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STATE INFRASTRUCTURE AND PRODUCTIVE PERFORMANCE

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ABSTRACT

The impact of public infrastructure investment on the productive performance of firms has been an important focus of the recent literature on productivity growth. The size of this impact has important implications for policymakers' decisions to invest in public capital, and productivity analysts' evaluation of productivity growth fluctuations and declines. However, detailed evaluation of the infrastructure impact is difficult using existing studies which rely on restricted models of firms' technology and behavior.

In this paper we construct a more complete production theory model of firms' production and input decisions. We then apply our framework to state-level data on the output production and input (capital, nonproduction and production labor and energy) use of manufacturing firms to evaluate the contribution of infrastructure to firms' costs and productivity growth. We find that infrastructure investment does provide a significant direct benefit to manufacturing firms and thus augments productivity growth. We also show, however, that this evidence should be interpreted taking into account the social cost of such capital (which is not reflected in firms' costs), and the indirect impact resulting from scale effects.

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I. Introduction

Traditional measures of productivity growth typically neglect forces external to firms. In fact, they tend to ignore both external and internal scale effects in the long and short run by assuming constant returns to scale in measured inputs and instantaneous adjustment. However, both external and internal economies may greatly affect short and long run economic performance, since they affect the observed relationship between costs and output.

Public infrastructure investment is an important example of a good which could generate external economies. If expenditures on public capital have a positive productive impact -- and thus cause cost savings for firms which are currently experiencing economic difficulties -- the implications for policy decisions concerning infrastructure investment may be great. Internal effects such as long run scale economies and short run fixities are also important to recognize for evaluation of productive performance. Recognition of these impacts may provide insights about the impacts of expansionary policies and investment incentive programs.

Recently, a number of studies on productivity growth determinants have focused on the impacts of infrastructure and scale effects. Aschauer [1989,1990], for example, reported and compared correlations between productivity growth and public infrastructure across countries, and found a close correspondence between productivity slowdowns and stagnation in infrastructure expenditure. The importance of this external effect on productive performance has been further explored by a number of researchers including Munnell [1990], Garcia-Mila and McGuire [forthcoming], and Hulten and Schwab [1984,1991]. In addition, the significant influence of internal scale effects on productivity growth has been documented by Morrison [1989], as well as by Hall [1990].

These studies show that the standard maintained assumptions about external and internal scale effects are neither intuitive a priori, nor empirically valid for the construction of productivity growth measures. However, existing studies have not pursued an integrated analysis of the interactions among these scale effects and their impact on economic performance. Existing production models have generally disregarded the potentially large impact of public infrastructure on firms' costs and therefore economic performance, even when they incorporate fixity effects. On the other hand, most studies in the rapidly emerging literature on the productivity impact of infrastructure do not take advantage of the extensive framework for the analysis of firm behavior, technology and performance provided in the applied production theory literature.[1]

In this paper we attempt to synthesize these approaches to explore the role of infrastructure capital in productivity growth in greater detail for U.S. manufacturing by state. To accomplish this, we extend the production theory framework developed in Morrison [1989] to formalize and measure the effects of public infrastructure capital. Our analysis is based on cost-side productivity growth measures, which are designed to capture the reduction in input use (and thus costs) used to produce a given output level when technical change occurs. When external and internal scale economies and fixity affect firm technology and behavior, cost reductions due to changes in these characteristics also occur. Our cost-oriented productivity growth framework provides a useful vehicle for disentangling these effects by explicitly recognizing the dependence of costs, and thus the cost-output relationship, on infrastructure, scale economies and short run fixity of private capital.

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[1]The advantages of using a production theory framework based on a variable cost function and shadow values have, however, been emphasized by Friedlaender [1990] and Berndt and Hansson [1991].

Identifying and measuring these different cost effects requires a full theoretical and empirical framework representing firm technology and behavior. In the following sections such a framework is outlined and used to assess the impacts of infrastructure on costs and thus on productivity growth. Estimates of this model by region, obtained using a rich panel data set, are then presented. The data are for the manufacturing sectors of the 48 contiguous states in the U.S. for 1970-87, and include information on the quantities and prices of output, nonproduction and production labor, energy, and private and public capital inputs.

Estimation of the model generates results that support the use of a parametric structural model for considering infrastructure effects. Shadow values for both private and public capital are the appropriate sign and magnitude, and are significantly different from zero. They show a positive but declining cost benefit from infrastructure investment in all regions, with the most dramatic declines being in the "snowbelt" (North-East). When productivity growth measures are decomposed accordingly, it appears that infrastructure investment has contributed significantly to regional U.S. productivity growth. However, that impact has diminished over time due to both reduced investment rates, and lower values of such investment. This is particularly true when the social cost of such investment is taken into account. Also, using the structural model we show that sluggish investment in public capital *relative* to output production appears to have actually limited productivity growth, particularly in the sunbelt (South-West).

II. A Model of Firm Behavior and Productivity Growth with Infrastructure Effects

IIa. The Theoretical Model

The current literature on the representation of firm technology and behavior heavily depends on variable (restricted) cost functions. Basing analysis on a cost function is desirable since estimating equations result from direct differentiation of the function, and the endogeneity of the resulting dependent variables is consistent with intuition.[2] The cost function reflects technology as the dual to the production function, captures cost minimizing behavior, and can accommodate fixity and scale effects through explicit dependence on the levels of output and quasi-fixed inputs. In the current context, the cost function approach is especially useful since the cost effects of external factors such as public capital may be represented explicitly. Here, public capital is included as an argument of the variable cost function and, thus, as a factor explaining observed scale effects.

More specifically, including private capital (K_p) as an argument of the function permits the effects of capital fixity to be directly considered rather than, for example, building in an ad-hoc partial adjustment framework as in Munnell [1990]. Explicitly recognizing infrastructure (public or "government" capital, K_g) as a fixed input also allows the consideration of the direct and indirect external "scale" impacts arising from the exploitation of this good. A combination of these impacts and internal scale economies imbedded in the technology generates scale effects observed as the cost-output

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[2]This contrasts to the production function approach often used to analyze infrastructure impacts. Estimation of the production function either takes the form of direct estimation of the function, in which case the input levels are the independent variables, or is done in terms of marginal product equations where input prices become dependent variables. Either method raises serious questions about endogeneity and exogeneity.

relationship. These cost impacts can be independently evaluated and their effects on productive performance measured using the cost function framework.

The variable cost function can be specified in the general form $G(x,p,t,Y)$, where x is a vector of K quasi-fixed inputs[3] x_k (here private and public capital, K_p and K_g), p is a vector of the prices of variable inputs (p_{Lp}, the price of production labor, L_p, p_{Ln}, the price of nonproduction labor, L_n, and p_E, the price of energy inputs, E), Y is output and t is a time counter representing technology. Specifying K_g as an x_k variable in this framework implies that scale economies are defined including this argument of the function. This is consistent with intuition, since infrastructure may affect the shape of the long run average cost curve, as well as with existing studies such as Munnell [1990].

The cost impacts of infrastructure, fixity and internal scale economies can be specified in terms of the elasticity of costs with respect to output derived from the variable cost function. External scale economies which stem from outside forces with public goods characteristics will cause output and total cost changes to be nonproportional. In addition, if long run nonconstant returns to scale are imbedded in the firm's technology, the long run average cost curve representing this technology will be sloped; marginal and average costs will differ. Also, in the short run at least some inputs may not be instantaneously adjustable, resulting in a divergence between the market price and shadow value of the quasi-fixed input(s), captured in a more steeply sloped short run average cost curve. A combination of these impacts will determine the observed cost-output relationship.

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[3]These inputs are subject to homogeneity conditions in the sense that scale effects are dependent on them. By contrast, McFadden's "environmental variables" or "z-variables" discussed in Morrison [1988a] may have impacts on a firm's costs but do not affect scale properties.

More formally, the definition of the long run elasticity of costs with respect to output, ϵ^{L}_{CY}, can be used to decompose the observed short run cost response $\epsilon_{CY}=\partial\ln C/\partial\ln Y$ to distinguish these cost impacts. Following Morrison [1985], when nonhomotheticity exists ϵ^{L}_{CY} can be written as

$$(1)\quad \epsilon^{L}_{CY} = \frac{Y}{C}\left[\frac{\partial C}{\partial Y} + \sum_k \frac{\partial C}{\partial x_k}\frac{dx_k}{dY}\right] = \epsilon_{CY} + \sum_k \epsilon_{Ck}\epsilon_{kY} ,$$

where $C=G+\sum_k p_k x_k$ is total costs, $\epsilon_{Ck}=\partial\ln C/\partial\ln x_k$ is the elasticity of costs with respect to fixed input x_k, and ϵ_{kY} is the long run elasticity of x_k demand with respect to output.

When K_g is one of the x_k variables, some qualifications should be noted. First, this expression may appear to be inconsistent with the notion that K_g is an exogenous variable. While including the derivative $(\partial C/\partial K_g)\bullet(dK_g/dY)$ or the elasticity $\epsilon_{KgY}=(Y/K_g)\bullet(dK_g/dY)$ seems to suggest the firm will adjust the amount of K_g in the long run, K_g is not a "choice" variable. However, the elasticity form in (1) may be considered definitional rather than behavioral. ϵ_{KgY} can be thought of as the inverse of $\partial\ln Y/\partial\ln K_g$ from the production function, and is included as part of the scale "experiment" rather than as a long run adjustment expression. Second, public capital is not directly paid for by the firm; p_{Kg} is taken to be zero. The justification is that if K_g is exogenous, any payments made for this are not directly tied to the availability of infrastructure and thus do not affect behavior.

