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What Type of Public Capital Contributes to Private Production?

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What Type of Public Capital Contributes to Private Production?*

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[Abstract]: The main purpose of this study is to determine whether public capital contributes to productivity growth and, if so, what kind of public capital contributes most. We analyze a data set of 46 prefectures in Japan over 41 years, from 1955 to 1995, and estimate the production function as the first-differenced form. In the case where analysis was conducted using aggregate public capital, public capital shows a positive contribution to private production. However, we could find no clear productivity effects when using smaller components of public capital.

[JEL Classification] H50, H54, R53

[Key Words] Public Capital, Productivity Effect, Infrastructure, Spill-over Effect

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1. Introduction

Because recent investment in infrastructure has apparently failed to stimulate economic growth, there has lately been increasing interest in the issue of whether or not public capital contributes to the productivity level of the private sector. Critics of investing in the formation of public capital contend that such spending does not promote economic growth because it is concentrated in underdeveloped regions which have little impact on the growth of economic activity. Indeed, recent empirical studies show that the productivity effects of public capital on private economic activities are small or even negative. However, because we believe that previous studies have shortcomings, we think it is too early to state with certainty that public capital does not contribute to private production. The issue cannot be settled until the following problems with previous studies are addressed: 1) inappropriate estimation resulting in a multicollinearity problem and serial correlation and so on; 2) inappropriate or insufficient classification of public capital (e.g. failure to subdivide public capital by type); and 3) failure to take into account spill-over effects. The existence of such problems may lead to variant results when the productivity effect of public capital is analyzed.

The main purpose of our study is to find out whether or not public capital aids production in the private sector. Moreover, if we can subdivide public capital into several components, we aim to accomplish the further goal of evaluating what type of public capital contributes most. We also evaluate the spill-over effects of public capital. In order to accomplish our study, we first survey the many previous studies on this topic which have been published since the 1970s, at least 24 studies from both the U.S. and Japan appearing in international journals, Japanese journals and books. In order to clarify the methodology and productivity effects of public capital, we summarize the characteristics of these previous studies. Second, because some data are not publicly available, we construct a data set of public capital and related variables. In

this study, because the basic unit for data is the prefecture, we have compiled certain data from existing sources, so that all variables are summarized for 46 prefectures over 41 years, from 1955 to 1995 in Japan, making the total sample size in this study 1886. Third, after constructing the data set, we use a raw data set to obtain an overview of the regional distribution of public capital over 40 years and the relationship between public capital and production in the private sector. Last, we estimate the aggregate regional production function and evaluate whether or not public capital contributes to production and if so, what type of public capital contributes most to productivity for each prefecture. We also evaluate the spill-over effects of public capital into neighboring prefectures.

2. Related Previous Studies

As summarized in Table 1, there already exist many studies in both the U.S. and Japan which evaluate to what extent public capital contributes to the private sector's production. Most studies treat public capital as one input factor of the production function along with labor and energy, and they directly estimate the production function of aggregate products of the private sector by using empirical data sets. Other studies, such as Lynde and Richmond (1992), Morrison and Schwartz (1996), and Nadiri and Mamuneas (1994) estimate cost function rather than production function in their evaluation of the productivity effects of public capital. Here, we outline the previous studies, mainly focusing on those which use the production function. First, two kinds of functional form are most commonly used: the Cobb-Douglas function and the translog function. Many studies employed the Cobb-Douglas function, such as Ratner (1983), Ashauer (1989), Munnell (1990), Garcia-Milla (1992), Evans and Karras (1994), Holtz-Eakin (1994), Vijverberg, et al. (1997) in the U.S., and Mera (1973), Iwamoto (1990), Asako, et al. (1994), Mitsui, et al. (1995), Iwamoto et al. (1996), Yamamoto and Ohkawara (2000) and

Tanaka (2000) in Japan. The translog function is used in studies such as Cost et al. (1987), Merriman (1990), Yoshino and Nakano (1994), Doi (1998) and Yoshino and Nakajima (1999). The Cobb-Douglas function is used most because it is amenable to estimation and easily pinpoints the importance of individual effects on productivity, the functional form being expressed as log-linear form. However, the Cobb-Douglas function has the strong disadvantage of restricting the functional form (e.g. assuming that the elasticity of substitution between inputs is one). Because the translog function has the second-order and the cross effects of variables, the translog function is considered the more flexible form, allowing us to evaluate the complement and substitution effect between public and private capital in addition to the productivity of public capital. However, the disadvantage of the translog function is that because of its many variables we need a large sample size and there are possible estimation concerns, such as the occurrence of the multicollinearity problem.

