Infrastructure, Externalities, and Economic Development: A Study of the Indian Manufacturing Industry

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If infrastructure tends to generate spillover externalities, as has been the assumption in much of the development literature, one may reasonably look for evidence of such indirect effects in the accounts of manufacturing industries. Empirical support for this assumption has so far been ambiguous. This analysis of Indian data, however, reveals substantial externality effects from the states' infrastructure to manufacturing productivity. The analysis separates the direct effects of roads and electricity, as mediated by the infrastructure services purchased by manufacturing industries along with other intermediate inputs, from the indirect effects, as measured by the impact of infrastructure capacity on the Solow productivity residual. In the 20 years from 1972 to 1992, growth of road and electricity-generating capacity seems to have accounted for nearly half the growth of the productivity residual of India's registered manufacturing.

In what are now classics in the theoretical literature on growth and economic development, infrastructure investments are associated with significant spillover externalities, with benefits that accrue outside the target area of the investment (Young 1928; Rosenstein Rodan 1943; Hirschman 1958). This view also fits well with endogenous growth theory that sees externalities as the source of endogenous feedback effects on output growth (Romer 1986; Lucas 1988; Barro 1990). Empirical support for the existence of significant infrastructure externalities has, however, been far from unanimous. Aschauer's estimates (1989a, 1989b) of the macro effects of infrastructure investment support the hypothesis of significant spillovers. Not so the estimates of the infrastructure

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effects based on a growth-accounting model. In that model, spillovers from infrastructure should show up as increases in total factor productivity. Young (1992, 1995) found only a limited role for total factor productivity as a source of growth in four East Asian economies, implicitly limiting the role of infrastructure spillovers operating through increased productive efficiency. Other studies, however, have found significant total factor productivity effects for Japan (Nishimizu and Hulten 1978) and East Asia (Hsieh 1999).

None of these growth-accounting studies links infrastructure explicitly to growth externalities. This step was taken by Hulten and Schwab (1984, 1991, 2000) in their studies of regional total factor productivity in U.S. manufacturing. Modifying the conventional growth-accounting model to isolate the effect of infrastructure externalities on growth, they found no evidence of externalities in explaining the growth of total factor productivity of U.S. manufacturing industry.

This article joins this debate by investigating the effects of infrastructure in the manufacturing sector of a large low-income developing economy. India experienced a rapid increase in highway infrastructure and electricity-generating capacity during 1972–92, and when the Hulten–Schwab framework is applied to data developed from the Indian Annual Survey of Industries (ASI) for these years, the results suggest that, unlike the case of U.S. manufacturing, spillovers account for a large part of total factor productivity growth.

I. INFRASTRUCTURE IN THE STRUCTURE OF PRODUCTION

Because the focus is on the industrial development effects of infrastructure, infrastructure is placed directly in the production function for manufacturing output as an unpaid factor of production (Meade 1952). A general form of the production function can be written as:

$$(1) \qquad Q = A(B,t)F(K,L,M(B))$$

where Q denotes gross output, B infrastructure stock, K privately owned (non-infrastructure) capital, L labor input, and M intermediate inputs. The term $A(B,t)$ is a standard Hicks-neutral efficiency function that allows for exogenous shifts in the production function. This technology may exhibit diminishing, constant, or increasing returns to scale.[1]

1. Gross output is used in equation (1), because it is the appropriate measure of the actual product made by manufacturing firms—the actual quantity of textiles, steel, autos, and so on. Value added is, in fact, a measure of primary input (Hulten 2001). Real value added is sometimes used in industry studies, because it is easily related to aggregate output. This is rarely an appropriate procedure for productivity studies, because it requires the assumption of a separable production function. [Pradhan and Barik (1998) tested for separability with Indian industrial data and concluded that the value added function did not exist.] Furthermore, the value-added approach assumes that the efficiency change affects only labor and capital but not intermediate inputs (a dubious assumption, at best, and inappropriate in the current context because of the role of intermediate inputs in transmitting the effects of infrastructure). However, to facilitate comparison with other research, results are displayed based on the value-added approach at various points in this article.

This specification allows infrastructure systems to affect the manufacturing industry through two channels. First, changes in the stock of infrastructure are reflected in the intermediate input variable, $M(B)$. The intermediate goods and services purchased by manufacturing firms include transportation services and electricity, each produced by its own industry with its own particular infrastructure. An increase in either road capacity or electricity-generating capacity tends to lower the cost of producing the corresponding services and, from the standpoint of the manufacturing sector, lowers the price paid for road transport and electricity—the cost of acquiring $M(B)$. This is the *market-mediated* effect of infrastructure on manufacturing output.