Rearranging (1) in terms of the ϵ_{CY} elasticity allows us to motivate the decomposition of observed cost changes into terms representing fixity, internal scale impacts and infrastructure effects. ϵ_{CY} can be written as:

$$(2)\quad \epsilon_{CY} = \epsilon^{L}_{CY} - \sum_k \epsilon_{Ck}\epsilon_{Ky} = \epsilon^{L}_{CY} - \epsilon_{CKp}\epsilon_{KpY} - \epsilon_{CKg}\epsilon_{Kgy} ,$$

where the first component, ϵ^{L}_{CY}, represents long run scale effects from (1). The second and third terms, $\epsilon_{CKp}\epsilon_{KpY}$ and $\epsilon_{CKg}\epsilon_{KgY}$, capture the effects of K_p fixity and the shadow value of K_g. This can be shown as follows.

A standard property of G(•) that is crucial for applying this framework to the analysis of infrastructure impacts on costs and productivity is that the shadow value of input x_k may be specified as $Z_k = -\partial G/\partial x_k$. That is, the marginal value of input x_k to the firm is the reduction in variable costs permitted by a marginal addition to the input stock.[4]

The shadow value will be positive as long as x_k provides benefits in terms variable input savings due to substitution possibilities. Further, if x_k is a choice variable for the firm (like K_p) this implies demand for x_k in long run equilibrium will be such that $Z_k = p_k$; if this is not true the fixity effect is binding. However, since K_g is not a choice variable, and the firm does not face the direct costs of accumulating this input, this balance will not obtain for K_g even in the long run. Firms benefit from having additional K_g as long as $Z_{Kg} > 0$, which suggests further expenditure on public capital is supported in terms of cost savings and thus productive performance.[5]

More formally, the shadow value property can be used to interpret ϵ_{CKp} and ϵ_{CKg} and thus to attribute cost changes to fixity and infrastructure effects. As discussed in Morrison [1985], using the definition $C = G(\bullet) + \sum_k p_k x_k$, it can easily be derived that $\epsilon_{CKp} = (\partial G/\partial K_p + p_{Kp}) \bullet K_p/C = (p_{Kp} - Z_{Kp}) \bullet K_p/C$. The ϵ_{CKp} measure will therefore be equal to zero under instantaneous adjustment or full equilibrium, and its deviation from zero represents the degree of fixity -- the extent to which the fixity constraint is binding.

[4]This is the inverse or "dual" of the notion of the marginal product -- the additional output possible by one more unit of the input.
[5]Note that this is based only on private costs; social costs of infrastructure are certainly positive so the social optimum would differ from this. Some of this is addressed below. In addition, firms do pay for infrastructure in terms of taxes; in subsequent work we plan to consider this more directly.

Similarly, when $p_{Kg}=0$, $\epsilon_{CKg}=(\partial G/\partial K_g)\bullet K_g/C=-Z_{Kg}\bullet K_g/C=-S^*_{Kg}$, where S^*_{Kg} is the "shadow share" of K_g in total costs. This will not equal zero unless infrastructure capital has a zero marginal product for the firm. Thus the observed cost response to changing output (ϵ_{CY}) and the slope of the long run cost curve (ϵ^L_{CY}) will directly be affected by the shadow value (marginal product) of K_g. If social costs are taken into account so $p_{Kg}\neq 0$, however, $\epsilon_{CKg}=p_{Kg}-Z_{Kg}\bullet K_g/C\neq -S^*_{Kg}$. This more appropriately represents the net social benefit of expenditure on K_g, since such expenditures are not costless even if the firm does not face these costs. This should be recognized for a full evaluation of the impacts of infrastructure investment.

Thus, (2) decomposes the scale expression ϵ_{CY} into a long run internal scale effect, a fixity impact, and an infrastructure benefit adjustment. This elaboration of ϵ_{CY} from the model structure provides a useful basis for considering the effects of these different factors affecting firms' costs. This has important implications for the construction, decomposition and interpretation of productivity growth measures to identify infrastructure impacts, since the cost-output relationship crucially affects such measures. This linkage is further elaborated in the next subsection.

IIb. Productivity Measurement and Adjustment

To motivate the analysis of efficiency changes or productive performance, we need to formally represent productivity growth in terms of different factors causing cost changes -- technical change, infrastructure, internal scale economies and fixity of K_p. To pursue this we use an expanded version of the traditional cost-side specification of productivity growth:

$$(3) \qquad \epsilon_{Ct} = \frac{\partial \ln C}{\partial t} = \frac{dC/dt}{C} - \frac{dY/dt}{Y} - \sum_j \frac{p_j v_j}{C}\frac{dp_j/dt}{p_j} = \frac{\dot{C}}{C} - \frac{\dot{Y}}{Y} - \sum_j S_j \frac{\dot{p}_j}{p_j} ,$$

where the "•" represents a time derivative and S_j is the share of input j in total costs, and which Ohta [1975] showed is equivalent to (but opposite in sign to) the primal-side measure of productivity growth:

$$(4) \qquad \epsilon_{Yt} = \frac{\partial \ln Y}{\partial t} = \frac{dY/dt}{Y} - \sum_j \frac{p_j v_j}{C} \frac{dv_j/dt}{v_j} = \frac{\dot{Y}}{Y} - \sum_j S_j \frac{\dot{v}_j}{v_j} = -\epsilon_{Ct} ,$$

when perfect competition, instantaneous adjustment and constant returns to scale prevail.[6]

These expressions are designed to represent efficiency change in terms of the decrease in input use and thus costs when technical change occurs, for a given output level and input prices. In practice, however, this residual measure captures cost fluctuations resulting from changes in anything other than input prices. In particular, it does not disentangle the important scale factors shown above to affect the costs through the cost elasticity with respect to output, ϵ_{CY}. The scale effects captured in this measure are instead imbedded in the productivity residual or "measure of our ignorance" ϵ_{Ct}. Recognition of the factors affecting ϵ_{CY} therefore facilitates appropriate measurement and interpretation of productivity growth measures.

More formally, if $\epsilon_{CY} \neq 1$ due to any of the production characteristics captured in (2), (3) is an invalid measure of technical change. Adaptation of this measure accordingly allows us to assess the independent contributions of these characteristics to productive performance.

For example, the construction of (3) is based on the erroneous assumption of constant returns to scale, which implies that the cost function can be represented by $C=Yc(p,t)$ so $\epsilon_{CY}=1$ and $d\ln (C/Y)/dt = d\ln C/dt - d\ln Y/dt$. However, if $\epsilon_{CY} \neq 1$ due to internal scale economies, this becomes

[6] This result may be easily derived by substituting the derivative of costs, $dC/dt = \sum_j p_j \, dv_j/dt + \sum_j v_j \, dp_j/dt$ from the definition $C = \sum_j p_j v_j$ into (2).

$d\ln(C/Y)/dt = d\ln C/dt - \epsilon_{CY}(d\ln Y/dt)$. The deviation of ϵ_{CY} from one thus generates an error bias in traditional measures. Correcting for this error allows assessment of the independent productivity effects of technical change and scale economies.

If ϵ_{CY} differs from one also because of short run fixity in privately demanded inputs an additional adaptation must be made according to (2), since $\epsilon_{Ck} \neq 0$. In this case, not only the weight on the output growth expression in (3), but also the difference between the market and shadow prices of the quasi-fixed inputs must be adjusted for. Specifically, the derivation of (3) depends on instantaneous adjustment through Shephard's lemma, which is used to substitute v_j, the cost minimizing demand for variable input j, for $\partial C/\partial p_j$ for all inputs. If any input x_k is fixed, however, this is invalid. In the short run the firm cannot choose a cost minimizing demand for x_k, so the share weight on the x_k growth term should be expressed in terms of the shadow value (Z_k) rather than the market value (p_k).[7]

Adaptation of the productivity growth measure to take infrastructure effects into account is similar to that for fixity. (2) distinguishes the cost impact of public infrastructure as a "fixity effect" that "explains" part of the deviation of ϵ_{CY} from one separately from the more commonly recognized cases of $\epsilon^L{}_{CY} \neq 1$ and $Z_{Kp} \neq p_{Kp}$. When $Z_{Kg} \neq 0$ this generates a scale effect on productivity growth which is identifiable through its impact on ϵ_{CY}.

Adding this last adaptation to further generalize the expanded productivity growth expression developed in Morrison [1989] results in a measure that accomodates all these characteristics of the production process:

$$(3') \quad \epsilon^T_{Ct} = \frac{\dot{C}}{C} - \epsilon_{CY}\frac{\dot{Y}}{Y} - \sum_j \frac{p_j v_j}{C}\frac{\dot{p}_j}{p_j} - \frac{p_{Kp}K_p}{C}\frac{\dot{p}_{Kp}}{p_{Kp}} - \frac{(p_{Kp}-Z_{Kp})K_p}{C}\frac{\dot{K}_p}{K_p} + \frac{Z_{Kg}K_g}{C}\frac{\dot{K}_g}{K_g},$$

[7]These two adaptations are developed further in Morrison [1989].

or, using an Ohta-type adaptation to express the cost-side productivity growth measure more directly in terms of output and input growth:

$$(4') \quad \epsilon^T_{Ct} = -\epsilon_{CY} \frac{\dot{Y}}{Y} + \sum_j \frac{p_j v_j}{C} \frac{\dot{v}_j}{v_j} + \frac{Z_{Kp} K_p}{C} \frac{\dot{K}_p}{K_p} + \frac{Z_{Kg} K_g}{C} \frac{\dot{K}_g}{K_g} .$$

Both of these expressions can be rewritten in terms of error biases in traditional measures as:

$$(5) \quad -\epsilon^T_{Ct} = -\epsilon_{Ct} + (\epsilon_{CY} - 1) \frac{\dot{Y}}{Y} + \epsilon_{CKp} \frac{\dot{K}_p}{K_p} - S^*_{Kg} \frac{\dot{K}_g}{K_g} ,$$

where T stands for "Total correction", ϵ_{Ct} is expressed as a positive number by adding a negative sign, and the right-hand terms represent bias corrections for internal scale economies, short run fixity of private capital, and external infrastructure effects.