As for data set and estimation methods, in the early stages of this kind of study, time-series data sets for the entire country have been most commonly used, and such studies have mostly shown positive productive effects of public capital (e.g. Ratner (1983) and Aschauer (1989)). When studies use a pooling data set of cross section (regional) data and a time-series data set, they usually conclude that public capital contributes to private production (e.g. Munnell (1990) and Duffy-Deno and Eberts (1991)). However, in more recent years, when a region-specific fixed effect on production was considered, panel data sets using both cross sections of states in the U.S. (prefectures in Japan) and time-series have become common. When studies use panel data sets when considering region-specific fixed effects, the results may differ: some studies conclude that public capital has positive effects on private production (e.g. Merriman (1990) and Yamano and Ohkawara (2000)), but other studies suggest that public capital does not contribute to private production (e.g. Holtz-Eakin (1994) and Evans and Karras

(1994)). Garcia-Mila, McGuire and Porter (1996) tested the effect of public capital for various specifications by using a panel data set for the 48 states from 1970 to 1983. They found that public capital is not significant in the specification of first differences with fixed state effects, which is the preferred specification, while public capital is significant when panel data sets with the fixed state effects were used .

To select one aggregate public capital was the most common method used in early studies on this subject (e.g. Ratner (1983), de Silva Cost (1987)). However, since around the early 1990s, public capital has been disaggregated into its component parts, with, for example, Garcia-Mila and McGuire (1992) disaggregating it into two components (Highway and Education). Munnell (1990) and Evans and Karras (1994) used three components (Highway, Water Supply and Disposal, and Others). In Japan, since the first study dividing into four components (Agriculture, Industry, Transportation, Telecommunication and General Welfare) by Mera (1974), considerable time elapsed until other studies appeared with multiple components: Mitsui, et al. (1995) disaggregated into two (Core Infrastructure and Non-Core Infrastructure). Also, Ida and Yoshida (1999) disaggregated public capital into six components (Industry, Living, Environment, Education, Agriculture and Land Security).

The estimation results of public capital on productivity vary according to different studies. In the U.S., Munnell (1990) and Garcia-Mila and McGuire (1992) find that some components of public capital such as Highway, Water Supply and Disposal, and Education are positive and make a statistically significant contribution to private production. On the other hand, Evans and Karras (1994) show the quite different result that while the public capital of education is productive no evidence exists that other government activities aid private production. In Japan, Mitsui et al. (1995) show that core infrastructure of public capital makes a positive contribution but that non-core infrastructure is not significant. Ida and Yoshida

(1999) show that public capital such as industry, living, and environment are positive but public capital such as education and land security make a negative contribution.

In conclusion, results are not concrete and estimation bias exists in previous studies. Therefore, it remains to be seen whether public capital truly contributes to private production and, if so, what components of public capital are most beneficial.

Table 1 Summary of Previous Studies on Productivity of Public Capital

Study	Data	Model	Kinds of Public Capital	Productivity Effects of Public Capital	Spill-over Effects
Mera (1973)	1954-63 for 9 regions: Japan	Cobb-Douglas: Pooling	4 (Agriculture, Industry, Transportation, Telecommunication & General Welfare)	0.258-0.279 (primary sector) -0.456 - -0.347 (secondary sector) 0.508-1.169 (tertiary sector)	-
Ratner (1983)	1949-73 for whole country: US	Cobb-Douglas: Time Series	1 aggregate public capital	0.058	-
de Silva Costa et al. (1987)	1972 for 48 states: US	Translog: Cross Section	1 aggregate public capital	0.189-0.259	-
Aschauer (1989)	1949-85 for whole country: US	Cobb-Douglas: Time Series	1 aggregate nonmilitary public capital & 2 (core-infra & non-core infra)	0.390-0.360 (aggregate) 0.240 (core-infra) *** (non-core infra)	-
Munnell (1990)	1970-86 for 48 states	Cobb-Douglas: Pooling	1 aggregate public capital & 3 (Highway, Water Supply & Disposal, Others)	0.060-0.150 (aggregate) 0.060 (Highway) 0.120 (Water) *** (Others)	-
Merriman (1990)	1972 for 48 states: US 1954-63 for 9 regions: Japan	Translog: Time Series for US & Panel for Japan	1 aggregate public capital	0.200 (US) 0.430-0.580 (JPN)	-
Iwamoto (1990)	1955-84 for whole country: Japan	Cobb-Douglas: Time Series	1 aggregate public capital	0.238-0.408	-
Duffy-Deno and Eberts (1991)	1980-84 for 28 SMSAs: US	log-linear: Pooling	1 aggregate public capital	0.081	-
Garcia-Mila and McGuire (1992)	1969-83 for 48 states: US	Cobb-Douglas: Panel	2 (Highway & Education)	0.044-0.045 (Highway) 0.072-0.165 (Education)	-