The second channel through which an increase in the stock of infrastructure capital may affect manufacturing output is through an outward shift in the Hicksian efficiency term, $A(B,t)$, caused by the efficiency-promoting externalities associated with an increase in infrastructure, which may lead to an increase in manufacturing output. This is the type of effect envisioned by the endogenous growth literature and by the new economic geography. Lower transport costs, for example, may lead to economies of scale and agglomeration and to better inventory management. Similarly, an increase in electricity-generating and distribution capacity promotes continuous supply and more stable voltage and thus allows more sophisticated machinery in the manufacturing industry and reduces the need for firms to provide their own generating capacity (Lee and Anas 1992).

These are *nonmarket-mediated* infrastructure effects, operating through the $A(B,t)$ channel in the manufacturing production function. This second channel permits isolating the spillover effects from the market-mediated effect of infrastructure and measuring them using well-established techniques for estimating the Hicksian shift term. Assuming that the Hicksian efficiency term and its components are multiplicative, production function 1 can be written as

$$Q_{i,t} = A_{i,0} e^{\lambda_i t} B_{i,t}^{\gamma_i} F^i(K_{i,t}, L_{i,t}, M(B_{i,t})) \tag{2}$$

with subscript t denoting time and i denoting region, the dimensions relevant for the empirical work. The parameter $A_{i,0}$ indicates the initial level of productive efficiency, λ_i is the exogenous rate of productivity change, and the parameter γ_i measures the infrastructure spillover effect and is assumed to be constant over time but can vary among regions.[2] The infrastructure stock, $B_{i,t}$, has both a time and a

2. The cost of producing output tends to fall, other things remaining equal, as the production function shifts outward. Thus, under conventional restrictions on the production function, $-\gamma$ will also be the elasticity of the cost of production with respect to infrastructure: each 1 percent increase in the stock of infrastructure reduces cost by γ percent, other things remaining equal.

The time-shift term, λ, is usually interpreted as the average rate of costless technical change. However, it is well known that λ also includes the effects of omitted variables. Explicit allowance has not been made for human capital variables, education and health, nor implicit allowance for the "quality" of labor input. These effects may therefore be suppressed into the λ term. However, to the extent that expenditures for education and health are correlated with expenditures for hard infrastructure, the infrastructure spillover term, γ, could pick up some of the human capital effects.

regional dimension, with the index i referring to the region in which the stock is located. This formulation can be expanded to allow the infrastructure in other regions to generate cross-regional spillovers.

II. Productivity and the Solow Residual

Although the problem of estimating the externality parameter γ is not familiar in the empirical growth analysis, the problem of estimating the Hicksian shift term, of which γ is a component, has been solved by the Solow (1957) model of residual total factor productivity growth. Total factor productivity is defined as the ratio of output to the direct inputs used in production. At the level of the manufacturing sector, intermediate inputs also have to be included, in addition to labor and capital. The relevant ratio (for total productivity) is then $TP_{i,t} = Q_{i,t}/F(K_{i,t}, L_{i,t}, M_{i,t})$. Substituting from equation (2) shows that total productivity is directly associated with the parameters of interest in the analysis

$$TP_{i,t} = A_{i,t}e^{\lambda_i t}B_{i,t}^{\gamma_i}. \tag{3}$$

This expression, in logarithmic form, is the basis for the estimate of the infrastructure externality parameter, γ. The variables on the right side of equation (3), infrastructure and time, can be measured directly. The left-side variable, total productivity, must be estimated.

The first step in estimating $TP_{i,t}$ follows Solow in measuring productivity as the residual output not attributable to the inputs of labor, capital, and intermediate inputs. Analytically, the Solow residual is the growth rate of output less the growth rates of these inputs weighted by their shares in total cost (π_K, π_L, π_M). This procedure yields the expression

$$\frac{\Delta \ln TP}{\Delta t} = \frac{\Delta \ln Q}{\Delta t} - \pi_K \frac{\Delta \ln K}{\Delta t} - \pi_L \frac{\Delta \ln L}{\Delta t} - \pi_M \frac{\Delta \ln M}{\Delta t}. \tag{4}$$

For ease of exposition, the time and region subscripts associated with each variable are omitted here. When input prices are assumed to be proportional to marginal products, the output elasticities of K, L, and M are equal to the corresponding cost shares, and the residual measures the shift in the production function.[3] Each item on the right side of equation (4) can be measured or imputed from published data, yielding an estimate of total productivity growth

3. As shown, equation (4) is a continuous time differential equation, referred to in the literature as the growth rate of the Divisia Index of total productivity. In the actual computation of the Solow residual, the discrete time Tornquist approximation to the Divisia index is used, in which case the shares (π_K, π_L, π_M) are estimated using the average share from 1 year to the next [e.g., (1/2) ($\pi_{K,i,t} + \pi_{K,i,t-1}$)], and the growth rates by the year-to-year change in the logarithm (e.g., $\Delta \ln Q_{i,t} = \ln Q_{i,t} - \ln Q_{i,t-1}$).

that can be used, in the context of equation (3), to estimate the infrastructure externality parameter, γ.