These effects can also be interpreted as the "contributions" of infrastructure capital to productive performance, in terms of either output growth, cost declines or productivity. To see this, we can rewrite (2'), (3') and (5) as "growth accounting" types of equations:

$$(3'') \quad \frac{\dot{C}}{C} = \epsilon^T_{Ct} + \epsilon_{CY} \frac{\dot{Y}}{Y} + \sum_j \frac{p_j v_j}{C} \frac{\dot{p}_j}{p_j} + \frac{p_{Kp} K_p}{C} \frac{\dot{p}_{Kp}}{p_{Kp}} + \frac{(p_{Kp} - Z_{Kp}) K_p}{C} \frac{\dot{K}_p}{K_p} - \frac{Z_{Kg} K_g}{C} \frac{\dot{K}_g}{K_g} ,$$

$$(4'') \quad \frac{\dot{Y}}{Y} = -\epsilon^T_{Ct} + (1 - \epsilon_{CY}) \frac{\dot{Y}}{Y} + \sum_j \frac{p_j v_j}{C} \frac{\dot{v}_j}{v_j} + \frac{Z_{Kp} K_p}{C} \frac{\dot{K}_p}{K_p} + \frac{Z_{Kg} K_g}{C} \frac{\dot{K}_g}{K_g} ,$$

$$(5') \quad -\epsilon_{Ct} = -\epsilon^T_{Ct} - (\epsilon_{CY} - 1) \frac{\dot{Y}}{Y} - \epsilon_{CKp} \frac{\dot{K}_p}{K_p} + S^*_{Kg} \frac{\dot{K}_g}{K_g} ,$$

$$= -\epsilon_{Ct}^{T} - (\epsilon_{CY}^{L}-1)\frac{\dot{Y}}{Y} + \epsilon_{CKp}\epsilon_{KpY}\frac{\dot{Y}}{Y} - S_{Kg}^{*}\epsilon_{KgY}\frac{\dot{Y}}{Y} - \epsilon_{CKp}\frac{\dot{K}_p}{K_p} + S_{Kg}^{*}\frac{\dot{K}_g}{K_g} .$$

These equations clearly distinguish the independent impacts of four components of overall efficiency change -- technical change, internal scale economies, fixity of private capital, and external infrastructure effects. Although the terms representing the impacts of variable and private fixed inputs and scale differ somewhat according to the focus on prices (dual) or quantities (primal), they are essentially the same for technical change and scale as well as for infrastructure.

In addition, from the expanded version of (5′) obtained by substituting for ϵ_{CY} from (2), it is evident that fixity and infrastructure affect not only the weights on not only quasi-fixed input growth, but also on output growth. This suggests that the impact of infrastructure on productivity growth can be divided into two components: the direct effect reflected by the last term in the error bias, $K_g DIR = S^*_{Kg} \bullet (d\ln K_g/dt)$, and an indirect effect, $K_g IND = -\epsilon_{KgY} S^*_{Kg} \bullet (d\ln Y/dt)$.

Thus, if infrastructure capital is increasing, the direct effect causes productivity growth to be overstated as a technical change measure; some of the measured productivity must be attributed to infrastructure investment. Thus, since $S^*_{Kg}>0$ the adjusted productivity growth measure (representing only technical change) is smaller in absolute value than the traditional measure. Thus some productivity growth is "explained" by infrastructure effects.

The output growth term has the opposite sign; if $d\ln Y/dt>0$, this term represents an understatement of traditional productivity growth. Technically, the term represents the effect of increasing output given a constant level of K_g, so if the marginal product of K_g is positive the returns to increasing output are less than would be the case if K_g had no productivity impact.

More intuitively, this suggests that the *relative* growth rates of Y and K_g determine whether infrastructure investment has a positive impact on productivity growth. This can be formalized by putting the two infrastructure effect terms together to obtain $S^*_{Kg}(dlnK/dt-\epsilon_{KgY} \bullet dlnY/dt)$ as the full effect of infrastructure. Thus, if the rate of infrastructure investment is at least as great as the growth rate of output (adjusted by the output elasticity with respect to government capital ϵ_{KgY}), standard productivity growth measures overstate technical change -- the positive impact of infrastructure investment appears as part of the technical change measure.

This development has at least two important implications. One issue arising from this theoretical structure is that the direct cost elasticity with respect to K_g (used to reflect the productivity impact of infrastructure in a number of studies) will exaggerate the social impact of public capital investment since the analysis neglects the social costs of such investment. In addition, the importance of the relative growth rates of infrastructure and output is ignored. On the other hand, the harm in terms of productive performance resulting from investment falling short of output growth is also disregarded.

This framework also shows that evaluating the contribution of public infrastructure (as well as internal scale effects and fixity) on productivity growth involves measuring output, cost and productivity changes over time, and then using the cost elasticity with respect to output and its individual elasticity components to decompose the overall measure of productive performance. I.e., identifying the infrastructure impacts requires computing the shadow value of infrastructure capital, Z_{Kg}, the shadow share S^*_{Kg}, the imputed long run elasticity of K_g demand with respect to output changes, ϵ_{KgY}, and the resulting direct and indirect contributions to productive performance $S^*_{Kg} \bullet (dln\ K_g/dt)$ and $\epsilon_{KgY} S^*_{Kg} \bullet (dln\ Y/dt)$.

Estimation of the elasticities and shadow values is, however, not possible using a nonparametric index number methodology; it requires a parametric framework representing the firm's technology. The production theory structure outlined in the previous subsection is ideal for such an analysis of infrastructure contributions to productive performance, since empirical implementation of this framework allows direct calculation of the required elasticities.

III. Empirical Implementation

Computing the measures developed in the previous section requires assuming a specific functional form for the variable cost function G(•), to use as a basis for representation of the firm's pattern of responses. The functional form used in this paper is a generalized Leontief (GL) variable cost function incorporating nonconstant returns to scale and fixed inputs, developed in Morrison [1988], which can be expressed as:

$$(6)\quad G(Y,t,x,p) = Y[\textstyle\sum_i\sum_j \alpha_{ij}\, p_i^{.5}\, p_j^{.5} + \sum_i\sum_m \delta_{im}\, p_i\, s_m^{.5} + \sum_i p_i \sum_m\sum_n \gamma_{mn} s_m^{.5}\, s_n^{.5}]$$

$$+\; Y^{.5}[\textstyle\sum_i\sum_k \delta_{ik}\, p_i\, x_k^{.5} + \sum_i p_i \sum_m\sum_k \gamma_{mk} s_m^{.5}\, x_k^{.5}] + \sum_i p_i \sum_k\sum_l \gamma_{lk} x_k^{.5} x_l^{.5} \quad ,$$

where x_k, x_l denote the quasi-fixed inputs subject to homogeneity conditions, p_i and p_j index the prices of variable inputs, and s_m, s_n depict the remaining arguments (here Y and t). This flexible function accommodates a full range of substitution possibilities, and thus is a more desirable representation of technology and behavior than restricted functions like the Cobb-Douglas used by many researchers studying the impacts of public capital expenditures.[8]

Estimation of the parameters of G(•) allows computation of the elasticity measures required for analysis of infrastructure's contribution to

[8]Exceptions to this include Eberts [1986], Berndt and Hansson [1991], and Nadiri and Mamuneas [1991].

productive performance. This empirical implementation was carried out by constructing a system of estimating equations including input-output equations for the variable inputs derived from Shephard's Lemma; $v_j = \partial G/\partial p_j$ ($j = L_n, L_p, E$):

$$(7)\quad \frac{v_i}{Y} = \frac{\partial G}{\partial p_i}\frac{1}{Y} = \sum_j \alpha_{ij} (p_j/p_i)^{.5} + \sum_m \delta_{im} s_m^{.5} + \sum_m\sum_n \gamma_{mn} s_m^{.5} s_n^{.5}$$

$$+ Y^{-.5} [\sum_k \delta_{ik} x_k^{.5} + \sum_m\sum_k \gamma_{mk} s_m^{.5} x_k^{.5}] + Y^{-1} \sum_k\sum_l \gamma_{lk} x_k^{.5} x_l^{.5} .$$

and a short run pricing expression to incorporate profit maximization:

$$(8)\quad p_Y = MC = \frac{\partial G}{\partial Y} = \sum_i\sum_j \alpha_{ij} p_i^{.5} p_j^{.5} + \sum_i\sum_m \delta_{im} p_i s_m^{.5} + \sum_i p_i \sum_m\sum_n \gamma_{mn} s_m^{.5} s_n^{.5}$$

$$+ .5\, Y^{-.5}[\sum_i\sum_k \delta_{ik} p_i x_k^{.5} + \sum_i p_i \sum_m\sum_k \gamma_{mk} s_m^{.5} x_k^{.5}]$$

$$+ .5\, Y^{.5} [\sum_i \delta_{iY} p_i + \sum_i p_i \sum_m \gamma_{mY} s_m^{.5}] + .5 \sum_i p_i \sum_k \gamma_{Yk} x_k .$$

Estimation was carried out by region -- Northeast (East), North Central (North), South and West[9] -- for these four equations, with fixed effects for each state incorporated as state-specific intercept terms on the v_j/Y equations.[10] The data used for the empirical implementation are annual data on the prices and quantities of output and inputs in the manufacturing sectors of the 48 contiguous states for 1970 through 1987. As outlined above, inputs were divided into private and public capital (K_p and K_g), production and

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[9]These regions were defined as combinations of the nine Census regions, as in Munnell [1990]. See Appendix B for further information.

[10]In some cases regional-specific dummies were also added to the cross K_p, K_g terms to stabilize the results. In addition, although the GL functional form does not contain intercepts for the cost and thus the pricing equation, fixed-effect intercepts were initially added to (8) to assess the sensitivity of the results to the pooling process. Since the parameters on the pricing equation were uniformly insignificant (and not theoretically justified in terms of the construction of the GL functional form), they were dropped for the final specifications.

nonproduction labor (L_p,L_n), and energy (E). Capital quantity data were graciously provided by Alicia Munnell.[11] The remaining input and price data were primarily obtained from the Annual Survey of Manufactures (ASM). Further information on the construction of the data is provided in Appendix A.

