levels are insignificant.

The second result derives from “between” estimates, which emphasize the cross-sectional dimension of the data. Here, we find the opposite is true: there is a strong reduced-form relationship between industry

productivity and the activity level of suppliers, but no relationship with customer activity levels. We interpret the first two results as suggesting that over shorter horizons the linkage between an industry and its customers is pivotal in the transmission of external effects, while in the long run external effects are mostly related to intermediate goods linkages.

The third result concerns the transition from short to long run. We find that as the number of periods over which the variables are averaged is incrementally increased from one year toward the full sample period (27 years), the significance of customers versus suppliers smoothly reverses itself.

The remainder of the paper is organized in four sections. Section I presents the core model and the econometric methods for disentangling the external effects; Section II describes the data and estimation; Section III presents the main results; and our conclusions are presented in Section IV.

I. The Core Model and Some Econometric Considerations

Expressing all variables in rates of growth (log differences), one can write a production function that includes a generic externality in the following simple form:

$$(1) \quad y_{it} = \gamma x_{it} + \beta x_{it}^a + v_{it}$$

where y_{it} is the growth of gross production in industry i ; x_{it} is the growth rate of industry i 's inputs [defined as $\alpha_{\ell it} l_{it} + \alpha_{k it} k_{it} + (1 - \alpha_{\ell it} - \alpha_{k it}) m_{it}$, with $\alpha_{\ell it}$ and $\alpha_{k it}$ the shares of labor and capital in total costs, respectively, l_{it} the growth rate of labor input (hours), k_{it} the growth rate of capital input, and m_{it} the growth rate of materials

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input];¹ x_{it}^a is an appropriately weighted average of other industries' activity, as measured by the growth rate of their inputs, and v_{it} is the growth rate of industry i 's technology.²

The coefficient γ captures the conventional degree of internal returns to scale, while β (possibly a vector) captures any external effects deriving from changes in aggregate activity levels. The subindex i spans 450 four-digit manufacturing industries. Since one of our objectives is to disentangle short- from long-run externalities, we allow for different coefficients in the "within" and "between" dimensions of the panel data (see Yair Mundlak, 1978). The "within" estimator, by removing the sample time averages for each industry, puts greater emphasis on the fluctuations-oriented relationships. The "between" estimator, on the other hand, removes all the fluctuations and thereby puts more emphasis on the longer-horizon relationships.

To formalize the separation of these two estimators, we decompose the disturbance in equation (1) into three terms: a constant, an industry-specific term, and a residual that is independent across industries:

$$u_{it} = \theta_0 + \theta_i + \theta_{it}.$$

In turn, the industry-specific term has three components: one that is related to its own-industry average rate of input growth, another that is related to the average rate of growth of more aggregate input measures, and a constant:

$$\theta_i = \lambda_1 \bar{x}_i + \lambda_2 \bar{x}_i^a + v_i$$

where the bar denotes a time average.

¹Using cost shares provides robustness to deviation from perfect competition (see Hall, 1990).

²The debate about the virtues and shortcomings of gross-production models is an old one. See Martin Baily (1986) for a summary of the central issues. He recommends using gross production in lieu of value added at more disaggregated levels, and that is the choice we have made here. See Bartelsman et al. (1991) for results for both value-added and gross-production models.

Equation (1) can be rewritten as follows:

$$y_{it} = \theta_0 + \gamma(x_{it} - \bar{x}_i) + \beta(x_{it}^a - \bar{x}_i^a) \\ + (\gamma + \lambda_1)\bar{x}_i + (\beta + \lambda_2)\bar{x}_i^a + v_i + \theta_{it}$$

or, more compactly, as

$$(2) \quad y_{it} = \theta_0 + \gamma(x_{it} - \bar{x}_i) + \beta(x_{it}^a - \bar{x}_i^a) \\ + \bar{\gamma}\bar{x}_i + \bar{\beta}\bar{x}_i^a + v_i + \theta_{it}.$$

Note that, among the parameters of main interest, the "within" procedure permits estimation of γ and β only, while the "between" procedure permits estimation of $\bar{\gamma}$ and $\bar{\beta}$ only.