III. Data on Output, Input, and Productivity

The data needed for implementation of the Solow residual [equation (4)] are obtained from India's ASI, which include annual estimates of gross output, intermediate inputs, labor input, and the book value of capital stocks for "registered" manufacturing firms by state.[4] Numerous empirical studies of Indian manufacturing have used this data set, and these studies formed the starting point for the aggregate and regional estimates of output and productivity reported here. The ASI data refer to manufacturing firms registered under the Factory Act, which are the larger manufacturing enterprises. The 1992/93 survey presents data for 24 industries that include both manufacturing and other related activities. The surveys are constructed from a probability sample, with large firms enumerated every year but smaller firms included according to a sampling probability. Thus, the time series constructed from the ASI does not necessarily represent the same firms over time, and year-to-year sampling variation can introduce volatility. The estimates used in this study are based mainly on industry data at the one-digit (all manufacturing) level of detail.

Studies of productivity and, more generally, of the structure of production require estimates of output and input in constant (real) prices. The ASI data are in current prices and therefore require deflation. Alternative approaches have been hotly debated (Ahluwalia 1991, 1994; Balakrishnan and Pushpangadan 1994, 1995; Dholakia and Dholakia 1994, 1995; Rao 1996a, 1996b). The Divisia-type deflation approach used by Rao (1996a, 1996b) is applied here, because it is consistent with equation (4), but unlike in Rao, the wholesale price index (WPI) is not used here as the deflator for intermediate goods. The WPI approach to price deflation combined with the other data yields a suspicious pattern of total productivity growth, with dramatic growth from 1973 to the mid-1980s and then a sharp and prolonged decline through the early 1990s.[5] A prolonged inward shift in the manufacturing production function is intuitively implausible and hard to square with the events of that period, which include the movement toward liberalization of planning controls.

Based on an empirical regularity in the data on manufacturing output and inputs, in which output and material inputs tend to be highly collinear, the procedure applied here is therefore to assume that the ratio of intermediate input to output quantity is constant over time for each two-digit manufacturing

4. See Hulten, Bennathan, and Srinivasan (2000) for a more detailed description of the data used in this study.

5. Such a pattern is often associated with mismeasurement in one or more data series. When the price deflation strategy used here is substituted for the WPI, the resulting pattern of total productivity shows a steady and moderate increase over the entire period. The endpoint, however, is the same in both price deflation approaches. See Hulten and Srinivasan (1999) for further discussion.

industry in each Indian state. This assumption is a matter of expediency rather than choice, forced by the data, but the resulting price indexes do capture changes in the mix of industrial production over time. Moreover, the procedure produces the same result as the WPI approach for the period as a whole but changes the pattern in the years between the endpoints of the sample period. For this period, the Indian manufacturing industry seems to deviate from the finding by Kubo and others (1986) that intermediate inputs rise faster than output in the manufacturing sectors of industrializing economies. The difference may be due to the difference in procedures, because Kubo and others used input–output data.

In any event, this assumption permits deriving price deflators for intermediate goods that vary over time and across regions. Real gross output grew at a respectable average annual rate of more than 7 percent a year for the two decades of the sample (table 1). Growth in inputs explains most of the growth in output, with material the primary explanatory factor. Growth in materials was steady over the period at roughly the growth rate of output (hardly surprising in view of the way it was estimated), and the share was almost 80 percent of total product. Labor's share was smaller than that of capital (although some of the return to capital is probably a return to the labor of entrepreneurs and family), and it declines in the second half of the period. Of greater significance is the low rate of growth of labor input (total employment) and its decline from 2.8 percent to 1.4 percent in the second half of the period. Capital grew faster and accelerated in the second half of the period.