Seemingly unrelated (SUR) systems techniques were used for estimation, since the estimating system is not simultaneous. Three stage least squares (THSLS) was also used in preliminary computations, in order to instrument output levels and input prices for possible endogeneity, but the results were sensitive to the construction of the instruments, and were more volatile and less robust to specification changes than those based on SUR methods.

Based on the resulting estimated parameters, the production characteristics identified in the previous section as determinants of observed economic performance (such as shadow values and scale measures) were measured by direct calculation of the required derivatives. Standard and adjusted productivity growth measures were generated using index number procedures. These indicators of productive performance and infrastructure effects were measured for each state, as well as for an "average state" for each region. The averaging process involved constructing a weighted average for each input and output price and quantity, and generating a "weighted average coefficient" for parameters augmented by dummies. These measures are reported and summarized in the next section.

IV. The Results

Results from estimation of the system of equations given by (7) and (8) suggest that our approach has great promise for evaluating the infrastructure

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[11]The "other" component of K_g was dropped, so the results represent the effect of highways, water and sewers; the impact is somewhat smaller if the "other" component, apparently containing largely government buildings which do not augment efficiency, is included.

effects on economic performance. The results generated were quite robust, and indicators constructed from the estimated parameters were of the correct sign, and of reasonable magnitudes. This was especially true for specifications including the breakdown of labor and energy inputs used for our analysis, and when pooled cross-section time-series estimation techniques were used.

In particular, including energy as well as disaggregating the labor input seem crucial for generating reasonable values. The breakdown of variable inputs turned out to be a considerable improvement over the basic value added (K_p,K_g,L) specification which we used for preliminary investigation, and which has generally provided the basis for studies of infrastructure impacts.[12] R^2s for the estimated models for all regions were much higher than for the more restricted input specification; in our final model the R^2s for the estimating equations were all greater than .90, and most exceeded .98. In addition, curvature conditions were satisfied throughout for variable and quasi-fixed inputs. Finally, the magnitudes of the estimated elasticities were all very plausible.[13]

The results were also quite robust to changes in specification (such as using different starting values, constraining parameters to be zero, and trying different pooling procedures), although pooling parameters representing fixed effects were required (they were almost invariably significant).[14] Attempts to impose constant returns to scale, or limiting the time trend impact by restricting terms on the "t" values to zero (since they tended to be individually insignificant), were rejected. Imposing a zero cross K_g-Y term, however, stabilized results for all regions. This might be interpreted as

[12]We are currently in the process of generating non-energy intermediate materials data by state to further extend the analysis of input use.
[13]In Morrison and Schwartz [1992] we explore the substitution patterns of private inputs and public capital in more detail.
[14]The North seemed somewhat less robust to specification changes than the other regions. In some specifications the public capital impact was somewhat larger than suggested here, although still in the same range.

evidence that some heteroskedasticity problems remain when pooling states with very different output levels.[15]

Overall, the intuitive and theoretical plausibility of the results support the use of our model and data for assessing the impact of infrastructure across states. The indicators constructed from these estimates, based on our theoretical development in Section II, also provide a rich structure for evaluation of these impacts. As a foundation for analyzing these indicators, it is useful first to briefly consider variations in the patterns of infrastructure investment across the different regions.

Table 1
Ratios of Public Capital to Private Capital and Output

	EAST		NORTH		SOUTH		WEST	
Year	K_g/K_p	K_g/Y	K_g/K_p	K_g/Y	K_g/K_p	K_g/Y	K_g/K_p	K_g/Y
71	1.018	0.066	0.936	0.069	1.130	0.093	1.916	0.127
76	1.145	0.072	0.973	0.067	0.977	0.088	1.704	0.111
81	1.063	0.073	0.930	0.077	0.872	0.093	1.345	0.099
86	1.015	0.070	0.905	0.070	0.857	0.087	1.262	0.094
Ave.	1.045	0.069	0.931	0.069	0.972	0.087	1.576	0.102
AAGR	-.006%	0.094%	-.231%	0.091%	-1.642%	-.866%	-2.537%	-2.478%

Note: Ave. is the mean of all values from 1971 to 1987; AAGR is the average annual growth rate from 1971 to 1987.

Table 1 documents the availability of public capital in the four regions, in terms of ratios of K_g to both private capital and output for selected years, plus the average over the entire time period and the average

[15]The most obvious effect of this constraint was in the western region, where it resulted in more reasonable estimates (which were also more consistent with individual state and pooled pacific region estimates) for California. This was less evident in other regions where the difference in output levels across states was not as dramatic.

annual growth rates for each region. These ratios suggest that the "sunbelt" (the South and West as defined by Hulten and Schwab [1984],[1991]) has more public capital relative to both private capital and to output than do the "snowbelt" (North and East) states.

The main change in this pattern over time has been in the South, where private capital investment has been very substantial relative to both public capital and output growth, causing the K_g/K_p ratio to drop to a lower level than for any other region by the end of the sample period. The West has a greater proportion of public capital than the other regions, which might be expected since these states are less dense in terms of population and manufacturing establishments compared to their land mass. However, even though all regions have decreasing public to private capital ratios over time, the West has experienced the greatest decline. In addition, the North and East are very similar, especially in their K_g/Y ratios.

Table 2 provides additional information about the growth rates of public and private capital and output, which will have important impacts on the productivity adjustments. These numbers show much greater volatility in output than private capital growth, and in private than public capital growth. However, there has been a downward trend in infrastructure investment everywhere, which even turns to a decline in the stock for 1983-84 in the East when investment did not even keep up with depreciation.

The averages highlight that output growth has been largest in the West and South, although investment in private capital has surpassed output growth on average and that for public capital has fallen short. This is true even for the South, which has the largest growth rate compared to other regions.

Table 2

Yearly Growth Rates of Public Capital, Private Capital, and Output (%)

	EAST			NORTH		
Year	$\dot{K}_g/K_g$	$\dot{K}_p/K_p$	$\dot{Y}/Y$	$\dot{K}_g/K_g$	$\dot{K}_p/K_p$	$\dot{Y}/Y$
71	3.88	1.04	-5.12	2.29	2.51	1.70
72	3.67	2.32	4.58	2.19	-2.87	3.34
73	2.94	2.34	6.43	2.04	2.34	8.90
74	2.36	3.01	0.47	1.55	3.01	1.49
75	2.46	4.74	-13.07	1.30	4.74	-13.84
76	1.59	-11.18	5.87	1.02	-2.99	10.88
77	0.95	2.52	5.57	1.28	2.52	6.06
78	0.48	2.91	3.74	1.08	2.91	4.31
79	0.98	3.82	-1.49	1.14	3.82	-5.81
80	0.67	3.94	-3.17	0.99	3.94	-6.20
81	0.31	-2.41	-2.70	1.08	-3.06	-6.55
82	0.02	3.13	-0.33	0.61	3.34	-3.48
83	-0.23	1.58	1.49	0.14	1.37	5.72
84	-0.06	-0.52	5.83	0.06	-0.52	8.92
85	0.13	0.90	-1.94	0.53	0.90	-1.06
86	0.44	-0.10	-1.07	0.44	-0.64	1.83
87	0.98	0.78	5.94	0.42	0.78	2.55
Ave.	1.27	1.11	0.065	1.07	1.30	1.10

	SOUTH			WEST		
	$\dot{K}_g/K_g$	$\dot{K}_p/K_p$	$\dot{Y}/Y$	$\dot{K}_g/K_g$	$\dot{K}_p/K_p$	$\dot{Y}/Y$
71	2.99	7.12	1.66	3.38	5.21	-2.00
72	3.08	2.32	8.16	2.63	2.32	9.89
73	2.52	2.34	6.91	2.13	2.34	10.34
74	2.70	3.01	6.19	1.66	3.01	3.79
75	2.65	4.74	-10.10	1.28	4.74	-9.49
76	2.65	15.80	8.09	1.30	8.37	7.40
77	2.55	2.52	7.69	1.32	2.52	9.35
78	2.05	2.91	4.96	0.98	2.91	6.57
79	2.18	3.82	-2.39	1.17	3.82	0.91
80	1.96	4.36	-2.60	0.94	3.96	0.28
81	1.86	8.35	-2.44	0.88	15.71	-0.05
82	1.40	3.13	1.90	0.38	3.13	2.75
83	1.42	1.58	2.32	0.65	1.58	-0.69
84	1.17	-0.52	6.34	0.73	-0.52	8.19
85	1.18	0.90	-0.55	1.18	0.90	-0.84
86	1.30	3.10	2.34	1.57	5.78	0.54
87	1.91	0.78	9.13	1.41	0.78	11.57
Ave.	2.09	3.90	2.80	1.39	3.92	3.44

These growth rates were computed according to the continuous formula dln Y/dt to make them consistent with the methodology used for Divisia index computations. This tends to exacerbate volatility when large changes occur.

Investigating the motivations for these patterns as well as the impact of infrastructure investment on productive performance crucially involves the shadow value or marginal benefit of K_g, $Z_{Kg}=-\partial G/\partial K_g$, as discussed in Section II. Indexes of these measures over time, along with the analogous shadow value of private capital, are presented by region in Table 3. In all cases the shadow value of public capital exceeds zero,[16] indicating a positive marginal benefit or marginal product of infrastructure capital for firms. It does, however, tend to be lower and have a smaller upward time trend than Z_{Kp} (except in the South), suggesting a decline in the relative value of public to private capital over time.