Evans and Karras (1994)	1970-86 for 48 states: US	Cobb-Douglas: Panel	1 aggregate public capital & 3 (Highway, Water Supply & Disposal, Others)	-0.110 (aggregate) -0.061 (Others)	-
Holtz-Eakin (1994)	1969-86 for 48 states & 8 regions: US	Cobb-Douglas: Panel	1 aggregate public capital	***	-
Asako et al. (1994)	1975-88 for 46 prefectures: Japan	Cobb-Douglas: Cross Section, Pooling & Panel	1 aggregate public capital	0.228 (Panel) 0.156 (Pooling)	-
Yoshino and Nakano (1994)	1975-84 for 9 regions: Japan	Translog: Panel	1 aggregate public capital	0.161	-
Holtz-Eakin and Schwartz (1995)	1975-86 for 48 states: US	Cobb-Douglas: Panel	Highway	***	Not Exist spill-over
Mitsui, Takezawa and Kawachi (1995)	1966-84 for 46 prefectures: Japan	Cobb-Douglas: Pooling	1 aggregate public capital	0.147 (self-prefecture) 0.106 (other-prefecture)	Exist spill-over effects
Mitsui, Inoue and Takezawa (1995)	1956-89 for whole country: Japan	Cobb-Douglas: Time Series	2 (core-infra & non-core infra)	0.172 (core infra) *** (non-core infra)	-
Ohkawara and Yamano (1995)	1976-91 for 47 prefectures: Japan	Cobb-Douglas & modified Cobb-Douglas: Cross Section	1 aggregate public capital	-0.279 (Cobb-Douglas) -0.236 - 0.267 (modified Cobb-Douglas)	-
Garcia-Mila et al. (1996)	1970-83 for 48 states: Japan	Cobb-Douglas: Panel	1 aggregate public capital & 3 (Highway, Water Supply & Disposal, Others)	***	-
Iwamoto et al. (1996)	1966-88 for 46 prefectures: Japan	Cobb-Douglas: Panel	1 aggregate public capital	-0.170 - 0.330	-
Vijverberg et al. (1997)	1958-89 for whole country: US	Cobb-Douglas & modified Cobb-Douglas: US	2 (Federal government capital & State government capital)	0.465-0.550 (Cobb-Douglas, State)	-
Doi (1998)	1968-93 for 46 prefectures: Japan	Translog: Japan	1 aggregate public capital	-0.082 (1966-93) 0.254 (1985-93) 0.131 (1966-74)	-
Ida and Yoshida (1999)	1955-82 at intervals of 5 year for 46 prefectures: Japan	Cobb-Douglas: Japan	6 (Industry, Life, Environment, Education, Agriculture & National land security)	0.152-0.347 (Industry) 0.123-0.306 (Life) 0.019-0.039 (Environment) -0.305 - -0.263	-

				(Education) -0.057 (National land security)	
Yoshino and Nakajima (1999)	1975-94 for 11 regions: Japan	Translog: Panel	1 aggregate public capital	0.048-0.242	-
Tanaka (2000)	1976-93 for 39 prefectures: Japan	Cobb-Douglas: Panel	1 aggregate public capital	0.095	-
Yamano and Ohkawara (2000)	1975-94 for 47 prefectures: Japan	Cobb-Douglas: Panel	1 aggregate public capital	0.148	-

(Note): The mark of “***” means that this factor is not statistically significant.

3. Empirical Model

3.1 Model of Regional Production Function

In this study, we assume that the production function is a function of five input factors: labor of private sector (L), private capital (K), regional technology (T), public capital stock (G) and time trend (t). The characteristics of the specification of the production function are as follows. First, other factors such as public capital and technology are assumed to be separate from labor and private capital stock of the private sector. The production function is assumed to be the Cobb-Douglas function of labor, private capital stock of the private sector, and other factors. The production function is assumed to be homogeneous of degree one for two inputs of the private sector (i.e. labor and private capital stock). Second, as for public capital stock, we consider the spill-over effect for public capital stock into neighboring prefectures, following the example of Holtz-Eakin and Schwartz (1995) and Mitsui et al. (1995). Therefore, we include the public capital stock of neighboring prefectures (S). Third, we divide public capital stock into several categories. In the next section, we explain the details of the definition. Finally, we assume that there is a prefecture-specific technology level, which does not vary with time.

$$Y_{it} = L_{it}^{\beta_L} K_{it}^{\beta_K} g(T_i, t, \mathbf{G}_{it}, \mathbf{S}_{it}), \quad (1)$$

where $\beta_L + \beta_K = 1$.

Y_{it} : Aggregate prefectural product of private sector in year t and prefecture-i,

L_{it} : Labor input of private sector in year t and prefecture-i,

K_{it} : Private capital stock in year t and prefecture-i,

T_i : Prefecture-specific technology in prefecture-i,

\mathbf{G}_{it} : Public capital stock in year t and prefecture-i,

\mathbf{S}_{it} : Spill-over effects in year t and prefecture-i from neighboring prefectures' public capital stock

i : Prefecture,

t : Time trend.