The 0.5 percent annual growth in total productivity may seem unusually small but recall that it measures the impact of innovation and infrastructure investment on a very broad base of inputs. Most other studies express the result of

TABLE 1. Sources of Growth of Gross Output in the Indian Manufacturing Industry (Average Annual Percentage Rates of Growth)

Source of growth	1973–92	1973–82	1983–92
Gross output	7.3	7.2	7.5
Materials	7.4	7.3	7.5
Labor	2.1	2.8	1.4
Capital	6.8	5.9	7.7
Total input	6.8	6.7	7.0
Total productivity	0.5	0.5	0.5
Material's share	77.9	77.2	78.6
Labor's share	9.0	10.0	8.0
Capital's share	13.1	12.8	13.4

Note: Detail may not sum to total because of rounding.

Source: Authors' analysis based on data from India's *Annual Survey of Industries*; see description in text.

TABLE 2. Sources of Growth of Real Value Added in the Indian Manufacturing Industry (Average Annual Percentage Rates of Growth or Ratios)

Source of growth	1973–92	1973–82	1983–92
Real value added	7.1	6.8	7.5
Labor	2.1	2.8	1.4
Capital	6.8	5.9	7.7
Total factor input	5.0	4.6	5.3
Total factor productivity	2.2	2.2	2.1
Ratio total factor productivity to real value added	31	32	28
Labor's value added share	41	44	37
Capital's value added share	59	56	63

Note: Detail may not sum to total because of rounding.

Source: Authors' analysis based on data from India's *Annual Survey of Industries*; see description in text.

total productivity change in terms of its value-added counterpart, total factor productivity, which equals total productivity divided by the sum of capital's and labor's share of income (in effect dividing total productivity by about 0.20). To facilitate comparison, we also calculated total factor productivity estimates (table 2). At 2 percent, the Solow total factor productivity residual is of a more conventional magnitude. The acceleration in real value-added growth in the second half of the period is apparent, but again it is caused by the increase in the capital–labor ratio not in productivity.

IV. TOTAL PRODUCTIVITY BY REGION

Tables 1 and 2 present estimates of the annual growth rate of productivity (total productivity and total factor productivity) for registered manufacturing for all the states of India combined and therefore do not have a regional dimension. Because transport and electricity generation and transmission systems are networks with a spatial dimension, differences in productivity and infrastructure across geographic regions are a potentially important source of variation that should not be excluded a priori when trying to pin down spillover effects. Consequently, sources of growth estimates were calculated for each of the 16 states in the regional sample (table 3).

As table 3 summarizes, there was much regional variation in the growth rates of real gross output and total productivity. Growth rates by themselves give an incomplete picture of the comparative growth dynamics of the various states. It is also important to know the levels of total productivity. For example, the situation in which a state has a more rapid rate of productivity growth than another state and starts with a lower level of productivity is quite different from the case in which a state has both a higher growth rate and a higher initial

TABLE 3. Average Annual Growth of Output and Productivity and Relative Productivity Levels in Manufacturing Industry in India's States 1973–92

	Average annual growth, 1973–92 (percent)		Total productivity level	
State	Gross output	Total productivity	1973	1992
Andhra Pradesh	8.20	0.00	0.961	0.961
Bihar	6.50	0.60	0.919	1.030
Gujarat	8.00	0.30	1.005	1.064
Haryana	8.70	0.60	0.983	1.102
Himachal Pradesh	14.20	1.20	0.855	1.074
Jammu and Kashmir	8.90	0.30	0.995	1.053
Karnataka	7.80	0.80	0.997	1.161
Kerala	7.60	0.00	0.921	0.921
Madhya Pradesh	8.20	0.40	0.992	1.070
Maharashtra	6.50	0.40	1.086	1.172
Orissa	8.10	0.30	0.981	1.039
Punjab	8.80	0.60	0.927	1.039
Rajasthan	9.90	0.60	0.990	1.110
Tamil Nadu	7.60	0.30	1.015	1.075
Uttar Pradesh	8.80	0.50	0.972	1.069
West Bengal	3.30	0.50	0.987	1.085
Rank by 1973 level of total productivity[a]				
Top five	7.76	0.42	1.020	1.105
Middle five	7.85	0.45	0.988	1.076
Bottom five	9.30	0.58	0.927	1.035

[a]Excludes Kerala because, alone among the states, real value-added growth in manufacturing was negative in the first part of the sample, an oddity that could well have been caused at least in part by sampling variation and deflator problems.

Source: Authors' analysis based on data from India's *Annual Survey of Industries*; see description in text.

level of productivity. In the first case, productivity levels in the two states are converging, whereas in the second case, one state is pulling away from the other.