Broadly speaking, our approach considers different variables (or sets of variables) as proxies for the aggregate activity index most directly affecting productivity growth at the four-digit level. We consider explicitly the interindustry linkages by testing the significance of various weightings for the aggregate activity variable in equation (1). For example, if externalities are transmitted via intermediate goods, then the appropriate weights for constructing the aggregate activity variable for each industry are the shares of materials *received* from other industries, rather than conventional value-weighted aggregate activity. On the other hand, if the externality derives from aggregate demand, then the appropriate weights are the shares of materials *sent* to other industries. Implications of a transactions externality are less clear-cut; both input weights and output weights are likely to be relevant, given that transactions occur both on the incoming side of operations (procurement) and on the outgoing side.

II. Data and Estimation Description

The data sets used in this study are the NBER productivity data base, the input-output accounts for the U.S. economy, and parts of Hall's (1988, 1990) two-digit data set (namely, series used to compute the rental cost of capital, and instruments). The productivity data base contains information for four-digit manufacturing industries from 1958 through 1986, and it is being maintained and updated by

Bartelsman. Documentation of this data can be found in Wayne Gray (1989). The interindustry data are described in the Bureau of Economic Analysis (1984) *Survey of Current Business*, and they reflect the 1977 input-output structure of the U.S. economy for 537 industry/commodity classes.

The industry series used are gross production, nonproduction workers, production-worker hours, real capital stock, materials cost, production-worker wages, the shipments deflator, the materials deflator, and the investment deflator, for 450 four-digit manufacturing industries, as defined in the 1972 Standard Industrial Classification (SIC), for the years 1958–1986. Our measures of external activity include the non-manufacturing business sector, for which we have the same series except for materials.

The series from Hall's (1988) data set include variables needed to compute capital rental rates and some of the instruments used in the instrumental-variable (IV) estimation. The capital rental rates are computed as follows:

$$r = (\rho + \delta)[(1 - c - \tau d)/(1 - \tau)] p_k$$

where ρ is the firm's real cost of funds, δ is the economic rate of depreciation, c is the effective rate of investment tax credit, d is the present discounted value of tax deductions for depreciation, τ is the corporate tax rate, and p_k is the investment deflator.

The 1977 input-output accounts' "make" and "use" tables (BEA, 1984) are used to create an industry-by-industry direct-requirements matrix for the four-digit manufacturing and two-digit nonmanufacturing industries.³ To this end, a concordance

³Joseph P. Matthey (1992) shows the effects on parameter estimates in a model similar to ours of I/O coefficient change from the 1977 to the 1982 interindustry table: when the parameters are constrained to be equal across industries, using the 1982 instead of the 1977 I/O coefficients results in nearly identical estimates; in unconstrained versions, ignoring changes over time in I/O coefficients biases estimates away from externalities in those sectors where I/O coefficient changes are large.

among the 537 BEA categories, 450 four-digit manufacturing industries, and 10 non-manufacturing sectors was applied to the computed 537×537 direct-requirements matrix (see Matley, 1990). The direct-requirements matrix has elements ij , which show the value of products from industry i used as an intermediate material in industry j . To create an output-weighted, or *customer*, aggregate activity index for industry i , one computes an output-weighted average of percentage changes in activity of all other industries that purchase product from industry i . The weight applied to industry j when creating the aggregate index for industry i is the ij th element of the matrix, divided by the sum of the i th row:

$$x_{it}^{OW} = \sum_{j \neq i} \frac{\alpha_{ij}}{\sum_{j \neq i} \alpha_{ij}} x_{jt}$$

where α_{ij} is the ij th element of the direct requirements matrix. To get the input-weighted, or *supplier*, aggregate activity index for industry i , one computes a weighted average of the change in activity of the industries that deliver products to industry i . The weight applied to the activity of industry j is the ji th element divided by the sum of the i th column of the direct-requirements table:

$$x_{it}^{IW} = \sum_{j \neq i} \frac{\alpha_{ji}}{\sum_{j \neq i} \alpha_{ji}} x_{jt}$$

Nestor Terleckyj (1974) makes similar use of the interindustry flow matrix, constructing forward and backward linkages for the effects of R&D on productivity.

