Crowding-in Effect of Public Investment on Private Investment*

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Abstract

This study investigates the effects of public investment on private investment based on Japanese empirical data. Since public capital is accumulated in tandem with the accumulation of private capital in the long-run from a historical perspective, it is quite natural that there is a positive relationship between private investment and public investment. However, some previous studies have provided evidence for the crowding-in effect of public investment on private investment while other studies have provided evidence for the crowding-out effect. What is the reason for these inconsistent results on the crowding-in effect? In order to answer this question, we will consider the possibility of analyzing the long-run relationship between private and public investment on the stock phase rather than the flow phase. Our empirical results show that there is a cointegration relationship between private capital and public capital. Accordingly, the relationship between private and public investment should be represented by an error correction mechanism designed to achieve a long-run stock equilibrium. Estimating the error correction model, we affirm the crowding-in effect of public investment on private investment.

I. Introduction

I.1. Crowding-out and Crowding-in

In economic arguments concerning the effect of public investment on private investment, the crowding-out effect has traditionally been the focus of attention. During the period when Keynesian economics prevailed, and even after the monetarist criticisms and the rise of the rational expectations, crowding-out was always at the center of policy debates despite differences in evaluation perspectives. Crowding-out was also the most important

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issue in the macroeconomic evaluation of fiscal policies including public investment spending. Needless to say, it was for this reason that in order to defend fiscal policies based on public investment, which were the pillar of the Keynesian economics, it was necessary to emphasize that crowding-out was of minor importance both in theory and in practice.

Meanwhile, Aschauer (1989) suggested the possibility that public investment may induce private investment, directing his attention to increases in the productivity of private capital resulting from the accumulation of public capital through public investment. Surprisingly enough, his theory was based on a highly neoclassical theory, not Keynesian theory. In fact, in addition to a private investment function which included public investment and the profit of private capital as right-hand side variables, the model also contained a profit function for private capital, which included public capital as a right-hand side variable based on a production function. Using this simple model of simultaneous equations and without resorting to the traditional argument that emphasizes the importance of aggregate demand management, Aschauer raised the possibility that an active fiscal policy may have a crowding-in effect through the productivity effect of public capital (investment). To be more specific about the characteristics of Aschauer's model, public investment affects private investment in his model largely through the following two routes. One is the negative effect of public investment that appears in the private investment function, and this effect is mainly composed of the so-called crowding-out effect. The other is the positive effect that appears in the profit function through the productivity effect of public capital, which is called the crowding-in effect as against the crowding-out effect.

Based on an empirical analysis performed in accordance with the above model, Aschauer suggested that the crowding-in effect is more dominant than the crowding-out effect in the United States. Similar conclusions have been obtained in a study by Argimón *et al.* (1997), who used panel data on 14 countries, and also in a study on Japan by Mitsui, Takezawa and Kawachi (1995). Various empirical studies that confirm the productivity effect of public capital make it highly likely that public investment has a crowding-in effect on private investment.[1)]

In contrast to these results, Bairam and Ward (1993), who analyzed data on 25 countries including Japan, Monadjemi (1993), who analyzed data on Australia and the United States, and Kitaoka (2002), who analyzed data on Japan, all maintained that the crowding-out effect was predominant based on their estimation of a reduced-form private investment function. More specifically, supposing a function that has private investment as the dependent variable and public investment as one of the independent variables, the coefficient of the public investment variable was estimated to be significantly negative in all these studies. This is confirmed by the following result of a regression analysis, which was performed assuming a log-linear function that has real private investment for year t (I_t) as the dependent variable, and real public investment (IG_t), real gross domestic product (Y_t) and private capital at the end of the preceding fiscal year t-1 (K_{t-1}) as independent variables.[2)] The values in parentheses represent t-values, u_t an error term, R^2 the coefficient of determination adjusted by the degrees of freedom and DW the Durbin-Watson ratio:

[1)] See Murata and Ohno (2000). This paper provides a survey of empirical studies for the productivity effect of public capital in Japan.

[2)] Details of the data used are provided in the Data Appendix at the end of this paper.

$$\ln I_t = -14.1085 - 0.3847 \ln IG_t + 3.1743 \ln Y_t - 0.9034 \ln K_{t-1} + u_t ,$$
$$(-15.53) \quad (-4.96) \qquad (14.87) \qquad (-9.78) ,$$

$R^2 = 0.99$, $DW = 0.49$,

Sample Period, 1956-2004.