And a function of combined technology level is assumed to be as follows:

$$g(T_i, t, \mathbf{G}_{it}, \mathbf{S}_{it}) = T_i \exp(\tau t) k(\mathbf{G}_{it}, \mathbf{S}_{it}) \quad (2)$$

We also consider three kinds of effects of public capital stock: (i) without spill-over effects from neighboring prefectures, (ii) with separated spill-over effects, (iii) with combined spill-over effects. That is,

$$\text{(without spill-over effects):} \quad k(\mathbf{G}_{it}, \mathbf{S}_{it}) = \prod_j (G_{it}^j)^{\gamma_j} \quad (3a)$$

$$\text{(with separated spill-over effects):} \quad k(\mathbf{G}_{it}, \mathbf{S}_{it}) = \prod_j (G_{it}^j)^{\gamma_j} \prod_k (S_{it}^k)^{\delta_k} \quad (3b)$$

$$\text{(with combined spill-over effects):} \quad k(\mathbf{G}_{it}, \mathbf{S}_{it}) = \prod_j (G_{it}^j + S_{it}^j)^{\gamma_j} \quad (3c)$$

Substituting equation-(3a), (3b) and (3c) into equation-(1) and (2) and taking natural logarithm, we can obtain the following equation.

$$\ln Y_{it} = \beta_L \ln L_{it} + \beta_K \ln K_{it} + \ln T_i + \sum_j \gamma_j \ln G_{it}^j + \tau t. \quad (4a)$$

$$\ln Y_{it} = \beta_L \ln L_{it} + \beta_K \ln K_{it} + \ln T_i + \sum_j \gamma_j \ln G_{it}^j + \sum_k \delta_k \ln S_{it}^k + \tau t. \quad (4b)$$

$$\ln Y_{it} = \beta_L \ln L_{it} + \beta_K \ln K_{it} + \ln T_i + \sum_j \gamma_j \ln (G_{it}^j + S_{it}^j) + \tau t. \quad (4c)$$

3.2 Estimation Models

When we review the original data set, we find a gap between before and after the oil shock in 1974, indicating the possibility that the structure of economic activity changed after oil shock. Therefore, the original models shown in equation-(4a), (4b) and (4c) can be modified by including dummy variable after oil shock in 1974. Furthermore, when we look into the relationship between the productivity level and public capital stock, we find no clear positive relationship since 1965. In fact, around 1965, public capital development policy may have changed. The modified models are shown as follows:

$$\ln Y_{it} = \beta_L \ln L_{it} + \beta_K \ln K_{it} + \ln T_i + \sum_j (\gamma_j + \gamma_{j65} D_{65}) \ln G_{it}^j + (\tau + \tau_{74} D_{74}) t, \quad (5a)$$

$$\ln Y_{it} = \beta_L \ln L_{it} + \beta_K \ln K_{it} + \ln T_i + \sum_j (\gamma_j + \gamma_{j65} D_{65}) \ln G_{it}^j + \sum_k (\delta_k + \delta_{k65} D_{65}) \ln S_{it}^k + (\tau + \tau_{74} D_{74}) t, \quad (5b)$$

$$\ln Y_{it} = \beta_L \ln L_{it} + \beta_K \ln K_{it} + \ln T_i + \sum_j (\gamma_j + \gamma_{j65} D_{65}) \ln (G_{it}^j + S_{it}^j) + (\tau + \tau_{74} D_{74}) t, \quad (5c)$$

where D_{74} : oil shock dummy (year after 1974 $D_{74} = 1$, otherwise $D_{74} = 0$).

D_{65} : economic condition dummy (year after 1965 $D_{65} = 1$, otherwise $D_{65} = 0$).

When we conduct the preliminary analysis by using a panel data set, we cannot clear up estimation problems, especially the serial correlation problem. Therefore, we abandon the idea of accomplishing direct estimation with a panel data set. In order to avoid the serial correlation problem by direct estimation of the production function, we used the first-difference

form of the function, defined as follows: $\Delta \ln Y_{it} = \ln Y_{it} - \ln Y_{it-1}$, $\Delta \ln L_{it} = \ln L_{it} - \ln L_{it-1}$, $\Delta \ln K_{it} = \ln K_{it} - \ln K_{it-1}$, $\Delta \ln G_{it}^j = \ln G_{it}^j - \ln G_{it-1}^j$, $\Delta \ln S_{it}^k = \ln S_{it}^k - \ln S_{it-1}^k$, $\Delta \ln(G_{it}^j + S_{it}^k) = \ln(G_{it}^j + S_{it}^k) - \ln(G_{it-1}^j + S_{it-1}^k)$. Therefore, the first-differenced form of production functions is obtained as follows from equation-(5a), (5b) and (5c):

$$\Delta \ln Y_{it} = \alpha_L \Delta \ln L_{it} + \beta_K \Delta \ln K_{it} + \sum_j (\gamma_j + \gamma_{j65} D_{65}) \Delta \ln G_{it}^j + \tau + \tau_{74} D_{74}. \quad (6a)$$

$$\Delta \ln Y_{it} = \alpha_L \Delta \ln L_{it} + \beta_K \Delta \ln K_{it} + \sum_j (\gamma_j + \gamma_{j65} D_{65}) \Delta \ln G_{it}^j + \sum_k (\delta_k + \delta_{k65} D_{65}) \Delta \ln S_{it}^k + \tau + \tau_{74} D_{74}. \quad (6b)$$

$$\Delta \ln Y_{it} = \alpha_L \Delta \ln L_{it} + \beta_K \Delta \ln K_{it} + \sum_j (\gamma_j + \gamma_{j65} D_{65}) \Delta \ln(G_{it}^j + S_{it}^j) + \tau + \tau_{74} D_{74}. \quad (6c)$$