In general, unobservable productivity growth is likely to be correlated with changes in capital and labor, yielding simultaneity bias. It is natural to argue in this case for the use of an instrumental-variable procedure. Unfortunately, identifying aggregate instruments that are completely uncorrelated with productivity shocks while at the same time providing sufficient correlation

with regressors is a difficult—if not impossible—task.⁴

Our IV procedure in the “within” dimension uses an instrument set based on Hall (1990), consisting of the percentage change in defense expenditures, its lagged value, a dummy reflecting the political party of the president, its lagged value, the lagged percentage change in the ratio of the price of oil to the price of durables, and the lagged percentage change in the ratio of the price of oil to the price of nondurables. The first two instruments and their lagged values capture demand shocks which are unlikely to be the contemporaneous response to productivity shocks; the last two correspond to what are arguably exogenous supply shocks, also unlikely to be correlated with productivity shocks. Each of these time-series instruments has its mean removed. The coefficients of the projection of the right-hand-side variables onto the “de-meaned” instruments ($z_t - \bar{z}$), is allowed to vary by industry [i.e., the resulting instrument matrix can be written as $\mathbf{I}_N \otimes (z_t - \bar{z})$].

In the “between” dimension, we construct our instruments in two steps. We first look for variables that are likely to be correlated with the differential sectoral response to changes in our within-dimension instruments. Accordingly, we select the average level and average growth rate of the following variables: the capital-to-labor ratio, the materials-to-shipments ratio, the energy-to-shipments ratio, and the ratio of the shipments deflator to oil price. The first two are related to the sectoral flexibility to different demand shocks, while the last two are related to the “within” instruments based on the price of oil.

In the second step, we attempt to remove the obvious correlation between instruments based on own-sector shipments (and its deflator) and own-sector productivity shocks. We do this in the following way. From the cross-sectional variables generated in step 1 above we create two sets of instruments, industry by industry: one for

which each of the above variables is weighted by the input weights of other industries and one for which each variable is weighted by the output weights of other industries, that is, the instrument set $[\bar{z}_1^{IW}, \bar{z}_1^{OW}, \bar{z}_2^{IW}, \bar{z}_2^{OW}, \dots, \bar{z}_m^{IW}, \bar{z}_m^{OW}]$ of dimension $N \times 2m$, where N is the number of industries and m is the number of cross-sectional variables above. We then use as the instruments for industry i only these input- and output-weighted averages over other manufacturing industries. The instrument set for the “mixed” procedure contains the “within” and the “between” instruments.

We are aware of the limitations of our instruments. Moreover, even a very small correlation between instruments and productivity growth can induce large biases from IV relative to ordinary least squares (OLS) since the covariance between instruments and regressors is often much smaller than the variance of the regressors themselves.⁵ In a related point, Caballero and Lyons (1990) emphasize that the magnitude of the asymptotic bias in OLS decreases the higher is the variance of the regressors relative to their covariance with productivity growth. If the latter is small relative to the former, there is a basis for choosing the relative power of OLS over IV with poor instruments.

With these arguments as a backdrop, we present both OLS and IV results.

III. Empirical Evidence

Table 1 presents the “within” and “between” estimates, as well as the estimates from the decomposed or “mixed,” specification in equation (2). The table also presents the results for the model using both input-weighted (IW) and output-weighted (OW) externalities. In the decomposed specification we impose the constraint that the degree of internal returns to scale is the same over shorter and longer horizons. We

⁴See the discussion in Hall (1988 pp. 932–34).