Table 3
Shadow Values for Private and Public Capital

	EAST		NORTH		SOUTH		WEST	
Year	Z_{Kp}	Z_{Kg}	Z_{Kp}	Z_{Kg}	Z_{Kp}	Z_{Kg}	Z_{Kp}	Z_{Kg}
71	1.488	1.077	2.453	0.808	1.020	0.840	1.599	0.556
72	1.661	1.165	2.731	0.871	1.070	0.926	1.800	0.636
73	1.847	1.248	2.999	0.968	1.115	1.018	1.969	0.715
74	2.119	1.277	3.166	1.054	1.294	1.322	2.158	0.838
75	2.072	1.173	3.168	1.030	1.268	1.409	2.158	0.886
76	2.394	1.454	3.747	1.218	1.236	1.636	2.344	0.971
77	2.706	1.562	4.189	1.381	1.355	1.894	2.671	1.138
78	3.037	1.667	4.558	1.521	1.426	2.103	2.965	1.284
79	3.315	1.653	4.690	1.558	1.426	2.278	3.133	1.427
80	3.678	1.551	4.853	1.618	1.442	2.603	3.303	1.620
81	4.099	1.594	5.185	1.665	1.372	2.909	3.316	1.624
82	4.304	1.614	5.356	1.696	1.377	3.140	3.581	1.790
83	4.650	1.668	5.767	1.853	1.377	3.252	3.727	1.876
84	5.154	1.867	6.333	2.054	1.446	3.445	4.130	2.087
85	5.339	1.901	6.488	2.076	1.404	3.473	4.212	2.154
86	5.398	2.063	6.713	2.111	1.350	3.340	4.204	2.076
87	5.704	2.166	6.860	2.152	1.405	3.485	4.657	2.328
AAGR	8.76%	4.46%	6.64%	6.31%	2.00%	9.30%	6.91%	9.36%

[16]This value was tested for statistical significance at two points for each state and was uniformly significant in terms of a t-test using the estmated standard error.

These relative values convey some interesting information since the patterns vary significantly across regions. For the East, the Z_{Kg} value goes from about 75% of the Z_{Kp} value to less than half. In the North, the ratio is quite flat at about 30%. In the South it "flips" from below to above one -- it goes from 80% to 250% -- and in the West it rises from about 1/3 to 1/2. Thus, in the snowbelt, the Z_{Kg}/Z_{Kp} ratio is dropping, and in the sunbelt the ratio is increasing -- in the South to significantly greater than one. This suggests possible overinvestment by firms in private capital relative to public capital, especially in the South.

Combining this information with that provided in the first two tables supports this implication and suggests other interesting conjectures. For example, The lower K_g investment in the North and East as compared to the West and South seems to have been appropriate in light of the lower shadow values in these regions. It appears that infrastructure investment should be stimulated further in the South, even though the growth rates for K_g in this region are already relatively large. In reverse, investment in private capital appears to have been higher than optimal -- at least with respect to the snowbelt region -- for the West and particularly for the South. It seems, in fact, that private investment in the South has likely been too extensive in terms of its true marginal product.

To pursue this further, it is necessary to translate this discussion of relative stock valuation to one in "real" terms. This may be accomplished by comparing the shadow values of these stocks to their market prices. Since the shadow value measures are essentially measured in nominal dollars, doing this type of comparison facilitates appropriate interpretation and inference of motivation and optimality. This is particularly important since both the relative prices and efficiencies of the two types of capital differ, and also since the appropriate price at which to evaluate K_g is somewhat unclear.

More specifically, for private capital a unitless measure of the marginal contribution of K_p is often constructed by specifying the shadow value as a ratio, in the form of a Tobin's q measure; $q_{Kp}=Z_{Kp}/p_{Kp}$. This measure equals one in equilibrium if p_{Kp} appropriately measures the user cost of private capital, since Z_{Kp} represents the marginal benefit and p_{Kp} the marginal cost of K_p. If instantaneous adjustment were possible the firm would demand capital to its "desired" level where these two values were equated.

For purposes of comparison, therefore, a measure of p_{Kp} is provided in Table 4; construction of this measure is elaborated in Appendix A. From this measure it appears that private capital has been chronically overutilized in the East and North; more capital would have paid off since marginal benefits exceed marginal costs. This is also generally true for the West, except in the early 1980s. However, for the South over-investment (excess capacity) appears pervasive; a q_{Kp} measure would fall increasingly short of one.

Table 4
Capital Prices

YEAR	p_{Kp}	p_{Kg}
71	1.257	0.548
72	1.229	0.570
73	1.267	0.585
74	1.641	0.813
75	1.864	0.923
76	1.887	0.907
77	1.935	0.911
78	2.227	1.089
79	2.483	1.235
80	3.208	1.658
81	3.973	2.120
82	4.282	2.028
83	3.894	1.992
84	4.085	2.055
85	3.971	1.990
86	3.739	1.893
87	3.919	2.104

This type of comparison is trickier to carry out for K_g, since $p_{Kg}=0$ in terms of private optimization but not for society as a whole. For $p_{Kg}=0$ the q_{Kg} measure is undefined, but it is invariably true that $Z_{Kg}>p_{Kg}$. As long as the marginal product is positive firms benefit from having more K_g.

For social evaluation, however, Z_{Kg} can be interpreted in the context of a q_{Kg} measure. Essentially, the idea underlying construction of the q_{Kp} measure is that if $q_{Kp}>1$ the firm has an incentive to invest in K_p. Similar reasoning implies that if the social cost of investing in one more unit of public capital is less than Z_{Kg}, the expenditure by the state is justified in terms of the net benefits. The issue that arises in this case is how to measure the one-period social price of public infrastructure capital.[17]

The two main differences between p_{Kg} and p_{Kp} involve the differential cost of funds and the effective tax rates for public and private expenditure. Specifically, p_{Kp} is computed using a deflator for capital plant and equipment (p_I) to reflect inflation in investment prices, and adapting this into a user cost by taking depreciation (δ_t), the cost of funds (r_t), and tax rates (TX_t) into account according to the formula $p_{Kp}=TX_t p_I(r_t+\delta_t)$. To accomodate differences in the cost of funds, r_t may be approximated by the Moody Baa bond yield for private investment, but the Moody government bond yield for public investment. In addition, expenditures on public infrastructure are not subject to corporate taxation, so the tax rate adjustment may be ignored for public spending. The resulting measure of p_{Kg}, which is similar to that used in Berndt and Hansson [1991], is presented in Table 4.

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[17]Note that this evaluation of "social" benefits only pertains to the benefit to manufacturing firms of investment in K_g, ignoring the benefits to individuals and other types of businesses. In addition, part of the social user cost of the marginal unit of infrastructure is covered by the private cost associated with funding these projects through taxation. The complications associated with this "halfway house" are neglected here.

These values suggest that, although the Z_{Kg} values are lower than those for Z_{Kp}, much of this difference in terms of optimality results from the differentiation in user cost. In fact, it appears that infrastructure investment has almost invariably been too low for social optimization; $Z_{Kg}>p_{Kg}$. This is especially true for the South in the later part of the sample. For other regions, surprisingly, the Z_{Kg} and p_{Kg} measures are converging; although the net returns to infrastructure investment are positive, observed lower growth rates in K_g over time may have been justifiable.

Further assessment of the cost and ultimately productivity impacts of K_g can be accomplished by calculating the shadow share of K_g (S^*_{Kg}) and the long run scale elasticity with respect to infrastructure (ϵ_{KgY}), and using these values to compute the direct and indirect contributions to productivity growth, $S^*_{Kg}\bullet(d\ln K_g/dt)$ and $\epsilon_{KgY}S^*_{Kg}\bullet(d\ln Y/dt)$, as discussed in Section II.

The shadow shares presented in Table 5 range from about .15 to .3. These indexes have at least two useful interpretations. Since this share is computed as a ratio of the marginal valuation of the public capital stock ($Z_{Kg}K_g$) and the total private cost ($C-G(\bullet)+p_{Kp}K_p$), these numbers suggest that the public capital stock is worth from 15% to one-third of the firm's cost of production. This implies quite a large productive (cost-saving) benefit of additional units of infrastructure capital, which is statistically significant (since the shadow value is significantly different from zero).

These values are substantially larger in the sunbelt areas of the West and particularly the South (about 20-30%) than in the snowbelt regions (about 15-20%). Also, the shadow shares dropped during the early 1980s in the East and North and stayed somewhat low in the East, but declined very little if at all and had a generally upward trend in the South and West. This supports the earlier assertion that the incentive for infrastructure investment has been constant or dropping (although is generally positive) in the North-East but is relatively strong and increasing in the South-West.

Table 5
Shadow Share, K_g Cost Elasticity, and K_g Output Elasticity

	EAST			NORTH		
Year	S^*_{Kg}	ϵ_{CKg}	ϵ_{KgY}	S^*_{Kg}	ϵ_{CKg}	ϵ_{KgY}
71	0.217	0.106	0.827	0.173	0.056	1.462
72	0.230	0.117	1.064	0.184	0.064	1.408
73	0.234	0.124	1.201	0.189	0.075	1.576
74	0.212	0.077	1.085	0.184	0.042	1.187
75	0.190	0.040	0.938	0.171	0.018	0.950
76	0.235	0.088	1.053	0.189	0.048	1.207
77	0.231	0.096	1.190	0.194	0.066	1.406
78	0.218	0.076	1.173	0.188	0.053	1.283
79	0.198	0.050	1.167	0.181	0.038	1.109
80	0.163	-0.011	1.010	0.168	-0.004	0.823
81	0.150	-0.049	0.915	0.159	-0.043	0.618
82	0.143	-0.037	0.886	0.154	-0.030	0.713
83	0.148	-0.029	1.078	0.170	-0.013	0.760
84	0.157	-0.016	1.146	0.176	-0.00007	0.844
85	0.158	-0.007	1.232	0.178	0.007	0.868
86	0.176	0.014	1.344	0.186	0.019	0.900
87	0.181	0.005	1.385	0.182	0.004	0.791

	SOUTH			WEST		
Year	S^*_{Kg}	ϵ_{CKg}	ϵ_{KgY}	S^*_{Kg}	ϵ_{CKg}	ϵ_{KgY}
71	0.251	0.087	1.516	0.238	0.003	1.740
72	0.259	0.099	1.654	0.254	0.026	2.015
73	0.266	0.113	1.789	0.267	0.048	1.959
74	0.297	0.115	1.635	0.270	0.008	1.796
75	0.297	0.102	1.444	0.265	-0.011	1.450
76	0.304	0.136	1.701	0.263	0.017	1.390
77	0.325	0.169	1.997	0.274	0.055	1.406
78	0.318	0.153	1.842	0.266	0.040	1.409
79	0.317	0.145	1.703	0.267	0.036	1.267
80	0.311	0.113	1.368	0.260	-0.006	1.003
81	0.295	0.080	1.124	0.217	-0.066	0.892
82	0.296	0.105	1.250	0.218	-0.029	0.669
83	0.315	0.122	1.352	0.231	-0.014	0.880
84	0.318	0.128	1.405	0.242	0.004	0.899
85	0.322	0.138	1.458	0.250	0.019	0.937
86	0.317	0.138	1.483	0.243	0.021	1.065
87	0.322	0.127	1.422	0.255	0.025	1.193

Recognizing that the shadow share measure has been derived from the cost elasticity with respect to public capital ($\epsilon_{Ckg}=\partial \ln C/\partial \ln K_g$) facilitates comparison of these values with those found in other studies.[18] Our estimates of the shadow shares are smaller than the comparable values of the cost and thus productivity effect of K_g investment estimated by Munnell [1990] and especially Aschauer [1989] (using simple production function models), similar to those found by Nadiri and Mamuneas [1991] and Berndt and Hansson [1991] (with cost function approaches based on individual manufacturing industries for the entire U.S. and Swedish manufacturing, respectively), and larger than those computed by researchers such as Hulten and Schwab [1991] (using index number methods).

