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ESTIMATING THE CONTRIBUTION OF DISAGGREGATED PUBLIC CAPITAL TO PRODUCTIVITY IN EACH INDUSTRY*

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Previous tests of the effect of public capital on multifactor productivity using Solow's growth accounting technique yield differing estimates of this relationship. This paper reconciles these results and shows why they differ. I highlight the possible problems when Solow's technique is used in empirical work and the problems with previous works. To solve these problems, the paper uses the Malmquist Index to estimate multifactor productivity growth and shows a method to disaggregate this growth which, in turn, I use to estimate the output elasticity of public capital. My results show that, contrary to recent work, the effect of public capital on output is positive and significant. However, the effect of disaggregated public capital on each industry is smaller compared to its effect on total industry. The paper finds that the magnitude of this effect of each type of public capital varies across the different types of public capital.

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I. INTRODUCTION

Since Aschauer (1989) introduced the idea that changes in productivity growth may also be related to changes in public capital expenditures, much research has focused on the relationship between public capital and productivity. Munnell (1990a, 1990b) also showed that with the addition of public capital to models of multifactor productivity, the variation in estimates of multifactor productivity growth rate over time is reduced considerably. From these results she inferred that changes in public capital positively affect multifactor productivity. By contrast, Hulten and Schwab (1991) introduced public infrastructure as a direct and as an in-

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direct input. They found weak links between the regional growth rate of public capital and the regional growth rate of productivity. However, most research which tests the effect of public capital on multifactor productivity using Solow's growth accounting technique has some problems which may results in biased estimates.

First, to estimate multifactor productivity growth using Solow's growth accounting technique, the assumption that input markets are perfectly competitive is necessary.[1] However, if this assumption is not satisfied in the real economy, that is, if any input market in any state is not competitive, then income share is not equal to factor share and the estimate of multifactor productivity change may be biased.

Second, most research using Solow's growth accounting technique has used average input and output growth rates over time and across states to test the contribution of public capital to multifactor productivity. The average growth rates of public capital and multifactor productivity may mask year to year and state to state variation which may be important. Thus, the use of average data may result in a biased estimate.

Third, much research, such as Hulten and Schwab (1991), tests the contribution of public capital on the multifactor productivity growth by comparing the growth rate of public capital and the multifactor productivity growth rate affected by all the factors except private capital and labor inputs. However, public capital is only one factor among many which affect multifactor productivity growth rate. Therefore, if we do not use the multifactor productivity growth rate which is affected only by public capital, the test of the relationship between multifactor productivity growth rate and public capital growth rate misrepresents the true contribution of public capital on the multifactor productivity growth rate.

Fourth, much research, as pointed out by Holtz-Eakin (1994), estimates the contribution of aggregate public capital on multifactor productivity in the aggregate, even though the effect of each type of public capital on each industry may be different.

To solve these problems, first, I will use another technique (Malmquist Index)

[1] The common formulation of the production function $Y_t = MFP_t f(L_t, K_t)$ where Y_t denotes output, L_t denotes labor input, K_t denotes capital input, and MFP_t denotes multifactor productivity at time t. Taking the differential with respect to time and dividing by Y_t yields:

$$\frac{\dot{Y}_t}{Y_t} = \frac{\dot{MFP}_t}{MFP_t} + \frac{\Delta f(L_t, K_t^{pri})}{\Delta L} * \frac{L_t}{f(L_t, K_t^{pri})} * \frac{\dot{L}_t}{L} + \frac{\Delta f(L_t K^{pri})}{\Delta K^{pri}} + \frac{K_t^{pri}}{f(L_t K^{pri})} \frac{\dot{K}_t^{pr}}{K_t^{pri}}$$

where $\frac{\dot{Y}_t}{Y_t}$ denotes % Y growth, $\frac{\dot{MFP}_t}{MFP_t}$ % MFP growth, $\frac{\dot{L}}{L_t}$ % L growth and $\frac{\dot{K}_t}{K_t}$ % K growth at time t. This equation can thus be expressed for each year as,

% Ygrowth = % MFPgrowth + S_l(% Lgrowth) + S_k(% Kgrowth)

where S_l denotes the output elasticity (or factor share) of labor input and S_k denotes the output elasticity (or factor share) of capital input. Rearranging terms yields:

% MFPgrowth = % Ygrowth − S_l(% Lgrowth) − S_k(% Kgrowth)

To estimate percentage growth in MFP for each year, studies based on this technique have to involve assumptions. That is, each factor market is perfectly competitive (factors are paid their marginal product) and there is a constant returns to scale production function. With these assumptions, S_l, S_k are, respectively, the relative share of total income paid to labor and capital, each term in the right hand side can be measured directly and so, % MFPgrowth can be measured as a residual.

which doesn't require the assumption that factor share is equal to income share in order to estimate multifactor productivity. The Malmquist Index method enables me to estimate multifactor productivity for each state and each year. Thus, to estimate the contribution of each type of public capital on multifactor productivity, I can use individual estimates instead of average estimates for the US. as a whole. Second, to estimate the effect of public capital, I show a method which disaggregates multifactor procuctivity growth rate. I estimate two types of multifactor productivity growth rates. The difference of these multifactor productivity growth rates explains the effect of public capital on multifactor productivity which I use to estimate the output elasticity of public capital. Third, I decompose aggregate public capital into four categories as education, highways and streets, sewerage, and utilities and separately identify three industries as agriculture, manufacturing, and non-farm, non-manufacturing.

The results show that the output elasticity of each type of public capital is significantly positive and varies in magnitude across industries.

In section II, I explain the model for multifactor productivity growth (Malmquist Index). I explain the model used to estimate output elasticity of public capital using the estimated multifactor productivity growth in section III. Data and empirical estimation of multifactor productivity growth are in section IV and in section V, I estimate output elasticity of public capital. In section VI, I present some conclusions.

II. MODEL FOR THE MULTIFACTOR PRODUCTIVITY GROWTH[2]

I use the Malmquist Index to estimate multifactor productivity which is necessary to analyze the contribution of public capital to multifactor productivity and output of each industry. The Malmquist Index was introduced by Caves et al (1982). I estimate multifactor productivity change as the geometric mean of two Malmquist Indexes which were used by Fare, Grosskopf, Norris, and Zhang (1994). To estimate the Malmquist Index, they used distance functions which need only data on the quantities of inputs and outputs. First, I define the grand production possibility set and distance function to estimate the Malmquist Index.

1. Grand Production Possibility Set and Distance Function

Assume there is one output Y which is produced using a vector of inputs, $X=(X_1, X_2, \cdots, X_m)$. The associated production possibility technology set S will be

$$S=\{(Y,X): \text{Output } Y \text{ can be produced using inputs } X\} \quad X, Y \geq 0 \tag{1}$$

[2] More detail explanation is in Fare, Rolf; Grosskopf, Shawna and Lovell C. A. Knox. (1994).

If the amount of multifactor for each state is different across states, then each state has a different production possibility set. Thus, grand production possibility set is defined as the production possibility set which includes all the production possibility sets for all states in each year. The output difference between an input-output bundle which is on the grand production possibility frontier and another bundle which is below the grand production possibility frontier in each input level may result from a different amount of multifactor usage, different level of technology, or differences in both. The grand production possibility set[3] which satisfies non-increasing returns to scale can be shown as follows:

$$S(NIRS) = \{y: y \le \sum z_j y_j,\ \sum z_j x_{j,m} \le x_m,\ \sum_j z_j \le 1,\ x,y,z \ge 0\} \tag{2}$$

where y denotes output, x the vector of inputs, z the vector of intensity variables ($z_j \ge 0$), m the number of inputs ($m = 1,2,\cdots\cdots M$), j the state activities ($j = 1,2,\cdots\cdots J$), and $NIRS$ non-increasing returns to scale.

The vector of intensity variables allow us to expand or contract observed activities radially for the purpose of forming grand production possibility frontier. Using this grand production possibility set, I can define the distance function which explains "how close the output of an input-output bundle is to the frontier of the grand production possibility set for each input level."[4] The distance function assuming non-increasing returns to scale is

$$D(y^j, x^j) = max\,\{\Psi: \Psi y^j \in S(NIRS)\} \tag{3}$$

If the observed bundle (y^j, x^j) is located below the grand production possibility frontier, the measure of estimated distance is always greater than one ($\Psi > 1$). Since the observed output multiplied by distance estimate equals the output on the grand production possibility frontier at the observed inputs level, if the observed output is located below the grand production possibility frontier, then the distance estimate should be greater than one. If the observed production combination is on the grand production possibility frontier, then the measure of estimated distance is equal to one ($\Psi = 1$) since the observed output is equal to the maximum output at the observed inputs level.