⁵This is in addition to the *small-sample* problems discussed by Charles Nelson and Richard Startz (1988).

TABLE 1—SUMMARY TABLE

Estimate	Within		Between		Mixed	
	OLS	IV	OLS	IV	OLS	IV
γ	1.094 (0.007)	1.075 (0.014)			1.094 (0.007)	1.078 (0.014)
$\bar{\gamma}$			1.090 (0.024)	1.323 (0.118)		
β^{IW}	0.020 (0.028)	0.035 (0.048)			0.020 (0.029)	0.033 (0.048)
β^{OW}	0.119 (0.022)	0.120 (0.038)			0.119 (0.023)	0.118 (0.038)
$\bar{\beta}^{IW}$			0.313 (0.081)	0.308 (0.141)	0.312 (0.097)	0.444 (0.137)
$\bar{\beta}^{OW}$			0.066 (0.062)	-0.069 (0.141)	0.063 (0.071)	0.056 (0.127)
R^2 :	0.72		0.85		0.73	

Within:

$$y_{it} - \bar{y}_i = \gamma(x_{it} - \bar{x}_i) + \beta^a(x_{it}^a - \bar{x}_i^a) + \delta TD + \theta_{it}$$

Between:

$$\bar{y}_i = \theta_0 + \bar{\gamma}\bar{x}_i + \bar{\beta}^a\bar{x}_i^a + \theta_i$$

Mixed:

$$y_{it} = \theta_0 + \gamma x_{it} + \beta^a(x_{it}^a - \bar{x}_i^a) + \bar{\beta}^a\bar{x}_i^a + \delta TD + \theta_{it}$$

Notes: Standard errors are given in parentheses. The superscripts a in the above equations are shorthand for IW and OW, which denote input- and output-weighted activity aggregates, respectively. The variable y is the log first difference of real gross production; x_i is the log first difference of an own-input index. The data panel consists of 450 four-digit manufacturing industries from 1958 through 1986. The “within” and “mixed” estimates include time dummies, denoted as TD.

report the last column mostly as a benchmark for the dynamic analysis in the next section, which imposes the same constraint. The “within” and “mixed” regressions include time dummies.⁶

⁶The time dummies, combined with the restriction that coefficients are the same across industries, remove the possibility that the externalities are proxies for a common productivity shock, even if the shocks affect sectors differently. Though the size of the output-weighted externality does decrease with the inclusion of the time dummies, both the short- and longer-run effects remain large and significant. Indeed the size of the coefficient reduction in the “within” dimension can be interpreted as an upper bound on the contribution

The first two rows show that there is evidence of moderate internal increasing returns. The estimates are slightly below 1.1, except for the IV-between estimate which is larger but more imprecise. The next two rows show that, over the shorter run, the output-weighted externalities are positive and significant while the input-weighted ones are insignificant. The following two

of the “common productivity shock” explanation of the external-linkages finding. In Bartelsman et al. (1991), we report the results without time dummies.