These estimates of the level of total productivity are obtained using the translog index procedure developed by Jorgenson and Nishimizu (1978) and extended by Caves, Christensen, and Diewert (1982). This method computes total productivity in each state in some base year as the output of the state relative to the output index for all of India, less the private inputs in the state relative to the all-India index, weighted by the relative cost shares:

$$\ln\frac{TP_i}{TP^*} = \ln\frac{Q_i}{Q^*} - \bar{\pi}_K \ln\frac{K_i}{K^*} - \bar{\pi}_L \ln\frac{L_i}{L^*} - \bar{\pi}_M \ln\frac{M_i}{M^*} \quad (5)$$

where

(6) $$\bar{\pi}_K = \frac{(\pi^i_K + \pi^*_K)}{2}, \quad \bar{\pi}_L = \frac{(\pi^i_L + \pi^*_L)}{2}, \quad \bar{\pi}_M = \frac{(\pi^i_M + \pi^*_M)}{2}.$$

Because total productivity is an index number, it must be normalized to the base value of some year and place. The initial year of the sample is used for the base year, and the average level of total productivity across all states is used as the base place (set equal to 100). This gives the initial conditions, $A_{i,0}$, in equations (2) and (3). The $A_{i,0}$ is then "grown" by the rate of total productivity growth calculated using the Solow residual [summarized in column (2) of table 3]. The result is an estimate of the level of total productivity by state and year that can be used as the left-side variable in a regression based on equation (4) to produce estimates of γ and λ that exploit differences in infrastructure among states and over time.

Columns (3) and (4) of table 3 present summary estimates of the relative level of total productivity for each state for 1973 and 1992 using the Caves–Christensen–Diewert method. Maharashtra started the sample period with the highest level of total productivity and Himachal Pradesh with the lowest, lagging 27 percent behind. Growth rates of total productivity, however, were not even across states [column (2)], and total productivity levels were converging by the end of the sample period [column (4)]. To show this, we grouped states into terciles according to their initial levels of total productivity. (Kerala is omitted, because, alone among the states, real value-added growth in manufacturing was negative in the first part of the sample, an oddity that could well have been caused at least in part by sampling variation and deflator problems.) The bottom five states ranked by this criterion experienced a more rapid rate of both output and total productivity growth, implying that the states that started with the lowest levels of total productivity had narrowed (but not eliminated) the gap with the leaders by 1992. This finding is in accord with the findings of Mitra, Varoudakis, and Véganzonès (1998), who report convergence of total *factor* productivity across India's two-digit-level industries over a similar time period (but with a wider list of industries).

V. Estimation of the Infrastructure-Productivity Link

The parameters of equation (3) are estimated by regressing the natural logarithm of the annual estimates of total productivity levels by state on the natural logarithm of each state's own infrastructure, time, and a constant term. In addition, the correction terms suggested by Hall (1988) are included to allow for the possibility of increasing returns and for departures from marginal cost pricing. The Hall modifications appear in specification (3) as the additional variables $\ln K$, and $X = \pi_K \ln(M/K) + \pi_L \ln(L/K)$; the corresponding regression coefficients are $\varepsilon - 1$ and $\mu - 1$. Constant returns to scale obtain when $\varepsilon - 1$ is 0, increasing returns when it is greater than 0, and decreasing returns when it is less than 0. The parameter μ is equal to 1 when price equals marginal cost and greater than 1 when price exceeds marginal cost.[6] The resulting equation is

$$\ln TP = \ln A + \lambda t + \gamma \ln B + (\varepsilon - 1)\ln K + (\mu - 1)X. \tag{7}$$

This equation is the basic regression model for estimating infrastructure elasticity, γ. Time and region subscripts have been omitted for clarity, but the variables $\ln TP$, $\ln B$, $\ln K$, and $\ln X$ have both a time dimension (20 years) and a regional dimension (16 states), and $\ln A$ is the logarithm of the initial level of productivity in each region.

The parameters of equation (7) are estimated from the total productivity statistics and the data underlying table 3, combined with data on the infrastructure systems of interest: paved roads and electricity. Data on paved roads are from annual issues of the Ministry of Transport's *Basic Road Statistics of India*. The variables consist of lengths of several categories of paved roads: national highways (arterial roads for interstate movement), state highways (arterial roads for interdistrict movement, linking up with national highways and adjacent state highways), and district roads (other Public Works Department roads). Adequate data on road capacity (lanes) were not available. For electricity, time-series data on generating capacity in megawatts are from the energy reports of the Centre for Monitoring Indian Economy, which cover both the state utilities (State Electricity Boards) and centrally controlled capacities. State road lengths were normalized by state area and generating capacities by census data on state populations. To calculate rates of return from the regression estimates of equation (7), we derived estimates of the construction cost per kilometer for each type of road and of the cost per megawatt of generating and transmission capacity for 1985, based on World Bank data and project information.