The result of the estimation makes it clear that public investment has a crowding-out effect on private investment. It also shows that the traditional acceleration principle and adjustments in accordance with the amount of capital stock are effective.[3] However, since these series used for the analysis might be all nonstationary, we took first differences for these series and made estimations, obtaining the following results, which leads to the same conclusion as the above: [4]

$$\Delta \ln I_t = -0.0127 - 0.3489 \Delta \ln IG_t + 3.3915 \Delta \ln Y_t - 0.9089 \Delta \ln K_{t-1} + u'_t ,$$
$$(-0.73) \quad (-3.09) \qquad (12.94) \qquad (-3.17) ,$$

$R^2 = 0.79$, $DW = 1.90$,

Sample Period, 1957-2004.

I.2. Dynamic Model and a Long-run Relationship

It is natural from the structure of the model above that traditional investment function analysis is unable to identify the crowding-in effect. Since the crowding-in effect suggested by Aschauer is caused by an increase in the marginal product of private capital through public capital accumulation as a result of public investment, we can easily imagine that time lags may occur before the effect is actually observed. It is therefore insufficient simply to include the relationship between private and public investment for the current term in the framework of empirical analysis. There is a need to include public capital as an independent variable in the profit function, as Aschauer did, or else to use an econometric tool such as VAR in order to analyze time lags. In fact, studies using VAR conducted by Erenburg (1993), Erenburg and Wohar (1995) and Pereira (2001), which targeted the United States, and a study by Otto and Voss (1996), which targeted Australia, confirmed the positive effect of public investment on private investment. However, Voss (2002), who studied the United States and Canada, and Kawade, Ito and Nakazato (2004), who studied Japan, deny the crowding-in effect. Unfortunately, the results of VAR analysis have remained ambiguous until now.

What is of greater importance for criticism about the crowding-in effect is whether or not any long-run positive effect can be identified between private and public investment— because while crowding-out is a short-run flow effect resulting from restrictions on available resources, crowding-in is a long-run stock effect resulting from an increase in the productivity of the private capital. For this reason, the crowding-in effect suggests a long-run positive relationship between private and public investment. Meanwhile, a study by Monadjemi (1996), who

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[3] There may be a need to add the real interest rate to the private investment function. However, including the real interest rate obtained by subtracting the private corporate equipment deflator rate of the gross fixed capital formation from the interest rate of government bonds did not cause any significant change in the result of the analysis. Although we also considered the effect of the privatization of the *Nippon Telegraph and Telephone Public Corporation* and the *Japanese National Railways* and transferred the public capital of these enterprises before privatization to private capital, this produced hardly any effect on the result of estimation.

[4] Since most of these series are I(1),first differences for these series are stationary. However, we are unable to rule out the possibility that private capital may be I(2). We will discuss this point later.

analyzed data on the United States and the United Kingdom, and another study by Monadjemi and Huh (1998), who analyzed data on Australia in addition to these two countries, both led to the conclusion that although there is a cointegration relationship between public and private investment, the effect of the former on the latter is either very small or negative, thus providing no support for the existence of the crowding-in effect.

What is the reason for these inconsistent results on the crowding-in effect? In order to answer this question, we will consider the possibility of analyzing the long-run relationship between private and public investment on the stock phase rather than the flow phase. In other words, we assume that there is a cointegration relationship between private capital accumulated through private investment and public capital accumulated through public investment. Accordingly, the relationship between private and public investment, which are flows, should be represented by an error correction mechanism designed to achieve a long-run stock equilibrium. If the argument in this paper is correct, the reason why Monadjemi and Huh were unable to discover the evidence of crowding-in effect was that they failed to take account of the stock equilibrium, and the effect accompanied by a time lag that Erenburg discovered may have been the result of an error correction mechanism designed to achieve a stock equilibrium.

This paper is organized as follows. In Section II, we will discuss the theoretical background to the view that explores the long-run relationship between private and public investment on the stock phase and examine empirical evidence to show the existence of such a relationship. In Section III, we will analyze deviations from the long-run stock equilibrium in order to formulate the short-run dynamics based on an error correction model, and perform empirical analysis to confirm the effects of the error correction mechanism. Section IV provides a summary of this paper.

II. Long-run Equilibrium between Private and Public Capital

II.1. The Model Based on a Production Function

As mentioned above, many previous studies have revealed that there is no clear empirical evidence to show that an increase in public investment induces private investment either in Japan or in other countries. In particular, traditional regression analysis suggests quite strongly that there is a negative relationship between public investment and private investment. The implication obtained from these studies is simple and clear: if we aim to achieve the growth of a market-oriented economy by the accumulation of private capital, excessive dependence on public investment will lead to undesirable results. Even from the viewpoint of a short-run economic stability, traditional Keynesian policies that depend on public investment leave room for doubt about their positive effects, most of which are offset by the crowding-out of private investment.