Note that our measure does not include "other" public capital. Since this component of infrastructure tends to depress the cost impact, including it would likely generate somewhat smaller values of S^*_{Kg}. Even so, since our measures lie in the middle to upper range of the values found in these studies and are quite robust, this suggests that both the very large and the negligible values found by studies using simpler methods are questionable.

The more structural model developed in this paper, however, not only generates reasonable results, but also provides theoretical and empirical information that facilitates interpretation of the measures. First, the shadow value shares identify the direct effect on manufacturing firms, but do not reflect the cost of infrastructure capital, which confuses the inference about social optimality. In particular, $\partial \ln C/\partial \ln K_g = -Z_{Kg}K_g/C = -S^*_{Kg}$ only if $p_{Kg}=0$; if the cost of K_g were taken into account in the cost computation this would instead be $\partial \ln C/\partial \ln K_g = (p_{Kg}-Z_{Kg})/C = \epsilon_{Ckg}$.

[18]This is also closely related to the output elasticity from the production function measured by researchers such as Hulten [1991] since the marginal product and shadow value are closely related -- they are essentially dual to each other.

Also, the impact of this cost effect on productivity growth depends on the growth rate of investment, not just the share. The direct productivity effect $K_gDIR = S^*_{Kg} \bullet (d\ln K_g/dt)$ will be zero even with a high S^*_{Kg} if K_g is not changing. Since K_g growth has generally been positive but declining, this will have a depressing effect on the productive contribution of infrastructure investment over time even for the South and West which have high and increasing shadow shares.

Thirdly, the theoretical development in Section II also showed that if K_g has a scale effect for firms, an additional indirect effect of K_g growth emerges from the term $\epsilon_{KgY} S^*_{Kg} \bullet (d\ln Y/dt)$. This highlights that not only the price of K_g and the growth of K_g affect net costs and observed productivity from expenditures on public infrastructure, but the <u>relative</u> growth rates of K_g and output production also make a difference. For example, since output growth has on average been higher than K_g growth in the South and West and similar or lower in the North and East, this exacerbates the evidence that K_g growth has been insufficient (even if relatively large) in the sunbelt.

To accomodate the first issue, we can consider the $-\epsilon_{CKg}$ measure in Table 5, which takes into account the social cost of infrastructure investment.[19] These numbers are primarily positive, although for the East, North and even the West the early 1980s are negative. This suggests that even socially the net benefits of additional public infrastructure investment would generally have been positive over this time period. However, it also supports the notion that observed sluggish public capital investment in the 1980s was at least somewhat justified when net costs are taken into account.

In addition, the scale effect of K_g may be ascertained by the elasticity ϵ_{KgY}, also presented in Table 5. ϵ_{KgY} reflects the "returns" to K_g as output

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[19]We measure this as the negative of the elasticity to indicate net benefits as a positive number.

changes; if the desired level of K_g increases more (less) than proportionately with increases in Y this measure will be greater (less) than one. The measures in Table 5 show that ϵ_{KgY} exceeds one in the sunbelt and varies, with a mean of greater than one, in the snowbelt.

Decreasing returns to K_g in the long run therefore seem pervasive; a higher proportion of K_g is desirable as output increases. Thus, output expansion in the South-West exerts increasing pressure on the existing infrastructure and motivates further expansion of public infrastructure. This is less so in the East and particularly in the North, although such a tendency is weakly evident. This augments the indirect effect; it suggests that the comparison of output and K_g growth is even more powerful in terms of the productivity impact. Growth in public infrastructure must <u>more</u> than keep up with output growth in order to have a postive productivity impact.

We can further pursue these implications about infrastructure effects by considering the direct and indirect infrastructure contributions presented in Table 6, which result from combining these measures. To facilitate interpretation of these measures, it is useful to refer to equation (5'), reproduced here in its expanded form and collecting the K_g effects to highlight the total effect:

$$(5'') \quad -\epsilon_{Ct} = -\epsilon^{T}_{Ct} - (\epsilon^{L}_{CY}-1)\frac{\dot{Y}}{Y} + \epsilon_{CKp}\epsilon_{KpY}\frac{\dot{Y}}{Y} - \epsilon_{CKp}\frac{\dot{K}_p}{K_p} + S^{*}_{Kg}\left(\frac{\dot{K}_g}{K_g} - \epsilon_{KgY}\frac{\dot{Y}}{Y}\right)$$

$$= -\epsilon^{T}_{Ct} + YDIR + K_pIND + K_pDIR + (K_gDIR + K_gIND) \,.$$

Table 6
Indirect and Direct Public Capital Impacts, and net effect

	EAST			NORTH		
Year	K_gIND	K_gDIR	NET	K_gIND	K_gDIR	NET
71	0.920	0.843	1.762	-0.430	0.397	-0.032
72	-1.118	0.841	-0.277	-0.867	0.404	-0.463
73	-1.805	0.686	-1.118	-2.645	0.385	-2.260
74	-0.107	0.500	0.393	-0.325	0.286	-0.039
75	2.324	0.466	2.791	2.251	0.222	2.473
76	-1.452	0.373	-1.079	-2.479	0.192	-2.287
77	-1.531	0.220	-1.311	-1.649	0.247	-1.402
78	-0.957	0.105	-0.852	-1.039	0.204	-0.836
79	0.345	0.195	0.539	1.169	0.207	1.376
80	0.521	0.108	0.630	0.859	0.166	1.025
81	0.370	0.046	0.416	0.644	0.172	0.816
82	0.042	0.004	0.045	0.382	0.094	0.476
83	-0.237	-0.034	-0.271	-0.741	0.024	-0.717
84	-1.049	-0.010	-1.059	-1.322	0.011	-1.311
85	0.379	0.020	0.400	0.164	0.095	0.259
86	0.253	0.078	0.331	-0.307	0.082	-0.225
87	-1.487	0.177	-1.309	-0.367	0.077	-0.290
Ave.	-0.027	0.272	0.245	-0.039	0.192	0.153

	SOUTH			WEST		
Year	K_gIND	K_gDIR	NET	K_gIND	K_gDIR	NET
71	-0.629	0.750	0.121	0.831	0.805	1.636
72	-3.491	0.796	-2.695	-5.064	0.669	-4.395
73	-3.286	0.670	-2.616	-5.402	0.568	-4.834
74	-3.007	0.802	-2.205	-1.840	0.447	-1.393
75	4.325	0.787	5.111	3.642	0.339	3.981
76	-4.181	0.805	-3.376	-2.706	0.341	-2.366
77	-4.992	0.829	-4.163	-3.598	0.360	-3.238
78	-2.907	0.652	-2.254	-2.460	0.261	-2.199
79	1.286	0.690	1.976	-0.307	0.312	0.005
80	1.107	0.609	1.716	-0.074	0.246	0.172
81	0.810	0.550	1.360	0.010	0.191	0.201
82	-0.702	0.415	-0.287	-0.402	0.083	-0.319
83	-0.989	0.448	-0.541	0.140	0.150	0.290
84	-2.831	0.372	-2.459	-1.784	0.176	-1.608
85	0.258	0.379	0.637	0.197	0.296	0.493
86	-1.104	0.413	-0.691	-0.140	0.382	0.242
87	-4.178	0.615	-3.563	-3.527	0.359	-3.168
Ave.	-1.442	0.622	-0.820	-1.323	0.352	-0.971

Thus, if $S^*_{Kg}>0$ the direct productivity impact of infrastructure investment is positive, but the net effect will only be positive if the augmented output growth measure $\epsilon_{KgY}(\mathrm{dln}\ Y/dt)$ is growing less rapidly than K_g. Alternatively, we can interpret this impact more along the lines of equation (5) where the roles of ϵ_{Ct} and ϵ^T_{Ct} are reversed. If the last term of (5'') is positive, standard productivity growth measures overestimate true technical change since some of the measured productivity growth may be attributed to infrastructure investment. Conversely, if this is negative, standard productivity growth measures as representative of technical change are biased downwards.

Expression (5'') shows clearly that the K_gDIR and K_gIND measures can be interpreted as the percentage impact on the productivity growth rate. The positive values for essentially all the K_gDIR values reported in Table 6, therefore, indicate a positive productivity impact of infrastructure investment which ranges between .192% (for the North) to .622% (for the South) on average. The decline in these values over time, especially for the North and East (from .843% to .177% in the East, for example, with negative values for 1983-84), suggests that the positive infrastructure investment impacts have been reduced due to lower growth rates of K_g. However, for the East (and also somewhat for the North), this is due also to lower returns to infrastructure investment, as reflected in the fall of the S^*_{Kg} values.