Using linear programming, I measure the distance estimate assuming non-in-

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[3] Grand production possibility set which satisfies constant returns to scale is
$S(CRS) = \{y: y \le \sum z_j y_j,\ \sum z_j x_{j,m} \le x_m,\ x,y,z \ge 0\}$

[4] Fare, Grosskopf, and Knox. (1994)

creasing returns to scale grand production possibility frontier.[5] Distance function in state j is given by:

$$
\begin{aligned}
&D(y^j, x^j) = max\,\Psi \\
&\text{s.t. } \Psi y^j \leq \textstyle\sum z^j y^j \\
&\quad \textstyle\sum z_j x_{jm} \leq x_{jm} \quad m = 1,2,\cdots\cdots M \\
&\quad \textstyle\sum z_j \leq 1 \\
&\quad z_j \geq 0, \; j = 1,2,\cdots\cdots J
\end{aligned}
\tag{4}
$$

2. Malmquist Index

To estimate the Malmquist Index, which measures multifactor productivity growth, one must first calculate output distance estimates with respect to two different time periods. The output distance estimate assuming non-increasing returns to scale grand production possibility frontier at time period t and $t+1$ is defined as follows:

$$D_t(y^j, x^j_t) = max\{\Psi: \Psi y^j \in S_t(NIRS)\} \tag{5}$$

$$D_{t+1}(y^j_t, x^j_t) = max\{\Psi: \Psi y^j_t \in S_{t+1}(NIRS)\} \tag{6}$$

$$D_t(y^j_{t+1}, x^j_{t+1}) = max\{\Psi: \Psi y^j_{t+1} \in S_t(NIRS)\} \tag{7}$$

$$D_{t+1}(y^j_{t+1}, x^j_{t+1}) = max\{\Psi: \Psi y^j_{t+1}\, z \in S_{t+1}(NIRS)\} \tag{8}$$

where $D(.)$ denotes the distance function, $j = 1,2,\cdots\cdots,J$: state indexes, S_t the Production Possibility Set in period t, S_{t+1} the Production Possibility Set at time period $t+1$, (y_t, x_t) the observed production combination at time t, and (y_{t+1}, x_{t+1}) the observed production combination at time $t+1$. Thus, equation (5) is the distance function required to make the observed production combination (y_t^j, x_t^j) in period t feasible in relation to the technology in period t. Equation (6) is the distance function required to make the observed production combination (y_t^j, x_t^j) in period t feasible in relation to the technology in period $t+1$. The other distance functions are similarly defined. Using the above four distance functions, we can define the Malmquist Index.

[5] The measure of distance estimate assuming constant returns to scale using linear programming program is

$$
\begin{aligned}
&D(y^j, x^j) = max\,\Psi \\
&\text{s.t. } \Psi y_j \leq \textstyle\sum z_j y_j, \; \sum z_j x_{jm} \leq x_{jm} \quad m = 1,2,\cdots\cdots M, \; z \geq 0, \; j = 1,2,\cdots\cdots J
\end{aligned}
$$

To avoid having the different index that results from using a different base year,[6] I will use the geometric mean of two Malmquist indexes following Fare, Grosskopf, and Knox (1994). The defined Index is

$$M = [(D_t(Y_t, X_t)/D_t(Y_{t+1}, X_{t+1}))^*(D_{t+1}(Y_t, X_t)/D_{t+1}(Y_{t+1}, X_{t+1}))]^{1/2} \tag{9}$$

This Malmquist Index shows multifactor productivity growth. That is, the distance function for each state at time t is

$$\begin{aligned} D_t(y_t, x_t) &= max\{(\Psi: \Psi y_t \leq A(t)f(x_t)\} \\ &= max\{\Psi: \Psi \leq A(t)f(x_t)/y_t\} \\ &= A(t)f(x_t)/y_t \end{aligned} \tag{10}$$