The infrastructure variables display strong growth over the sample period. The correlation between the main road variable (national and state highways) and time is 0.76, and the correlation between time and electricity capacity is 0.96. There is also a high degree of correlation between the two infrastructure variables, at 0.72, suggesting the possibility of a multicollinearity problem.

VI. Regression Results

The parameters of the infrastructure-productivity link expressed in equation (7) were estimated using the sample of 320 observations—20 years and 16 states (table 4). A fixed effect approach was used to allow for differences in the initial

6. The Hall (1988) corrections are needed for two reasons. First, the standard Solow residual [equation (4)] is computed under the assumption of constant returns to scale, which limits the generality of the approach in economies such as India, where scale economies are a potential source of growth. Second, the markup term helps ameliorate the possibility of noncompetitive pricing, noted by Tybout (2000) as characteristic of markets in developing economies.

Table 4. Determinants of Total Productivity in Indian Manufacturing: Parameter Estimates of Basic Model

Variable	(1)[a]	(2)[a]	(3)[a]	(4)[a]	(5)[b]	(6)[c]
Scale variable	0.038 (4.12)	0.033 (3.55)	0.033 (3.53)	0.030 (3.15)	−0.015 (−1.21)	−0.011 (−0.89)
Markup variable	0.082 (7.31)	0.086 (7.64)	0.083 (7.43)	0.086 (7.69)	0.076 (5.44)	0.079 (5.66)
Time	0.004 (4.81)	0.003 (4.53)	0.002 (2.52)	0.002 (2.58)	0.007 (4.40)	0.003 (1.22)
Log of highway variable		0.044 (2.71)		0.039 (2.37)	0.038 (1.90)	0.059 (1.92)
Log of electricity variable			0.024 (2.19)	0.019 (1.76)	0.022 (1.26)	0.068 (1.91)
R^2	0.809	0.814	0.812	0.816	0.901	0.901

[a]Estimated using annual data for 1973–92 for 16 states (320 observations).

[b]Estimated using annual data for 1981–90 for 16 states (144 observations).

[c]Estimated using annual data for 1981–90 for 16 states but includes adjacency variable.

Note: The dependent variable is the log of total productivity. The numbers in parentheses are *t*-statistics. State fixed effects are not shown.

Source: Authors' analysis based on data from India's *Annual Survey of Industries* and Centre for Monitoring Indian Economy; see description in text.

levels of technical efficiency (A) among the states and different initial endowments of infrastructure. The baseline regression without any infrastructure variables [column (1)] reveals a slight degree of increasing returns to scale (3.8 percent) and an 8.2 percent markup of price over marginal cost. The estimate of the scale parameter is within the range reported by Fikkert and Hasan (1998) in their study of scale elasticity in a panel of Indian manufacturing firms. The implied rate of pure technical change is 0.4 percent. All estimates are statistically significant at conventional levels.

The introduction of the national and state highways [column (2)] produces a statistically significant estimate of the key spillover elasticity (γ) of 4.4 percent. Inclusion of highways lowers the estimated rate of technical change but generally has only a small effect on the size and significance of the other parameters.[7] The introduction of electricity (by itself, without highways) yields an estimated spillover elasticity (γ) of 2.4 percent and lowers the rate of technical change but has little effect on the other variables [column (3)]. Inclusion of highways and electricity together [column (4)] produces estimated γs that are smaller than either of the separate estimates (and the electricity γ is marginally significant). The strong intercorrelation between infrastructure variables and time may be at work here, but it should be noted that the two γs yield a combined elasticity of 5.8 percent.

Without consistent time series of the two-digit industries within each state before 1980, state-specific price indexes could not be constructed for intermediate goods by the methods discussed earlier, and therefore, the corresponding all-India price had to be used for the period before 1980. Equation (7) was thus re-estimated using the more reliable data from 1980 onward, omitting the recession years of 1991 and 1992 to avoid a cyclical bias in the estimates. The results reveal constant or slightly decreasing returns to scale during this period, with little change in the markup estimate [column (5) of table 4]. The rate of technical change is appreciably higher, but although the point estimates of infrastructure elasticities of highways do not change much, their statistical significance is lower, possibly reflecting multicollinearity. The joint infrastructure parameter remains about 6 percent.