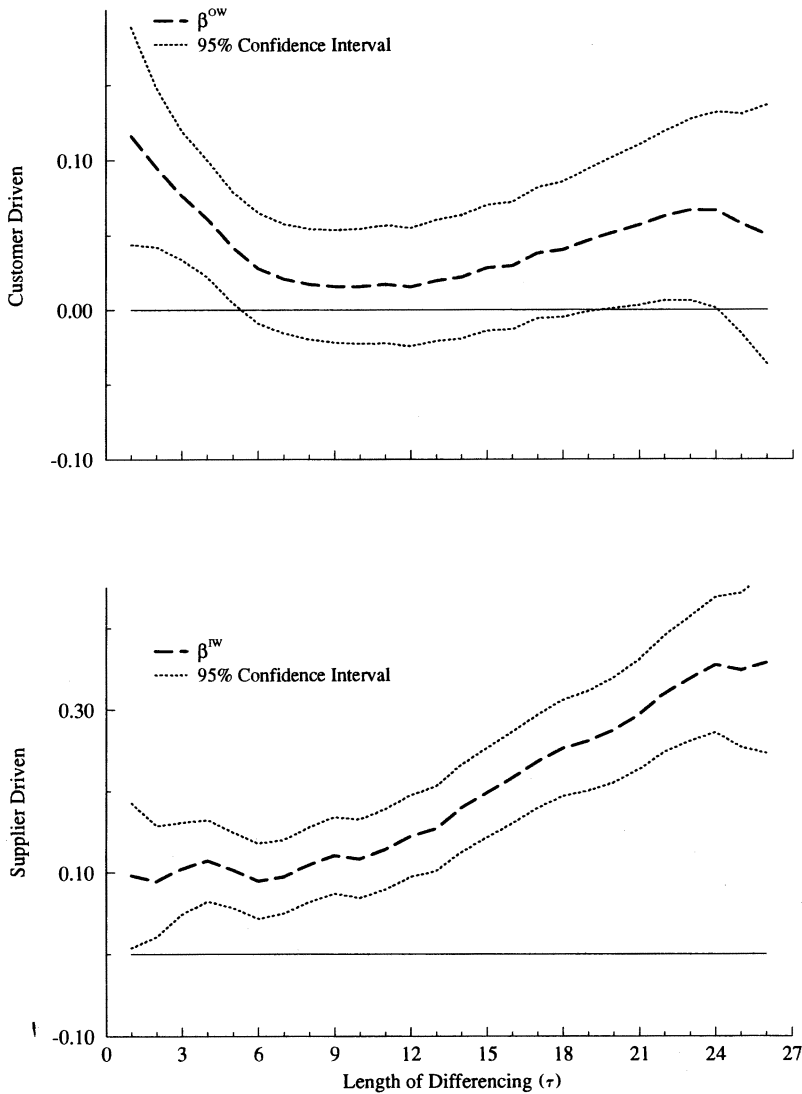


FIGURE 1. DYNAMIC PROFILE OF EXTERNAL EFFECTS: EQUATION (3)

rows, on the other hand, show a dramatic shift of the estimated externality toward the input-weighted aggregate: in all cases β^{IW} is positive and significant at conventional levels, whereas the output-weighted aggregate loses its significance completely. The central message of these two rows appears to be that, over longer horizons, intermediate-goods linkages are key to the transmission of external effects.

Dynamic Profiles

We have interpreted the “within” and “between” results as evidence on the magnitude and channels of external effects at both short and long horizons. A third important consideration is the dynamic profile of the effects between the short and long run. For this we estimate two sets of equations. The first one contains a series of