As for the components of public capital, we use three cases: 1 component, 3 components, or 6 components based on classification by the government, as Table 2 shows. First, in the case of 6 components, public capital is divided into (1) Transport (e.g. roads, ports and airports, railroads), (2) Telecommunications (e.g. telephones, postal service), (3) Agriculture (e.g. agriculture, forestry and fishing facilities), (4) Public housing, parks and water facilities, (5) Education (e.g. schools, museums and cultural activity buildings), (6) Land security (e.g. dams and banks). Second, in the case of 3 components, public capital is consolidated into three from six: (1) Industry (including Transport, Telecommunications and Agriculture), (2) Living environment (including Education and Public housing), (3) Land security, which is the same as for the six-component case.

Table 2 Definition of public capital stock and spill-over effect

Number of components	Definition of public capital stocks and spill-over effects
1 component (j and k = 1)	Aggregate ($G^{IN}: G^{TR} + G^{TL} + G^{AG} + G^{HW} + G^{SC} + G^{LS}$, $S^{IN}: S^{TR} + S^{TL} + S^{AG} + S^{HW} + S^{SC} + S^{LS}$)
3 components (j and k = 3)	Industry ($G^{IN}: G^{TR} + G^{TL} + G^{AG}$, $S^{IN}: S^{TR} + S^{TL} + S^{AG}$), Living environment ($G^{LE}: G^{HW} + G^{SC}$, $S^{LE}: S^{HW} + S^{SC}$), Land security (G^{LS} , S^{LS})
6 components (j and k = 6)	Transport (G^{TR} , S^{TR}), Telecommunications (G^{TL} , S^{TL}), Agriculture (G^{AG} , S^{AG}), Public housing, parks and water facilities (G^{PU} , S^{PU}), Education (G^{SC} , S^{SC}), Land security (G^{LS} , S^{LS})

4 Data

In this study, all variables are summarized based on prefectures over a period of the 41 years from 1955 to 1995. Although there are 47 prefectures in Japan, we use 46 prefectures, excluding Okinawa because it is not easy to obtain data for Okinawa during the U.S. occupation. Therefore, the total sample size for this study is 1886.

The variables used in this study are defined as follows and the statistical information for the variables is summarized in Table 3. First, the figure for gross prefecture products of the private sector (Y_{it}) is obtained from gross prefecture products under the item “industry” in the statistical data sources, *Annual Report on Prefectural Accounts (Kenmin Keizai Keisan Nenpo)* and *Report on Prefectural Accounts from 1955 to 1974 (Chouki Sokyū Suikei Kenmin Keizai Keisan Hokoku)* issued by the Economic Planning Agency.

Second, labor input (L_{it}) is defined here as total working hours, measured by the number of total employees times the total annual working time per person.

Third, capital stock of the private sector (K_t) is defined as the sum of capital stock in ten industries: (1) agriculture, forest and fishing, (2) mining, (3) construction, (4) manufacturing, (5) public utilities (electric power, gas, water supply and heat supply, (6) transport and telecommunications, (7) wholesale and retail, (8) banking and insurance, (9) real estate, and (10) service industry. Although the Economic Planning Agency reported each prefecture’s capital stock of the private sector from 1953 to 1963, there is no data for this measure, compelling us to estimate the capital stock of the private sector based on available data. The estimation of each prefecture’s capital stock is allocated from the national capital stock of the private sector according to the weight of the prefecture. Capital stock was explained in the previous section.