The analysis has thus far assumed that spillover effects occur within the boundaries of each state, with no allowance for spillover effects to neighboring states. However, one obvious role of highways is to connect the various regions of a country to promote commerce and population movement. Moreover, India's electricity grids extend across state boundaries, and some states get substantial quantities of energy from their neighbors. Variants of the basic approach were used to attempt to capture such superstate indirect effects. First, neighborhood indirect effects, γ^{ji}, which allow for spillovers from a neighboring state j to state i,

7. Experiments with different definitions of the road variables found that those with a broad regional reach produced results similar to those reported in table 4. However, the measure of district roads yielded estimates that were statistically insignificant, suggesting that this sort of road does not generate the indirect spillover effects in the manufacturing sector associated with national and state highways.

are distinguished from own indirect effects, output elasticities, γ^{ii}, which capture spillovers within state *i*. The inclusion of γ^{ji} in the analysis does not imply double counting when the states are summed to an all-India total but rather that the whole is greater than the sum of its parts viewed in isolation.

Several neighborhood approaches were attempted. An "extended neighborhood" definition of infrastructure adds the infrastructure in immediately adjacent states to a state's own infrastructure. Estimates of $\gamma^{ii} + \gamma^{ji}$ for highways and electricity for the shorter period 1980–91 comparable to that in column (5) are summarized in column (6). The implied spillover elasticities are much larger than in previous cases—a combined 12.7 percent—although the levels of significance are quite thin. The rate of technical change falls from 0.7 percent for the period to 0.3 percent, and it becomes statistically insignificant. Again, this implausible result probably reflects multicollinearity, which increases when adjacent infrastructure is included in the analysis.

VII. The Size of the Spillover Effect

Because total productivity is used as the measure of productive efficiency rather than total factor productivity, the estimated spillover elasticities, γ, appear absolutely small. It is therefore instructive to compare them with the size of the implied output elasticities of private capital and labor employed in manufacturing. These can be approximated by their value shares, π_K and π_L, which are 13.1 percent and 9 percent, respectively (see table 1). Compared in this way with the "private" inputs, the combined indirect infrastructure elasticity of 5–6 percent is by no means small.

Another way to assess the relative importance of the infrastructure spillovers is to compare marginal products. The marginal product of infrastructure, $\Delta Q/\Delta B$, can be computed from the corresponding elasticities that are equal to $(\Delta Q/\Delta B)B/Q$. In the regressions, B is measured as a physical quantity. To express the physical stock in constant prices (to be symmetrical with the estimates of Q), 1985 unit values were used (obtained from World Bank sources) and extrapolated to other years. Estimates of the marginal product of labor and private capital in manufacturing were also developed using similar methods. These estimates of marginal product can be interpreted as the gross of depreciation return to the different types of capital in terms of manufacturing output. The results are summarized in table 5 using the results from columns (2), (3), and (4) of table 4. The gross rate of return to highways rises over the sample period as does the overall return to the infrastructure aggregate, whereas electricity and private capital exhibit a more or less constant return. By 1992, the combined return to infrastructure was 9 percent, almost one-third of the direct return to private capital. Recall that the return to infrastructure is an indirect effect, over and above the return attributable to the direct use of highways and electricity.

TABLE 5. Comparison of Gross Marginal Product: All-India Average for Manufacturing Industry (Average Gross Return Per Rupee of Capital)

	1974	1985	1993
Highways alone	0.02	0.04	0.05
Electricity alone	0.05	0.05	0.05
Highways and electricity	0.06	0.07	0.09
Private capital	0.29	0.26	0.29

Note: Detail may not sum to total because of rounding.

Source: Authors' analysis based on data from India's *Annual Survey of Industries* and Centre for Monitoring Indian Economy; see description in text.

A third way to assess the importance of the indirect infrastructure effect is to examine its relative contribution to the growth of the overall total productivity residual. The first stage of the sources of growth approach decomposes the growth of output into the contributions of labor, capital, intermediate inputs, and residual total productivity, as in table 1. Equation (7) permits a second stage in which total productivity is further decomposed, first, into the indirect effects of highways and electricity capacity, a pure time effect (costless technical change), and second, into the errors that arise from assuming that returns to scale are constant when they are not, an error made by assuming price equals marginal cost when it does not, and a pure residual error.

Table 6 quantifies this second decomposition by multiplying the means of the variables in equation (7) by the corresponding elasticity estimates from table 4.

TABLE 6. Decomposition of the Growth Rate of Total Productivity: All-India Average for Manufacturing Industry (Average Annual Percentage Growth Rates)

	Using estimates of table 4 column		
	(2)	(3)	(4)
True productivity	0.30	0.20	0.24
Highways	0.09	–	0.08
Electricity	–	0.18	0.15
Subtotal	0.39	0.38	0.47
Scale effect	0.24	0.24	0.21
Markup effect and residual error	−0.13	−0.13	−0.18
Subtotal	0.11	0.11	0.03
Total productivity	0.50	0.50	0.50

Note: Detail may not sum to total because of rounding.