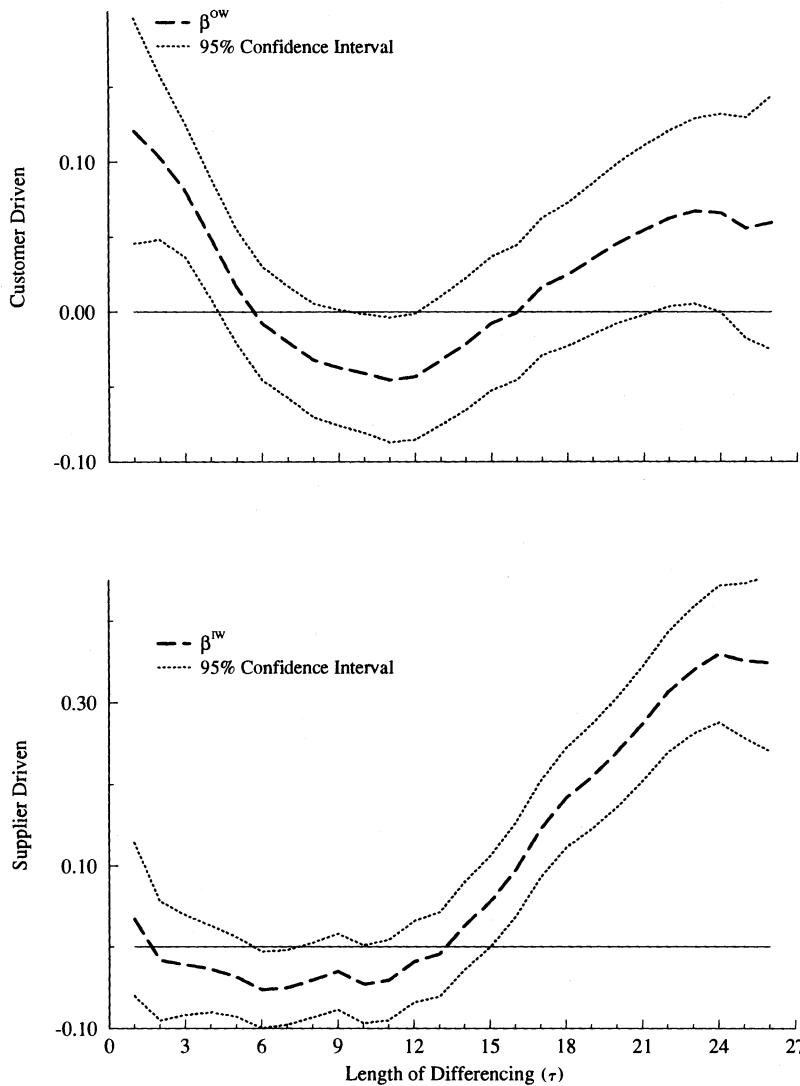


FIGURE 2. DYNAMIC PROFILE OF EXTERNAL EFFECTS: EQUATION (4)

equations of the following form:

$$(3) \quad y_{it\tau} = \theta_0 + \gamma x_{it\tau} + \beta x_{it\tau}^a + \theta_{it\tau}$$

for each $t = \tau$ to $t = T$ and each $\tau = 1$ to $T - 1$, where $y_{it\tau}$ is defined as $Y_{it} - Y_{it-\tau}$ and Y_{it} is defined as the log level of gross production in industry i . The same convention applies for the input measures. Thus, the number of periods used to compute the average growth of the basic unit of observation is incrementally increased from one

year toward the full sample period of 27 years (corresponding to “between” estimates).

Figure 1 illustrates the results from estimation of equation (3).⁷ The horizontal axis

⁷Figures 1 and 2 reflect the results of estimation using instrumental variables. Time-series and cross-sectional instruments are employed in the same manner as those used to produce the mixed estimates reported in

records the value of τ from equation (3), which corresponds to the horizon length, and the vertical axis records the externality parameter values. The dotted lines reflect intervals of ± 1.96 standard errors. The top panel shows the path of the output-weighted or *customer* externality coefficient, which remains significant for about five years. The bottom panel depicts the increasing path of the input-weighted or *supplier* coefficient.

The problem with the previous procedure, however, is that it does not start from the “within” estimates, but from the pooled regression, which weights both the “within” and “between” estimates. This is the reason why input-weighted externality estimates for $\tau = 1$ are larger than the within estimates reported in Table 1. For this reason, we provide an alternative measure of the transition from short- to long-run results. We estimate a set of regressions of the form

$$(4) \quad y_{it\tau}^* = \theta_0 + \gamma x_{it\tau}^* + \beta x_{it\tau}^{*a} + \theta_{it\tau}.$$

for each $t = \tau$ to $t = T$ and each $\tau = 1$ to $T - 1$, where

$$y_{it\tau}^* \equiv \frac{y_{it\tau}}{\tau} - \left(\frac{27 - \tau}{26} \right) \bar{y}_i$$

and the same convention applies for the input measures. This set of regressions is tied at both ends by the “within” and “between” procedures; it corresponds to the “within” regression when $\tau = 1$ and to the “between” regression when $\tau = 27$.