Table 3 Statistics of Selected Variables

Variable	Unit	Mean	Standard Deviation	Maximum	Minimum
Y_{it} (Gross prefecture products of private sector)	Billion yen	4,910	8,298	86,741	231
L_{it} (Labor input of private sector)	Ten thousand person-hour	264	260	1,890	68
K_{it} (Private capital)	Billion yen	6,821	11,754	141,559	192
G_{it}^{TR} (Public capital: Transport)	Billion yen	1,691	2,243	19,747	55
G_{it}^{TL} (Public capital: Telecommunications)	Billion yen	379	650	7,320	4
G_{it}^{AG} (Public capital: Agriculture)	Billion yen	630	944	12,034	12
G_{it}^{PU} (Public capital: Public housing, parks and water facilities)	Billion yen	768	1,446	14,843	8
G_{it}^{SC} (Public capital: Education)	Billion yen	511	692	7,375	38
G_{it}^{LS} (Public capital: Land security)	Billion yen	504	563	6,388	9
G_{it}^{IN} (Public capital: Industry)	Billion yen	2,700	3,522	34,810	77
G_{it}^{LE} (Public capital: Living environment)	Billion yen	1,279	2,111	22,218	51
G_{it} (Public capital: Aggregate)	Billion yen	4,483	5,932	51,190	169
S_{it}^{TR} (Spill-over effects: Transport)	Billion yen	6,394	6,835	43,740	92
S_{it}^{TL} (Spill-over effects: Telecommunication)	Billion yen	1,453	1,823	13,338	5
S_{it}^{AG} (Spill-over effects: Agriculture)	Billion yen	2,216	2,393	16,492	44
S_{it}^{PU} (Spill-over effects: Public housing, parks and water facilities)	Billion yen	3,027	4,185	31,003	12
S_{it}^{SC} (Spill-over effects: Education)	Billion yen	2,015	2,402	16,838	45
S_{it}^{LS} (Spill-over effects: Land security)	Billion yen	1,953	1,955	14,537	23
S_{it}^{IN} (Spill-over effects: Industry)	Billion yen	10,063	10,591	65,282	141
S_{it}^{LE} (Spill-over effects: Living environment)	Billion yen	5,042	6,529	47,374	59
S_{it} (Spill-over effects: Aggregate)	Billion yen	17,058	18,682	119,732	224
$G_{it}^{TR} + S_{it}^{TR}$ (Combined public capital: Transport)	Billion yen	8,086	8,149	49,570	222
$G_{it}^{TL} + S_{it}^{TL}$ (Combined public capital: Telecommunication)	Billion yen	1,832	2,195	14,303	13
$G_{it}^{AG} + S_{it}^{AG}$ (Combined public capital: Agriculture)	Billion yen	2,846	2,924	18,843	81
$G_{it}^{PU} + S_{it}^{PU}$ (Combined public capital: Public housing, parks and water facilities)	Billion yen	3,795	5,102	32,805	52
$G_{it}^{SC} + S_{it}^{SC}$ (Combined public capital: Education)	Billion yen	2,526	2,875	19,396	111
$G_{it}^{LS} + S_{it}^{LS}$ (Combined public capital: Land security)	Billion yen	2,457	2,319	16,538	32
$G_{it}^{IN} + S_{it}^{IN}$ (Combined public capital: Industry)	Billion yen	12,764	12,639	73,510	315

$G_{it}^{LE} + S_{it}^{LE}$ (Combined public capital: Living environment)	Billion yen	6,321	7,901	51,708	167
$G_{it} + S_{it}$ (Combined public capital: Aggregate)	Billion yen	21,541	22,317	137,177	516

5. Estimation Results

A summary of estimation results on the productivity effects of public capital is shown in Table 4. Details of our estimation results are also shown in Appendix-1. From these results, we can state the following conclusions.

First of all, when we look at the coefficients of aggregate public capital in three cases, all values show positive signs. Furthermore, almost all coefficients of the aggregate public capital except for those from before 1965 are statistically significant at 1%. In general, aggregate public capital is contributing positively to private production.

Second, when we disaggregate public capital into smaller components, the productivity effects of public capital became less clear. In three components cases, living environment before 1965 always made a positive contribution. However, other components such as industry, which is normally considered more contributory, are not statistically significant. In the case of six-components, negative effects sometimes appear. Our results differ from those of two previous studies in Japan--Mitsui et al. (1995) and Ida and Yoshida (1999)--but concur with those of Garcia-Mila, McGuire and Porter (1996). In the preliminary analysis using a panel data set, we faced estimation difficulties such as the multicollinearity and serial correlation problems. In order to avoid potential estimation problems, therefore, we chose the first-difference form of the original function.

Third, spill-over effects of public capital are not clear in the case of six components. However, in the case of three components, living environment was positive before 1965 but negative after 1965. We can interpret these results as follows. As the stock of living environment is developed in neighboring prefectures, residents commute to large cities, where

most industries locate from other prefectures during periods of high economic growth. But when the economy reaches a steady growth stage, people move to suburbs, thereby developing the suburbs' living environment capital as well, so that the economic activities of factories and commercial centers also relocate in suburban prefectures.

These results suggest that there may be reasons why public capital does not show a clear effect on private production. First, public capital has been allocated with the aim of encouraging regional development. Regions with relatively poor economic activity might have priority when funds are allocated, and their economic growth may not show up in statistics until quite some time after public capital is installed. Another possible reason why public capital does not seem to affect private production is that decisions regarding the allocation of public capital have been politically motivated. The way in which public capital is distributed in Japan will be a topic for future research.