The *net* effect is the sum of the K_gDIR and K_gIND measures; NET=K_gDIR+K_gIND. As is evident from Table 6, in many cases negative K_gIND measures counterract the positive K_g values so NET<0. This suggests that sluggish productivity growth has often been due at least partly to a shortfall of infrastructure investment *relative* to growth in output production. This is especially true for the South and the West, where infrastructure investment has simply not kept up with output expansion.

The averages emphasize this difference between the sunbelt and snowbelt; productivity growth has been augmented by .15-.25% in the snowbelt and depressed by from .8% to almost 1% per year in the sunbelt by low infrastructure investment. Firms have been unable to take advantage of potential scale effects arising from public infrastructure investment.

To further clarify how these effects support or counterract each other in terms of productivity growth, it is useful to examine the patterns of these effects at times when different K_g and Y growth rate patterns are observed. For example, if Y is increasing as K_g is declining (see 1983-84 for the East), both the direct and indirect impacts are negative; productivity growth is harmed by the stagnation of the existing infrastructure, and this damage is heightened by the fact that output is growing at the same time. In reverse, when the stock of infrastructure is increasing but output production is in a downturn, both these impacts are positive. Thus, in a recessionary period, both the direct and indirect impacts of positive infrastructure investment augment productivity growth.

If both are increasing or decreasing, however, the net effect depends on which is changing most rapidly. If both are increasing, for example, the direct effect is positive but the indirect is negative; only if K_g is increasing at a greater rate than the adjusted growth rate of output $\epsilon_{K_gY}(d\ln Y/dt)$ will the productivity growth impact be positive. This was the case in 1974 for the East, whereas the reverse occurred in 1976; productivity growth was hampered because output growth was not met by a corresponding increase in K_g.

It is useful also to consider the converse interpretation of these measures. I.e., when the NET effect is to reduce productivity growth from what it would have been if K_g investment had kept up with expanding production, the traditional productivity growth measure ($-\epsilon_{Ct}$) is low. Thus, the adjusted measure $-\epsilon^T_{Ct}$ reflecting only technical change is greater. Since this situation occurs when output expansion is large relative to K_g growth, it is likely to be observed when productivity already is high, and vice-versa.

Thus, the adjusted productivity measure will likely fluctuate *more* than the standard measure; taking infrastructure into account is unlikely to smooth cycles in technical change measures. This is evident from the Appendix Table B4, where the traditional and adjusted productivity growth measures allowing for both private and public capital effects are presented.[20] However, the secular trends show that infrastructure investment declines make it increasingly likely that K_g growth will be lower than growth in output production, harming productivity growth; true technical change will be greater than that measured using standard measurement procedures because some of the decline can be "explained" by a shortfall in public infrastructure investment.

V. Concluding Remarks

Declines in the cost of producing a particular output level (given constant input prices), represent an increase in productive performance of firms. These declines may, however, result from numerous types of efficiency changes, including not only technical change but also different types of scale effects. These scale effects, in turn, may arise from short run fixities of inputs, scale economies imbedded in the technology, or external impacts such as public infrastructure. In this paper we have modeled and measured the impacts of these effects on costs and thus on productivity, focusing on the impacts of public infrastructure investment in highways, water and sewers.

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[20]Note that the productivity growth numbers fluctuate more decisively than many multifactor measures, since this is essentially a value added measure (energy is a small proportion of these costs). Also, Table B5 shows the full decomposition into the different K_g and K_p effects from equation (5'').

Our results indicate the importance of infrastructure investment to firms' costs and productivity growth, and highlight the usefulness of a full structural model for both measuring and interpreting these impacts. In particular, we are able to measure the cost impact of infrastructure investment as a shadow value, using a representation of firms' technology and cost minimization behavior based on a variable cost function. We are able to pursue this further, however, to consider how private and social net benefits will differ according to the price of infrastructure investment incurred by the firms as compared to the government. We also show that indirect impacts also affect net benefits through the relative rates of growth of output and public infrastructure.

The direct cost impact of infrastructure investment appears to be quite extensive, although not as great as found by some researchers. The shadow share, reflecting the proportional cost savings compared to costs, ranges primarily from 15% to 20% for the "snowbelt" (North and East) states and from 20 to 30% in the "sunbelt" (South and West), with the values generally increasing for the latter regions and declining slightly or staying flat in the North-East. Increasing the stock of infrastructure thus has a significantly positive impact in terms of increasing the efficiency (decreasing costs) of production.

Recognizing the public cost of such expenditure implies a lower net value, represented by the cost elasticity $\epsilon_{CKg} = \partial \ln C/\partial \ln K_g$ including a price of public infrastructure capital (where K_g denotes this capital). This value is smaller than the shadow share, but remains positive throughout most of the time period and the regions (except the early 1980s in the East, North and West), since the shadow value is generally greater than the cost of capital. Thus, the net social as well as the private benefit of additional infrastructure investment is positive on average.

Computing the direct productivity growth impact from this information requires multiplying the shadow value measure by the growth in public infrastructure. This adaptation causes the declines in the marginal infrastructure benefits to be exacerbated in the North and East, and the benefits to show a somewhat declining trend in the South and West. Slowdowns in infrastructure investment have therefore reduced the positive productivity growth impacts of such investment, even in the South where investment has been quite extensive.

However, adapting this to take into account the importance of the *relative* growth rates of output and K_g -- including the "indirect" impact -- shows that shortfalls in infrastructure investment in terms of "keeping up" with output growth have actually been harmful to productivity growth (particularly in the South and West). Increases in public infrastructure investment are therefore essential to generate a positive impact on productivity growth when production is expanding; existing infrastructure investment has not generally been sufficient to accomplish this.

In sum, there appears to be a significant incentive for investment in public capital, especially in the South, in terms of the benefit accruing to manufacturing firms. This is even true when the costs of infrastructure investment are taken into account; there has been a positive net social benefit of additional infrastructure investment for most years and regions. This is particularly the case when output production is expanding, since shortfalls in infrastructure investment relative to output growth appear not only to have reduced the positive impact, but even to have proven harmful to productivity growth due to the scale effects of public capital.

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APPENDIX A: The Data

The data used for this empirical implementation are annual data on the manufacturing sector of the 48 contiguous states for 1970 through 1987. The 18 year panel is long enough to allow the separation of short and long run effects, and the investigation of changes in productivity and performance over time. Although a longer time series would be preferable for our analysis, we are effectively constrained from considering earlier or more recent data since some critical data series begin in 1970 and post-1986 data is still incomplete.

Although many state-level studies are based on data for gross state product (GSP), which includes production in many sectors, we have restricted our analysis to the manufacturing sector for two important reasons. First, the production theory model of firm production and decision making is particularly applicable to the production processes of manufacturing firms compared to firms in service sectors such as banking, in which output (and sometimes inputs) are conceptually and computationally difficult to define. Secondly, and perhaps even more importantly, the Annual Survey of Manufactured (ASM) provides unusually detailed data on the inputs used by manufacturing firms, expenditures on these inputs, value added by firms and other economic variables by state. This greater data availability has allowed us to break down labor into production and nonproduction workers, and to consider energy as a separate input, which are important for appropriate representation of production processes.

This Appendix provides a description of the underlying data and sources used for construction of the input and output price and quantity variables used in the analysis.

Private Capital

The quantity of private capital, K_p, is measured as the end-of-year private capital in the manufacturing sector, in 1982 dollars, with a one year lag adjustment to transform the data to beginning-of-year stocks. These data were generously provided on diskette by Alicia Munnell of the Federal Reserve Bank of Boston.

The user cost of capital, p_{Kp}, is constructed according to:

A1) $$p_{Kp} = TX_t p_I (r_t + \delta_t),$$

where TX_t is $(1+\tau)$, τ is the effective rate of corporate taxation (from the Bureau of Labor Statistics), p_I is a price deflator for capital equipment investment, r is the rate of return to capital, and δ represents the depreciation rate.[1] For this paper, r is approximated as the Moody Baa bond yield rate. Depreciation, δ, is measured as the ratio of total annual depreciation of equipment and structures in the national manufacturing sector to the national stock of equipment and structures, both in constant 1982 dollars (from the Bureau of Economic Analysis (BEA) publication Fixed Reproducible Tangible Wealth in the U.S.). The implicit price deflator for the manufacturing capital stock, ρ, is calculated as the ratio of BEA current and constant dollar estimates of the national manufacturing sector net equipment and structures capital.

Note that although it would be desirable to generate state specific estimates of the user cost of capital, the necessary data for constructing such estimates are unavailable. Since construction of the private capital data provided by Alicia Munnell was based on the national variables provided

[1]See Harper, Berndt and Wood [1989] for a detailed discussion of the user cost of capital computation.

in this BEA publication, however, the estimates of the stock and user cost of capital are consistent.

Public Capital

The stock of public capital, K_g, is measured as end-of-year public capital stock of highways, water and sewers, in 1982 dollars, with a one year lag to reflect beginning of year stocks. This eliminates the effects of "other public capital" measured by Munnell, which includes such capital assets as public buildings which are less likely to affect manufacturing productivity.[2] The public capital data were also provided by Alicia Munnell. See Munnell [1990] for a more complete description of their computation.

Labor

Two types of workers are distinguished: production and nonproduction workers in the manufacturing sector. The ASM provides the number of full-time and part-time employees on the payrolls of operating manufacturing establishments, L, and the number of workers engaged in production at operating manufacturing establishments, L_p). The number of nonproduction workers is found as the difference between these, $L-L_p=L_n$. Since data on hours worked is not available for nonproduction workers, employment data was used for both types of workers for conformability and comparability.[3]

In addition, the ASM reports gross earnings (wage bill) of all employees

[2]Estimates using both total public capital and total public capital less OTHPK were constructed. Including OTHPK tended to reduce the shadow value of public capital, suggesting that additional investment tends to be harmful rather than helpful to manufacturing establishments. These effects were small, however, and appeared to be statistically insignificant from carrying out estimation decomposing the public capital into its two components and considering them separately.