Using equation (10), the equation (9) can be changed as follows:

$$\begin{aligned} & M(y_t, x_t, y_{t+1}, x_{t+1}) \\ & = [\{D_t(y_t, x_t)/D_t(y_{t+1}, x_{t+1})\} * \{D_{t+1}(y_t, x_t)/D_{t+1}(y_{t+1}, x_{t+1})\}]^{1/2} \\ & = [\{A(t)f(x_t)/y_t\}\{y_{t+1}/A(t)f(x_{t+1})\} * \{A(t+1)f(x_t)/y_t\}\{y_{t+1}/A(t+1) \\ & f(x_{t+1})\}]^{1/2} \\ & = [(f(x_t)/y_t)(y_{t+1}/f(x_{t+1})) * (f(x_t)/y_t)(y_{t+1}/f(x_{t+1}))]^{1/2} \\ & = [f(x_t)/y_t] * [y_{t+1}/f(x_{t+1})] \end{aligned} \tag{11}$$

Using the production function given in equation (10), the above equation (11) is

$$\begin{aligned} & = [D_t(y_t, x_t)/A(t)] * [A(t+1)/D_{t+1}(y_{t+1}, x_{t+1})] \\ & = [A(t+1)/A(t)] * [D_t(y_t, x_t)/D_{t+1}(y_{t+1}, x_{t+1})] \end{aligned} \tag{12}$$

This is the multifactor productivity growth rate for each state at time t. Because Solow's growth accounting technique assumes that the observed output is optimal (efficient), the distance estimates are always equal to 1 (i.e., $D_t(y_t, x_t)=1$ and $D_{t+1}(y_{t+1}, x_{t+1})=1$). Assuming that the observed outputs are optimal (i.e., the observed output-input combination is on the grand production possibility frontier), equation (12) turns to $[A(t+1)/A(t)]$ which is equivalent to the growth of multifactor productivity from Solow's growth accounting technique. However, if the amount of multifactor used is not the same across the states, or if any of the industries in any state produces output inefficiently (i.e., $D_t(y_t, x_t)$ and $D_{t+1}(y_{t+1}, x_{t+1})$ are not equal

[6] The two Malmquist Indexes using a different year t or $t+1$ are

$$M_t = D_t(Y_t, T_t)/D_t(Y_{t+1}, X_{t+1}) \text{ or } M_{t+1} = D_{t+1}(Y_t, T_t)/D_{t+1}(Y_{t+1}, X_{t+1})$$

where M_t equals the Malmquist Index in period t. These indexes will be different because of using different base year.

to one), then the observed activity is located below the grand production possibility frontier and the Solow growth accounting index would be a biased estimate of multifactor productivity change because this method always regards $D_t(y_t, x_t)$ and $D_{t+1}(y_{t+1}, x_{t+1})$ as one. However, in equation (12), since the Malmquist Index does not assume that all input-output bundles must be technologically efficient, or that all states have the same amount of multifactor, the Malmquist Index is an alternative estimator of multifactor productivity growth.

III. THE MODEL FOR THE PUBLIC CAPITAL EFFECT ON THE REGIONAL ECONOMY

To estimate the effect of public capital on output, I use two types of production functional forms. To specify my statistical models, I use a Cobb-Douglas Production Function. The first production function, which includes public capital in the multifactor (MFP_t^1), for each state and industry at time t is specified as

$$Y_t = MFP_t^1 K_{pri,t}^{\alpha} L_t^{\gamma} \tag{13}$$

Taking the derivative with respect to time yields:

$$\frac{dY_t}{dt} = \frac{dMFP_t^1}{dt} K_{pri,t}^{\alpha} L_t^{\gamma} + \alpha MFP_t^1 K_{pri,t}^{\alpha-1} L_t^{\gamma} \frac{dK_{pri,t}}{dt} + \gamma MFP_t^1 K_{pri,t}^{\alpha} L_t^{\gamma-1} \frac{dL_t}{dt}$$

Dividing by Y_t yields:

$$\frac{\dot{Y}_t}{Y_t} = \frac{M\dot{F}P_t^1}{MFP_t^1} + \alpha \frac{\dot{K}_{pri,t}}{K_{pri,t}} + \gamma \frac{\dot{L}_t}{L_t} \tag{14}$$

where dots denote the time derivatives.