Table 4 Summary of Estimation Results

Kinds of public capital stock	Cases without spill-over effects		Cases with spill-over effects				Cases of combined public capital	
	Public capital stock		Public capital stock		Spill-over effects		Combined public capital stock	
	Before 1965	After 1965	Before 1965	After 1965	Before 1965	After 1965	Before 1965	After 1965
Aggregate	0.186	0.102	n.s.	0.087	0.218	n.s.	0.216	0.116
Industry	n.s.	0.081	n.s.	n.s.	n.s.	0.212	n.s.	0.188
Living environment	0.281	n.s.	0.163	n.s.	0.229	-0.216	0.332	-0.208
Land security	n.s.	0.078	n.s.	n.s.	n.s.	0.135	n.s.	0.213
Transport	0.165	n.s.	0.109	n.s.	n.s.	n.s.	0.261	0.099
Telecommunication	-0.086	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.144
Agriculture	-0.092	n.s.	n.s.	n.s.	-0.170	n.s.	-0.255	n.s.
Public housing etc.	0.074	n.s.	0.069	n.s.	n.s.	n.s.	n.s.	n.s.
Education	0.241	-0.082	n.s.	n.s.	0.523	n.s.	0.361	-0.162
Land security	n.s.	0.068	n.s.	0.061	n.s.	0.061	n.s.	0.222
(Note):								
(1) Numbers in this table show the elasticity of public capital.								
(2) The designation "n.s." indicates that numbers are not statistically significant at 5%.								

6. Concluding Remarks

This study aims to find out if public capital truly contributes to productivity growth, to

what extent it does so, and what type of public capital is the most beneficial. The basic unit for data in this study being the prefecture, we analyze data sets from 46 prefectures in Japan over a period of 41 years, from 1955 to 1995. From the analysis, our conclusion is summarized as follows:

(1) In the case where aggregate public capital is used, all coefficients of aggregate public capital show positive signs and almost all coefficients of the aggregate public capital, except for the period before 1965, are statistically significant at 1%. Therefore, in general, aggregate public capital is positively contributing to private production.

(2) However, when we use disaggregate public capital into smaller components, the productivity effects of public capital became less clear. Living environment before 1965 in the three-components case and Transport in the six-components case seem to contribute to productivity growth.

(3) The spill-over effects of public capital are not clear in the case of six components. However, in the three-components case, living environment was positive before 1965 but negative after 1965.

(4) Our results are different from those of two previous studies in Japan, Mitsui et al. (1995) and Ida and Yoshida (1999). With the preliminary analysis using panel data sets, we were concerned about estimation problems such as multicollinearity and serial correlation problems. Previous studies may not have sufficiently addressed estimation problems.

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Appendix-1 Estimation Results

Case				Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
Public capital stock				Gross	3 sectors	6 sectors	Gross	3 sectors	6 sectors	Gross	3 sectors	6 sectors
Spill-over effect				without			with (separated)			with (combined)		
Labor input		β_L		0.630** (17.085)	0.652** (17.030)	0.646** (16.889)	0.647** (17.313)	0.669** (17.290)	0.673** (17.111)	0.635** (17.634)	0.653** (17.771)	0.667** (17.472)
Private capital stock		β_K		0.370** (10.024)	0.348** (9.105)	0.354** (9.269)	0.353** (9.435)	0.331** (8.552)	0.327** (8.302)	0.365** (10.146)	0.343** (9.432)	0.333** (8.708)
Public capital stock	Gross	before 1965	γ_G	0.186** (4.223)	-	-	0.025 (0.298)	-	-	0.216** (4.867)	-	-
		after 1965	$\gamma_G + \gamma_{G65}$	0.102** (3.200)	-	-	0.087* (2.083)	-	-	0.116** (3.886)	-	-
	Industry	before 1965	γ_{IN}	-	0.043 (0.836)	-	-	-0.025 (0.401)	-	-	0.095 (1.225)	-
		after 1965	$\gamma_{IN} + \gamma_{IN65}$	-	0.081* (2.012)	-	-	-0.013 (0.269)	-	-	0.188** (3.533)	-
	Living Environ-ment	before 1965	γ_{LF}	-	0.281** (4.465)	-	-	0.163* (2.370)	-	-	0.332** (3.426)	-
		after 1965	$\gamma_{LF} + \gamma_{LF65}$	-	-0.060 (1.916)	-	-	0.018 (0.515)	-	-	-0.208** (5.209)	-
	Land Security	before 1965	γ_{NL}	-	-0.071 (1.855)	-	-	-0.065 (1.601)	-	-	-0.076 (1.182)	-
		after 1965	$\gamma_{NL} + \gamma_{NL65}$	-	0.078** (2.836)	-	-	0.055 (1.928)	-	-	0.213** (4.538)	-
	Transport	before 1965	γ_{TP}	-	-	0.165** (9.269)	-	-	0.109* (2.173)	-	-	0.261** (3.312)
		after 1965	$\gamma_{TR} + \gamma_{TR65}$	-	-	0.012 (0.330)	-	-	-0.053 (1.287)	-	-	0.099* (2.003)
	Telecomm-unication	before 1965	γ_{TL}	-	-	-0.086 ** (3.188)	-	-	-0.048 (1.558)	-	-	-0.030 (0.919)
		after 1965	$\gamma_{TL} + \gamma_{TL65}$	-	-	-0.011 (0.461)	-	-	0.000 (0.007)	-	-	-0.144** (3.777)
Public capital stock	Agriculture	before 1965	γ_{AG}	-	-	-0.092* (2.084)	-	-	-0.085 (1.757)	-	-	-0.255** (3.355)
		after 1965	$\gamma_{AG} + \gamma_{AG65}$	-	-	0.023 (0.691)	-	-	0.019 (0.569)	-	-	0.107 (1.818)
	Public hou-sing, parks, and water facilities	before 1965	γ_{PU}	-	-	0.074* (2.286)	-	-	0.069* (2.108)	-	-	0.040 (0.608)
		after 1965	$\gamma_{PU} + \gamma_{PU65}$	-	-	0.010 (0.331)	-	-	0.033 (1.115)	-	-	0.001 (0.014)
	Education	before 1965	γ_{SC}	-	-	0.241** (3.610)	-	-	-0.046 (0.573)	-	-	0.361* (3.985)
		after 1965	$\gamma_{SC} + \gamma_{SC65}$	-	-	-0.082** (2.585)	-	-	-0.043 (1.179)	-	-	-0.162** (3.460)