From a historical perspective, however, it is difficult to accept such arguments. In the long-run process of economic growth in industrialized countries, public capital is accumulated by public investment in tandem with the accumulation of private capital. At least, the author finds it difficult to provide an example of an industrialized society with abundant private capital and scarce public capital. Long-run observation is likely to reveal a process by which private and public capital increase side by side, making it difficult to conclude that crowding-out is the

only effect between private and public investment. It is consistent with historical evidence to assume, as Aschauer (1989) showed using his simple model, that the accumulation of public capital has a crowding-in effect on private investment through an increase in the marginal product of private capital.

Why then have so many previous studies indicated the overwhelming predominance of the crowding-out effect? The most serious problem with such analyses is the lack of a long-run equilibrium perspective and the absence of dynamic perspectives. In addition to these problems, we also need to consider the possibility that a long-run equilibrium is established on the stock phase rather than the flow phase, as will be discussed below. For these reasons, we will first explicitly examine the relationship between private and public capital in order to make an empirical analysis of long-run equilibrium between capital stocks.

Let us assume the following Cobb-Douglas production function that explicitly includes public capital,

$$Y_t = A_t L_t^{\alpha} K_{t-1}^{\beta} KG_{t-1}^{\gamma}, \qquad (1)$$

where the subscript t represents the time period, Y real aggregate output, A a measure of productivity, L aggregate labor input, K aggregate nonresidential capital of private sectors (private capital), and KG public capital. α, β and γ are parameters.[5)]

From (1), the marginal product of private capital is $\beta Y_t / K_{t-1}$ and that of public capital $\gamma Y_t / KG_{t-1}$. If the private sectors and the government accumulate capital optimally, these marginal products will be equal to their respective interest rates. If we denote the interest rate for the private sectors by q and that for the government by r, we are able to write,

$$q_t = \beta Y_t / K_{t-1}, r_t = \gamma Y_t / KG_{t-1}.$$

Since the two interest rates are subject to the arbitrage pressure of the market, we may assume that they move in parallel with each other, despite differences regarding risk premiums. Supposing that these two interest rates maintain the constant ratio θ such that the relationship $q_t = \theta r_t$ always holds, we can obtain

$$K_t = (\beta / \theta\gamma) KG_t. \qquad (2)$$

In a particular case where $\theta = 1$, the marginal product of private capital and that of public capital will be equal. The meaning of (2) is that there is a long-run stable relationship between the marginal products of private and public capital, with risk premiums held constant. Although a state like this may not always be achieved in the short run, we accept the possibility that the relationship expressed by (2) will be established in the long-run. If such a relationship exists, the growth rate of private capital will be equal to the growth rate of public capital in the long-run. With regard to this point, Kalyvitis (2003) showed that a similar conclusion can be obtained using a framework of an endogenous growth model and argued that the conclusion is consistent with long-run observation of Canadian data.

II.2. Cointegration Analysis

If we take the logarithms of equation (2), the long-run relationship between private and public capital can be expressed in a linear form. Let c_0 (= $\ln \beta - \ln \gamma - \ln \theta$) and c_1 be the parameters to be estimated and e_t the error

[5)] Assumptions concerning homogeneity are made in the macroeconomic analysis of production function. However, since these assumptions have no essential effects on the analysis in this paper, there is no need to pay particular attention to them.

term. Then, the first point that needs to be discussed is whether or not the following equation holds in the long-run.

$$\ln K_t = c_0 + c_1 \ln KG_t + e_t . \quad (3)$$

Since it is likely that $\ln K_t$ and $\ln KG_t$ are nonstationary processes, it will be useful to examine whether or not equation (3) expresses a cointegration relationship. Then, we conduct unit root tests on $\ln K_t$ and $\ln KG_t$ to examine their respective orders of integration. Needless to say, a cointegration relationship exists only between nonstationary series that are integrated of same orders. Therefore, if $\ln K_t$ and $\ln KG_t$ are found to follow the same integrated orders, we will conduct a cointegration test of the relationship between these two variables.