Similarly, the second production function, in which public capital is not included in the multifactor (MFP_t^2), for each state and industry at time t is specified as

$$Y_t = MFP_t^2 L_{pri,t}^{\alpha} L_{pub,t}^{\beta} L_t^{\gamma} \tag{15}$$

Taking the differential with respect to time yields:

$$\frac{dY_t}{dt}=\frac{dMFP_t^2}{dt}K^{\alpha}_{pri,t}K^{\beta}_{pub,t}L^{\gamma}_t+\alpha MFP^2_tK^{\alpha-1}_{pri,t}K^{\beta}_{pub,t}L^{\gamma}_t\frac{dK_{pri,t}}{dt}$$
$$+\beta MFP^2_tK^{\alpha}_{pri,t}K^{\beta-1}_{pub,t}L^{\gamma}_t\frac{dK_{pub,t}}{dt}+\gamma MFP^2_tK^{\alpha}_{pri,t}K^{\beta}_{pub,t}L^{\gamma-1}_t\frac{dL_t}{dt}$$

Dividing by Y_t yields:

$$\frac{\dot{Y}_t}{Y_t}=\frac{M\dot{F}P_t^2}{MFP_t^2}+\alpha\frac{\dot{K}_{pri,t}}{K_{pri,t}}+\beta\frac{\dot{K}_{pub,t}}{K_{pub,t}}+\gamma\frac{\dot{L}_t}{L_t} \tag{16}$$

Equations (14) and (16) yield the following equation:

$$\frac{M\dot{F}P_t^1}{MFP_t^1}+\alpha\frac{\dot{K}_{pri,t}}{K_{pri,t}}+\gamma\frac{\dot{L}_t}{L_t}=\frac{M\dot{F}P_t^2}{MFP_t^2}+\alpha\frac{\dot{K}_{pri,t}}{K_{pri,t}}+\beta\frac{\dot{K}_{pub,t}}{K_{pub,t}}+\gamma\frac{\dot{L}_t}{L_t} \tag{17}$$

Rearranging terms yields

$$\frac{M\dot{F}P_t^1}{MFP_t^1}-\frac{M\dot{F}P_t^2}{MFP_t^2}=\beta\frac{\dot{K}_{pub,t}}{K_{pub,t}} \tag{18}$$

For each state and industry at time t, β gives the output elasticity of public capital. Since I can estimate two types of multifactor productivity growths ($\frac{M\dot{F}P_t^1}{MFP_t^1}$ and $\frac{M\dot{F}P_t^2}{MFP_t^2}$) using the Malmquist Index and I have each type of public capital growth data, I can estimate the output elasticity of public capital for each public capital and industry via equation (18). If $\beta>0$, then an increase in public capital growth results in an increase in output and multifactor productivity.

IV. DATA AND THE ESTIMATION OF MULTIFACTOR PRODUCTIVITY GROWTH

The data consists of 18 annual observations from 1969 to 1986 for the 48 states[7] on output, total employment, private capital for each industry, and each public capital. All the data are measured in 1982 constant dollars. I decompose total industry into three sub-industries: agriculture, manufacturing, and non-farm, non-manufacturing.[8] I use gross state product (GSP) as a measure of output for each industry. Employment is measured as the average annual number of jobs. The source for

[7] Alaska, Hawaii, and District of Columbia are excluded.

[8] The non-farm and non-manufacturing is composed of mining, construction, transportation, communication, public utilities, wholesale trade, retail trade, finance, insurance, real estate, and services.

GSP and employment data is the Bureau of Economic Analysis at the Department of Commerce. Since the stock of private capital and public capital data is not available at the state level, it is necessary to disaggregate the national total data published by Bureau of Economic Analysis. I used Munnell's data for data on private capital. She calculated private capital by apportioning BEA national stock estimates of various sectors among the states.[9] The public capital data I used comes from Douglas Holtz-Eakin's works. He calculates estimates of aggregate capital accumulation and capital for each specific governmental function: education, highways and streets, sewerage, and utilities. The data to estimate for each type of public capital is taken from Governmental Finances and State Governmental Finances which provide data on annual investment flows for each state. Using the annual investment flows, Holtz-Eakin estimated each capital stocks with the perpetual inventory technique.[10]