	Land Security	before 1965	γ_{LS}	-	-	-0.024 (0.604)	-	-	-0.019 (0.454)	-	-	0.033 (0.494)
		after 1965	γ_{LS}^{+} γ_{LS65}	-	-	0.068* (2.428)	-	-	0.061* (2.090)	-	-	0.222** (4.189)
Spill-over effects	Gross	before 1965	δ_G	-	-	-	0.218* (2.432)	-	-	-	-	-
		after 1965	δ_G^{+} δ_{G65}	-	-	-	0.052 (1.520)	-	-	-	-	-
	Industry	before 1965	δ_{IN}	-	-	-	-	0.074 (0.886)	-	-	-	-
		after 1965	δ_{IN}^{+} δ_{IN65}	-	-	-	-	0.212** (3.586)	-	-	-	-
	Living Environ-ment	before 1965	δ_{LF}	-	-	-	-	0.229* (2.396)	-	-	-	-
		after 1965	δ_{LF}^{+} δ_{LF65}	-	-	-	-	-0.216** (4.926)	-	-	-	-
	Land security	before 1965	δ_{NL}	-	-	-	-	0.021 (0.308)	-	-	-	-
		after 1965	δ_{NL}^{+} δ_{NL65}	-	-	-	-	0.135** (2.835)	-	-	-	-
Spill-over effects	Transport	before 1965	δ_{TP}	-	-	-	-	-	0.135 (1.788)	-	-	-
		after 1965	δ_{TP}^{+} δ_{TP65}	-	-	-	-	-	-0.053 (1.287)	-	-	-
	Telecomm-unication	before 1965	δ_{TL}	-	-	-	-	-	-0.022 (0.638)	-	-	-
		after 1965	δ_{TL}^{+} δ_{TL65}	-	-	-	-	-	0.000 (0.007)	-	-	-
	Agriculture	before 1965	δ_{AG}	-	-	-	-	-	-0.170* (2.145)	-	-	-
		after 1965	δ_{AG}^{+} δ_{AG65}	-	-	-	-	-	0.019 (0.569)	-	-	-
	Public hou-sing, parks, and water facilities	before 1965	δ_{PU}	-	-	-	-	-	-0.047 (0.818)	-	-	-
		after 1965	δ_{PU}^{+} δ_{PU65}	-	-	-	-	-	0.033 (1.115)	-	-	-
	Education	before 1965	δ_{SC}	-	-	-	-	-	0.523** (4.775)	-	-	-
		after 1965	δ_{SC}^{+} δ_{SC65}	-	-	-	-	-	-0.043 (1.179)	-	-	-
	Land security	before 1965	δ_{LS}	-	-	-	-	-	0.093 (1.346)	-	-	-
		after 1965	δ_{LS}^{+} δ_{LS65}	-	-	-	-	-	0.061* (2.090)	-	-	-

Technology	before 1974	τ	0.033** (8.610)	0.038** (8.780)	0.046** (9.096)	0.031** (7.714)	0.031** (6.362)	0.050** (8.150)	0.032** (8.088)	0.029** (6.290)	0.045** (7.743)
	after 1974	$\tau + \tau_{74}$	-0.035** (14.868)	-0.037** (13.919)	-0.040** (12.770)	-0.034** (14.264)	-0.034** (11.519)	-0.045** (11.827)	-0.034** (14.362)	-0.033** (11.595)	-0.043** (11.566)
Adj.-R ²			0.497	0.504	0.508	0.498	0.514	0.526	0.498	0.513	0.522
Durbin-Watson statistics			1.851	1.881	1.919	1.858	1.924	1.962	1.861	1.919	1.943
Number of observations			1840	1840	1840	1840	1840	1840	1840	1840	1840