Figure 2 illustrates the results from estimation of equation (4). As before, the horizontal axis records the value of τ , which corresponds to the horizon length, and the vertical axis records the externality parameter values. The dotted lines reflect intervals of ± 1.96 standard errors. The top and bottom panels correspond to the output- and

input-weighted externality coefficients, respectively. The patterns in Figure 2 summarize well the findings of this paper: over short horizons the OW externality dominates, whereas the IW externality dominates over the longer run.

IV. Conclusions

The purpose of this paper was to provide empirical results useful for distinguishing different types of activity spillovers and their pattern. We pursued this by exploiting two key dimensions of the data: disaggregate input-output relationships and differences between estimates that emphasize the time-series versus the cross-section dimensions of external effects. In the end, our conclusions are two-layered: first, we obtain three main results that refine the reduced-form impact of aggregate activity on industry productivity; second, we interpret those results as providing suggestive new evidence for distinguishing different externalities. Since the interpretation layer of our conclusions is much more controversial, we separate it in what follows.

The first of our three main results comes from estimates emphasizing the time-series dimension. We find a strong relationship between industry productivity and the activity level (input growth) of *customers*, suggesting that over shorter horizons the linkage between an industry and its customers plays a pivotal role in measured productivity.

The second result derives from cross-section estimates. Here, we find that the opposite is true: there is a strong reduced-form relationship between industry productivity and the activity level of *suppliers*, but no relationship with customer activity levels. These long-run results suggest that intermediate-goods linkages play an important role in addition to the above-mentioned short-run effects.

The third result concerns the transition from short to long run. If our association of “within” estimates with shorter horizons and “between” estimates with longer horizons is reasonable, then one would expect smooth changes in the results as differenc-

the last column of Table 1. For Figure 1, the time-series instruments are differenced with lag τ , whereas for Figure 2 the time-series instruments undergo the transformation procedure described in equation (4).

ing is incrementally increased from one year toward the full sample period (27 years). In fact, we find that as differencing is extended, the relative significance of customers versus suppliers does indeed reverse itself smoothly.

Though our main results do provide some resolving power, they do not allow us to identify the precise source(s) of the effects; consequently, our preferred interpretation of them as evincing externalities remains controversial. Overall, we view our results as evidence that fluctuations-oriented and growth-oriented external economies are present, both of which depend crucially on interindustry linkages.⁸ Considering the fluctuations-oriented effects first, our results indicate that the linkage between an industry and its *customers* is the overriding factor in the transmission of external effects: the output-weighted aggregates remain significant throughout our "within" estimation, even though we remove aggregate fluctuations with time dummies. All this suggests that over shorter horizons the external economies are likely to derive from either thick markets or *externally driven* changes in effort.

As for growth-oriented externalities, the linkage with *suppliers* is the dominant factor. That is, the growth performance of suppliers of intermediates matters for measured productivity downstream. This role for intermediates could reflect either the direct embodiment of knowledge, a proxy for less specific technological linkages, or unpriced specialization/quality.

Finally, a number of robustness tests were performed and reported in our longer working paper (Bartelsman et al., 1991). In particular, we find that capacity utilization is unable to account for our measured externalities; our tests utilize as a proxy for ca-

capacity utilization the ratio of hours per worker to peak hours per worker for each industry, as suggested by Matthew Shapiro (1989) and Thomas Abbott et al. (1988). We also explore whether the restriction of equal coefficients across industries is able to account for our results; when the constraint is relaxed, the medians of the coefficients provide very similar results. Finally, we present evidence that generalizing the model to distinguish between production and nonproduction workers does not affect our conclusions either.

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⁸For recent work on the importance of vertical linkages see Paul Geroski (1992). On page 142 he asserts: "Indeed, so important are vertical associations between suppliers and users on the one hand and innovation producers on the other, that the innovation process is often user or supplier led and not producer led."

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