1. The estimation of multifactor productivity in each industry

In this section, I estimate multifactor productivity and compare my estimates with existing ones. Using equation (13) and (15), I estimate multifactor productivity growth rate for each production function over 18 years for 48 states. For each industry, the average multifactor productivity growth rates over the states for the two sub-periods are shown in Table 1. Each estimate is the average multifactor productivity growth rate for each sub-period. In this table, multifactor productivity growth rates are measured with non-increasing returns to scale production function.[11] $MFPGR^1$ is the multifactor productivity growth rate including total public capital in the multifactor (i.e., including the contribution of public capital to multifactor productivity growth), $MFPGR_{pub}^2$ is the multifactor productivity growth rate excluding public capital from the multifactor (i.e., excluding the contribution of public capital from the multifactor productivity growth rate). The second and third columns indicate average multifactor productivity growth rates for each period. $\Delta MFPGR$ shows the difference of % multifactor productivity growth over two period in the fourth column. Thus, $\Delta MFPGR^1 - \Delta MFPGR^2_{pub}$ shows the effect of public capital on the multifactor productivity growth. The difference of % public capital growth over two period are in sixth column in the table. The multifactor productivity growth rate decreased by 0.16 in total industry when the growth rate of total public capital decreased by 1.22 in this period. Thus, in the analysis using the average estimates which were used by previous works, the relationship between the growth of total public capital and the multifactor productivity growth is positive and supports the

[9] The detail explanation of the private capital is in Munnell (1990b).

[10] The detail explanation of the public capital is in Douglas Holtz-Eakin (1991).

[11] The estimates assuming constant returns to scale are similar to those assuming non-increasing returns to scale.

Table 1. Average Multifactor Productivity Growth Rates and the effect of public capital on multifactor productivity growth in *NIRS* production

$MFPGR$	69-78	79-86	$\Delta MFPGR$	$\Delta MFPGR^1$ $\Delta MFPGR^2_{pub}$	ΔKGR_{pub}
Total Industry					
$MFPGR^1$	0.91	0.45	−0.46	−0.16	−1.22
$MFPGR^2_{pub}$	0.91	0.61	−0.30		
Agriculture					
$MFPGR^1$	−0.42	8.22	8.64	0.03	−1.22
$MFPGR^2_{pub}$	−0.75	7.86	8.61		
Manufacturing					
$MFPGR^1$	1.68	2.50	0.82	0.08	−1.22
$MFPGR^2_{pub}$	1.44	2.18	0.74		
Non-farm, non-manufacturing					
$MFPGR^1$	0.24	−0.38	−0.62	0.01	−1.22
$MFPGR^2_{pub}$	0.47	−0.16	−0.63		

results of Munnell (1990a).[12]

In manufacturing, all the average multifactor productivity growth rates increased over the periods. From the fifth and sixth, the relationship between the growth of total public capital and the multifactor productivity growth are negative and supports the results of Hulten and Schwab (1991).

Thus, even though the papers mentioned earlier show different results on the output effect of public capital, my results reconcile the previous results which are derived using Solow's growth accounting technique. Previous works found different results because they estimate the effect of public capital on the multifactor productivity with different sector and method.[13]

However, the problem of this method with previous research is that they use average growth rates to analyze the effect of public capital. Since the average relationship may be different from the true relationship, the results may be biased. Second, much research tested the effect of public capital on the multifactor productivity

[12] Munnell showed that the contribution of total public capital on multifactor productivity of private non-farm business sector.

[13] Hulten and Schwab (1991) concluded that the effect of public capital is not a key determinant of productivity growth in manufacturing. However, Munnell (1990a) showed that there is positive contribution of public capital on multifactor productivity of the private non-farm business sector. Both of these results may be true if the effect of public capital on productivity in the manufacturing is insignficant while this effect on productivity in other industries except manufacturing is large and positive.

growth by comparing the growth rate of public capital and the multifactor productivity growth affected by all the factors. If we do not use the multifactor productivity growth affected only by public capital, the test misrepresents the true contribution of public capital on this growth. The last problem is that previous work used aggregate data even though there is substantial variation across industries in productivity changes intensity of public capital and in the types of public capital used. Thus, to test for a more exact effect, I disaggregate the economy into three sectors as agriculture, manufacturing, non-farm, non-manufacturing. In addition to this disaggregation, I also disaggregate public capital into four types as education, highways and streets, sewerage, utilities capital because the effect of each public capital is different.