Source: Authors' analysis based on data from India's *Annual Survey of Industries* and Centre for Monitoring Indian Economy; see description in text.

This yields the mean percentage contribution to total productivity of the infrastructure, scale, markup, and "true" productivity variables, with a residual error term accounting for the balance. Results are shown for the estimates of columns (2), (3), and (4) of table 4 (the base case 1973–92, without adjacency effects). For the combined effects of highways and electricity summarized in the last column, the average annual growth rate of the true productivity residual is 0.47 percent, of which highways and electricity account for nearly half. This suggests that infrastructure is an important contributor to productivity growth and hence to a reduction in the cost of production.

VIII. Final Remarks

Most macro studies of infrastructure and economic growth have sought to measure the overall impact of infrastructure on growth. This analysis differs by attempting to isolate the component of the overall impact that is associated with the indirect effects of infrastructure, as they affect India's registered manufacturing sector. These indirect effects are traditionally viewed, in the broader literature on economic development, as an important dimension of industrialization. However, while widely assumed to be important, such externalities have not been quantified at the industry-wide level of growth. The findings here suggest, first, that these externalities exist and, second, that they are an important part of productivity growth in India's modern manufacturing industry.

When investments can be shown to have external effects, standard reasoning sees this as evidence of underinvestment. If this conclusion is to apply to the results here, it can hold only within the strict limits of the study. The physical infrastructure found to be exerting indirect effects on the productivity of registered manufacturing will have been laid down for the benefit of a wider constituency than registered manufacturing. Thus, nothing can be said about infrastructure externalities in general or in terms of gross benefits and certainly not in terms of net benefits, which would have to account for environmental impacts.

With the meaning of the study thus narrowed, what are the implications of the results for industrialization policy, specifically investments intended to support the growth of India's modern manufacturing sector? From the strict point of view of this sector, the results suggest that there has been underinvestment in the kinds of infrastructure covered in the study. Still left open is the question of the point at which the results of this analysis ought to enter the process of India's investment decision. Externalities are not generally considered in project evaluation, but World Bank project criteria require successful infrastructure projects to pass a 12 percent (internal) rate of return test. The indirect rates of return summarized in table 5 are one-half to three-quarters of this test rate, suggesting that conventional project analyses may lead to significant underinvestment in infrastructure systems. More research is needed.

The inadequacy of the data, particularly on intermediate inputs, is fully acknowledged, and with that the possibility of biases arising from model misspecification. Also, because the analysis is based on industry data at the one-digit level, aggregation biases due to changes in the composition of the manufacturing industry within any state cannot be ruled out.[8] These problems are common to many econometric studies and are likely to be even greater when models developed for high-income industrial economies are applied to a developing economy. Moreover, the fact that the infrastructure systems are lumpy networks of interlocking investments may cause specification problems. The network feature suggests, for example, that the externality parameter, γ, may change over time as the network evolves rather than remaining fixed over the period of analysis. Also, there is a tendency to build capacity in advance of demand, causing a divergence between the measures of the stock of infrastructure and the corresponding flows that determine the volume of output. There may also be important omitted variables, such as human capital, that are highly correlated with expenditures on roads and electricity and whose effects may be present in the estimates of γ.

However, these caveats notwithstanding, the results are quite consistent with the micro evidence from Lee and Anas (1992), and with the assessments of Ahluwalia (1998, 2000) and Acharya (2002), as well as with the overwhelming impressionistic evidence about the inadequacy of transport and electricity systems in India. Also, although the results stand in stark contrast to those reported for the U.S. manufacturing industry by Hulten and Schwab (1991, 2000), the difference is comforting in one sense. Their results and those reported here were obtained by essentially the same method, so that one may conclude that the model itself is not predetermining the results. Rather, the difference may point to asymmetrical effects in which infrastructure investments play a larger role in developing economies than in developed economies with more mature and denser infrastructure systems.

8. As an example, a bias might arise from a clientele effect in which infrastructure-intensive industries within the manufacturing sector are drawn to regions in which infrastructure is plentiful. If these industries also have the highest levels of total factor productivity, estimates of the externality parameter, γ, may be biased upward, because they are based on industry data at the one-digit level that do not take industry composition into account. However, composition effects do not necessarily create a selection bias in the model. If infrastructure-intensive industries within the manufacturing sector are drawn to infrastructure-rich regions, because its infrastructure causes their total factor productivity to increase, this is a relocation effect and is commonly regarded in location theory as a system externality (recall that the direct effect of infrastructure on output is reflected in the purchase of intermediate services from the transport and electricity generation sectors).

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