[3]Unfortunately, the ASM suspended the collection and reporting of these data for 1979-81. The 1978 and 1982 data were interpolated to estimate values for the missing years

(PQL) and of production workers (PQP) on the payroll of operating manufacturing establishments paid in a calendar year. Gross earnings of nonproduction workers is found as the difference between these: $PQN = PQL - PQP$.

Finally, for each category of worker, wage bill per worker is found as the ratio of gross earnings to the number of employees ($p_{Lp} = PQP/L_p$, $p_{Ln} = PQN/L_n$).

Energy

The ASM reports total expenditures on fuels and electricity used for heat and power in the manufacturing sector (PQE).[4] The price of energy used is the cost per million BTUs of purchased fuels and electricity in the industrial sector from <u>State Price and Expenditure Report</u>, published by the Energy Information Administration (p_E), and augmented by data from their system. The estimated quantity of energy was therefore constructed as the ratio of total energy expenditure to the price of energy (PQE/p_E).

Output

The price of output, p_Y, was measured as the implicit price deflator for Gross State Product (GSP), computed for each state as the ratio of BEA current and constant dollar estimates of GSP. Our measure of output -- gross output net of non-energy materials -- was computed by deflating value added reported by the ASM by p_Y ($PQVA/p_Y = VA$) and adding back constant dollar expenditures on fuels and electricity ($Y = VA + E$).

[4]Total expenditures were interpolated from 1966 and 1972 data for 1970 and 1971.

APPENDIX B: Supplementary Tables

Table B1. Definition of Model Variables

Quantities

K_p	Private capital stock, $1982
K_g	Public capital stock (highway, water and sewers only), $1982
L_p	Number of production employees, millions
L_n	Number of nonproduction employees, millions
E	Euantity of energy used, millions of BTUs
Y	Gross output net of non-energy intermediate materials, $1982

Prices

p_{Kp}	User cost of private capital
p_p	Annual wage bill per production employee
p_n	Annual wage bill per nonproduction employee
p_E	Price of energy
p_Y	Price of gross output

Table B2. Descriptive Statistics for Model Variables

	Mean	Minimum	Maximum	Standard Deviation
K_p	13332.098	240.712	69470.740	14353.362
K_g	13917.747	2088.627	68523.840	13485.076
L_p	0.271	0.004	1.240	0.280
L_n	0.128	0.002	0.864	0.154
E	221.567	0.901	1367.735	254.231
Y	17595.769	316.157	110377.052	19541.688
p_{Kp}	0.157	0.067	0.257	0.071
p_p	12822.450	4867.886	27907.675	4880.742
p_n	19860.134	2712.963	42532.399	7426.552
p_E	3.915	0.476	12.429	2.413
p_Y	0.785	0.257	1.270	0.260

Table B3. Geographic Definition of Census Regions and Regions Used

Region	States
New England	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut
Mid Atlantic	New York, New Jersey, Pennsylvania
East North Central	Ohio, Indiana, Illinois, Michigan, Wisconsin
West North Central	Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas
East South Central	Kentucky, Tennessee, Alabama, Mississippi
West South Central	Arkansas, Louisiana, Oklahoma, Texas
South Atlantic	Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida
Pacific	California, Oregon, Washington
Mountain	Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada

Summary Regions

East	New England and Mid Atlantic
North	East North Central and West North Central
South	East South Central, West South Central and South Atlantic
West	Pacific and Mountain

Table B4. Traditional and Adjusted Productivity Growth Indexes

	EAST		NORTH		SOUTH		WEST	
Year	$-\epsilon^T_{Ct}$	$-\epsilon_{Ct}$	$-\epsilon^T_{Ct}$	$-\epsilon_{Ct}$	$-\epsilon^T_{Ct}$	$-\epsilon_{Ct}$	$-\epsilon^T_{Ct}$	$-\epsilon_{Ct}$
71	-2.342	-0.110	3.308	3.788	0.751	0.660	-1.214	0.592
72	4.561	4.215	6.925	5.133	4.008	2.522	7.270	4.963
73	5.195	4.093	6.295	4.173	3.940	2.618	7.883	5.383
74	0.900	1.494	0.495	1.128	6.832	5.774	2.566	2.183
75	-13.220	-8.953	-15.486	-9.249	-10.638	-7.914	-10.145	-6.915
76	11.826	9.481	14.690	10.072	2.001	-1.075	3.312	2.115
77	3.861	2.416	3.660	2.470	6.079	4.557	5.325	3.085
78	1.741	0.895	0.949	0.542	1.594	0.668	1.507	0.141
79	-2.694	-1.651	-7.248	-3.851	-4.079	-3.446	-1.351	-1.006
80	-3.214	-2.021	-6.408	-3.522	-3.274	-3.264	-1.768	-1.550
81	-1.339	-0.648	-4.240	-2.724	-4.234	-6.072	-5.524	-6.351
82	0.293	0.378	-3.466	-2.111	1.426	0.765	1.434	0.877
83	2.763	2.389	8.012	6.363	2.476	2.251	-0.816	-0.549
84	7.536	5.675	9.131	6.201	5.181	5.023	7.676	6.079
85	-1.202	-0.420	-1.013	-0.326	-0.228	-0.031	-1.063	-0.550
86	0.929	1.393	3.828	3.020	2.516	1.827	-1.623	-1.126
87	7.391	5.535	1.279	0.645	7.501	6.798	9.810	7.311
Ave. (AAGR)	1.352	1.421	0.728	1.280	1.285	0.686	1.369	0.864

Table B5. Components of Productivity Growth Adjustment

EAST

Year	YDIR	K_pIND	K_gIND	K_pDIR	K_gDIR
71	-0.002	0.424	0.920	0.047	0.843
72	0.490	-0.750	-1.118	0.191	0.841
73	1.183	-1.411	-1.805	0.245	0.686
74	0.023	-0.054	-0.107	0.232	0.500
75	0.806	0.513	2.324	0.158	0.466
76	0.168	-0.635	-1.452	-0.799	0.373
77	0.533	-0.922	-1.531	0.255	0.220
78	0.267	-0.541	-0.957	0.280	0.105
79	-0.036	0.184	0.345	0.356	0.195
80	0.231	0.145	0.521	0.188	0.108
81	0.277	0.024	0.370	-0.027	0.046
82	0.033	0.0005	0.042	0.006	0.004
83	-0.115	-0.092	-0.237	0.105	-0.034
84	-0.240	-0.516	-1.049	-0.046	-0.010
85	0.044	0.236	0.379	0.102	0.020
86	-0.034	0.181	0.253	-0.014	0.078
87	0.364	-1.023	-1.487	0.114	0.177

NORTH

Year	YDIR	K_pIND	K_gIND	K_pDIR	K_gDIR
71	0.878	-1.052	-0.430	0.686	0.397
72	2.588	-2.992	-0.867	-0.925	0.404
73	8.481	-9.147	-2.645	0.804	0.385
74	0.704	-0.859	-0.325	0.828	0.286
75	-2.952	5.615	2.251	1.100	0.222
76	5.443	-6.888	-2.479	-0.887	0.192
77	4.040	-4.659	-1.649	0.830	0.247
78	2.362	-2.821	-1.039	0.888	0.204
79	-2.124	3.077	1.169	1.068	0.207
80	-0.497	1.603	0.859	0.755	0.166
81	0.177	0.904	0.644	-0.381	0.172
82	0.135	0.386	0.382	0.359	0.094
83	0.241	-1.438	-0.741	0.265	0.024
84	1.130	-2.639	-1.322	-0.111	0.011
85	-0.175	0.386	0.164	0.218	0.095
86	0.543	-0.941	-0.307	-0.184	0.082
87	0.671	-1.229	-0.367	0.214	0.077

Table B5. Continued

SOUTH

Year	YDIR	K_pIND	K_gIND	K_pDIR	K_gDIR
71	0.137	0.095	-0.629	-0.445	0.750
72	0.961	0.338	-3.491	-0.090	0.796
73	1.106	0.268	-3.286	-0.081	0.670
74	0.948	0.406	-3.007	-0.206	0.802
75	-0.981	-0.872	4.325	-0.535	0.787
76	1.466	0.791	-4.181	-1.956	0.805
77	2.162	0.736	-4.992	-0.257	0.829
78	1.185	0.507	-2.907	-0.363	0.652
79	-0.494	-0.260	1.286	-0.589	0.690
80	-0.429	-0.287	1.107	-0.990	0.609
81	-0.428	-0.246	0.810	-2.524	0.550
82	0.430	0.197	-0.702	-1.001	0.415
83	0.505	0.262	-0.989	-0.450	0.448
84	1.442	0.714	-2.831	0.145	0.372
85	-0.130	-0.063	0.258	-0.247	0.379
86	0.552	0.270	-1.104	-0.820	0.413
87	2.048	1.021	-4.178	-0.208	0.615

WEST

Year	YDIR	K_pIND	K_gIND	K_pDIR	K_gDIR
71	-0.369	0.142	0.831	0.397	0.805
72	3.112	-1.299	-5.064	0.275	0.669
73	3.930	-1.915	-5.402	0.319	0.568
74	1.052	-0.307	-1.840	0.265	0.447
75	-1.365	0.386	3.642	0.228	0.339
76	1.148	-0.587	-2.706	0.608	0.341
77	2.128	-1.395	-3.598	0.266	0.360
78	1.348	-0.784	-2.460	0.269	0.261
79	0.138	-0.086	-0.307	0.289	0.312
80	0.010	-0.003	-0.074	0.039	0.246
81	0.0003	-0.002	0.010	-1.026	0.191
82	-0.188	0.154	-0.402	-0.205	0.083
83	0.012	-0.010	0.140	-0.025	0.150
84	0.046	-0.033	-1.784	-0.002	0.176
85	-0.019	0.020	0.197	0.019	0.296
86	0.032	-0.026	-0.140	0.249	0.382
87	1.467	-0.848	-3.527	0.050	0.359