V. THE ESTIMATION OF PUBLIC CAPITAL EFFECT ON THE REGIONAL ECONOMY

In this section I estimate the output elasticity of each type of public capital in each industry using equation (18) which can solve the problems of previous research. To estimate the effect of each public capital on the output in each industry, I run regressions which control for unobserved, state-specific characteristics and business cycle fluctuations using state and time dummies[14] for each case.

Table 2 shows the output elasticity of each type of public capital in each industry. The output elasticity of total public capital in total industry is 0.28 and significant. This result supports Munnell's result even though the estimated coefficient is a little less than hers (0.37-0.49). Since Munnell did not control for the state-specific characteristics, as Douglas Holtz-Eakin (1994) pointed out, the magnitude of the estimated coefficient may be exaggerated by those characteristics. But contrary to Douglas Holtz-Eakin's results (1994), the magnitude decrease of output elasticity is minor instead of closing to zero. When I estimate the output elasticities of each type of public capital in each industry, the magnitudes of estimated output elasticities decreases[15] and are different among each type of public capital. The output elasticities of highways and utilities are near zero while the output elasticities of sewerage and education are positive.

In agriculture, the direct effect of total public capital decreases much compared with that in total industry and the estimated output elasticity is statistically insignificant. In the decomposed public capital analysis, the effects of highways and streets and sewerage capitals are a little larger while the effects of education and utilities capitals are near zero.

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[14] As previous research like Douglas Holtz-Eakin pointed out, I find that these two factors affect on the estimates of output elasticity of each public capital.

[15] The change of public capital will affect the output in all industries and this output change in one industry will affect on the output in other industries again. However, in disaggregate analysis, when the output elasticity in each industry is measured, the effect of other industries' outputs on the output change is excluede. That is, the output elasticity in this analysis measure only the direct effect of public capital and so, the output elasticity of each industry is less than that in total industry. The estimate of output elasticity is affected only by public capital.

Table 2. The elasticity of each public capital

	Tot. Pub. Cap.	Highways	Sewerage	Education	Utility
Total Industry	0.28 (8.98)	0.06 (4.42)	0.29(26.39)	0.25 (10.92)	0.05 (5.88)
Agriculture	0.05 (1.00)	0.10 (3.05)	0.10 (6.63)	0.04 (1.27)	0.07 (2.66)
Manufacturing	0.12 (2.84)	0.08 (2.64)	0.23 (15.17)	0.11 (4.28)	0.04 (2.73)
NFM	0.20 (7.91)	0.04 (3.21)	0.28 (22.19)	0.18 (9.96)	0.05 (5.97)

* The figures in parentheses are t-statistics

In Manufacturing, even though the estimated elasticity of total public capital on output decreases, this result shows a positive effect of public capital on output which is different from the results of Hulten and Schwab (1991) and Eberts (1990b) which showed the insignificant effect of public capital on output . As I elaborated in the last section, they estimate the contribution of public capital growth rate on multifactor productivity growth rate using the average multifactor productivity growth rate affected by all multifactor including average total public capital growth. I corroborated their results when I use an average growth rate effect which they used to test the link between the growth rate of public capital and multifactor productivity growth rate. However, when I estimate the output elasticity of total public capital using the fitted regression line, the estimated output elasticity is positive and significant. Thus, their results may be biased because they test the effect using an average effect. In the sub-public capital analysis, the effect of sewerage is biggest among all public capitals and the rest of public capitals have smaller estimated elasticities. In non-farm, non-manufacturing, the estimated elasticity of total public capital on output is largest in this industry compared to the agriculture and manufacturing. The effects of sewerage and education capitals are larger while the effects of highways and streets and utilities capitals are smaller in this industry.

IV. CONCLUSION

In this paper, I disaggregate the multifactor productivity growth rate. Using this disaggregated growth rate, I estimate the output elasticity of each public capital in each industry. In the test of the effect of total public capital on output in total industry, the estimated output elasticity is large and significant. However, in the disaggregated industry analysis, the estimated direct output elasticity decreases greatly.[16] The output elasticity of total public capital is largest in the non-farm and non-manufacturing while it is smallest in agriculture. In the analysis of each type of public capital, the output elasticity of highways and streets capital in total indus-

[16] This result shows that the output change in one industry positively affect on the output on the change in other industries.

try is small. In the analysis of the effect of this capital in each industry, I find larger output elasticity in agriculture compared with manufacturing and non-farm and non-manufacturing.[17] The estimated output elasticity of sewerage capital on output in total industry is largest among all public capitals and it is largest in non-farm and non-manufacturing. The effect of education capital on output in total industry is large. However, the effect of this capital for each industry is decreases greatly. The estimated output elasticity of utilities capital in total industry is small and the estimated results for each industry are similarly small. Therefore, the results I estimated suggest some points. First, the output elasticity of public capital is positive and significant, and thus, results from previous research which show small and insignificant effect of total public capital on output using Solow's technique may come from using biased average growth rates or focusing a specific industry (manufacturing). Second, since my results show that the estimated output elasticity of decomposed public capital and industry is absolutely different from the estimated results using aggregate public capital and total industry, to estimate the exact contribution of each public capital on output, we need to use disaggregate data as much as possible.

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[17] This result does not mean that the amount of output increase in agriculture is largest. It just shows that the % increase is largest among all industry.

REFERENCES

Aschauer, David Alan. "Is Public Expenditure Productive?," *Journal of Monetary Economics*, 23(2), March 1989.

——— "Why is Infrastructure important?," in Alicia H. Munnell(ed.) *Is There a Shortfall in Public Capital Investment?*. Federal Reserve Bank of Boston, 1990.

——— "Is Government Spending Stimulative?," FRB Chicago Staff Memorandum, 1989.

Caves, Douglas W; Christensen, Laurits R; Diewert, W. Erwin. "Multilateral Comparisons of Output, Input, and Productivity using Superlative Index Numbers," *The Economic Journal*, 92, March 1982.

Caves, Douglas W; Christensen, Laurits R; Diewert, W. Erwin. "The Economic Theory of Index Numbers and The Measurement of Input, Output, and Productivity," *Econometrica*, Vol. 50, No.6, Nov. 1982.

Eberts, Randall W. "Estimating the Contribution of Urban Public Infrastructure to Regional Growth," FRB Cleveland Working Paper 8610, Dec. 1986.

——— "Public Infrastructure and Regional Economic Development," *FRB Cleveland Economic Review*, 1990a.

——— "Cross-sectional Analysis of Public Infrastructure and Regional Productivity Growth," FRB Cleveland Working Paper 9004, 1990b.

Fare, Rolf; Grosskopf, Shawna; Norris, Mary and Zhang, Zhongyang. "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries.," *American Economic Review*, 84(1), march 1994.

Fare, Rolf; Grosskopf, Shawna and Lovell C.A. Knox, *Production Frontiers*, Cambridge : Cambridge University Press, 1994.

Garcia-Mila, Teresa, and Therese J. McGuire, "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*, 22, June 1992.

Gramlich, Edward M, "Infrastructure Investment : A Review Essay" *Journal of Economic Literature*, Vol.32, Sep. 1994.

Holtz-Eakin, Douglas, "State-Specific Estimates of State and Local Government Capital," *Regional Science and Urban Economics*, 23, 1993.

——— "Public-Sector Capital and The Productivity Puzzle," *Review of Economics and Statistics*. Vol. 76, 1994.

Hulten, C. R. and Schwab, R. M., "Public Capital Formation and the Growth of Regional Manufacturing Industries," *National Tax Journal*, 44, 1991.

Munnell, Alicia, "Why Has Productivity Growth Declined?," *Productivity and Public Investment*, New England Economic Review, Jan-Feb, 1990a.

——— "How does Public Infrastructure Affect Regional Economic Performance?," in Alicia Munnell, ed., *Is There a Shortfall in Public Capital Investment?*. Federal Reserve Bank of Boston, 1990b.

Solow, Robert M., "Technical Change and The Aggregate Production Function," *Review of Economics and Statistics*, 39(3), August 1957.