Table 1 shows the results of ADF (Augmented Dickey-Fuller) tests applied to the logarithms of private and public capital, and Table 2 the results of PP (Phillips-Perron) tests applied to the same variables.[6] In view of the breaks caused by the privatization of the *Nippon Telegraph and Telephone Public Corporation* (NTT) and the *Japanese National Railways* (JNR), we performed the same analysis for the case where the capital of these two enterprises was all transferred from public to private capital. It is possible to construct three different models depending on the presence or absence of the constant term and trend term. However, since either a deterministic trend or a stochastic trend is considered to be contained in level data, we eliminated the model that has neither the constant term nor a trend term.

The results support the conclusion that the series are stationary in all cases if we take second order differences. First order differences were found to constitute a stationary process only in one case, with the results supporting the general conclusion that the series are nonstationary. With level data, we are often led to the conclusion that the series are stationary with the model that includes only the constant term. However, since unit root tests have a bias toward identifying I(2) variables as stationary, the reliability of above conclusion is not very high.[7] Overall observation supports the conclusion that there is a strong possibility that $\ln K_t$ and $\ln KG_t$ are I(2) variables.

Table 1
ADF Tests Regarding Private and Public Capital

	constant terms	Trends	Private capital			(+ NTT and JNR)			Public capital			(– NTT and JNR)		
			Statistics	(P value)	Lag	Statistics	(P value)	Lag	Statistics	(P value)	Lag	Statistics	(P value)	Lag
Level	○	○	−0.586	(0.975)	1	−1.449	(0.833)	1	−1.544	(0.800)	2	−0.458	(0.982)	2
	○	×	−3.306	(0.020)	1	−3.560	(0.010)	1	−4.105	(0.002)	2	−5.345	(0.000)	5
1st order	○	○	−3.484	(0.053)	0	−3.186	(0.099)	0	−3.049	(0.131)	1	−3.708	(0.032)	1
	○	×	−1.349	(0.599)	0	−0.911	(0.776)	0	−0.721	(0.831)	1	−0.643	(0.850)	5
	×	×	−0.891	(0.325)	0	−0.773	(0.376)	0	−0.574	(0.464)	1	−0.414	(0.529)	0
2nd order	○	○	−8.056	(0.000)	0	−5.784	(0.000)	0	−12.456	(0.000)	0	−3.535	(0.048)	3
	○	×	−8.099	(0.000)	0	−5.911	(0.000)	0	−11.799	(0.000)	0	−3.022	(0.041)	3
	×	×	−8.133	(0.000)	0	−5.929	(0.000)	0	−11.915	(0.000)	0	−3.665	(0.001)	0

(Note) The data period is from 1955 to 2004. The lag order was determined using the Schwartz information criterion.

[6] See Dickey and Fuller (1979, 1981) for ADF test. See also Phillips and Perron (1988) for PP test.
[7] For various arguments about the analysis of variables that follow I(2) processes, see Maddala and Kim (1998), Chapter 11.

Table 2
PP Tests Regarding Private and Public Capital

	constant terms	Trends	Private capital			(+ NTT and JNR)			Public capital			(– NTT and JNR)		
			Statistics	(P value)	Statistics	Statistics	(P value)	Lag	Statistics	(P value)	Lag	Statistics	(P value)	Lag
Level	○	○	0.356	(0.998)	1	−0.006	(0.995)	1	−0.201	(0.991)	2	1.109	(1.000)	2
	○	×	−3.928	(0.004)	1	−4.092	(0.002)	1	−2.415	(0.143)	2	−5.597	(0.000)	5
1st order	○	○	−3.484	(0.053)	0	−3.186	(0.099)	0	−3.441	(0.058)	1	−3.217	(0.093)	1
	○	×	−1.349	(0.599)	0	−0.911	(0.776)	0	−0.944	(0.766)	1	−1.490	(0.530)	5
	×	×	−0.891	(0.325)	0	−0.776	(0.376)	0	−0.568	(0.466)	1	−0.414	(0.529)	0
2nd order	○	○	−8.056	(0.000)	0	−5.784	(0.000)	0	−12.456	(0.000)	0	−6.784	(0.000)	3
	○	×	−8.099	(0.000)	0	−5.911	(0.000)	0	−11.799	(0.000)	0	−3.874	(0.005)	3
	×	×	−8.133	(0.000)	0	−5.929	(0.000)	0	−11.915	(0.000)	0	−3.665	(0.001)	0

(Note) The data period is from 1955 to 2004. The lag order was determined using the Schwartz information criterion.

Subsequently, we performed Johansen tests on the logarithms of private and public capital to find cointegrating relationships.[8] As in unit root tests, we applied the same tests to the case where the capital of the NTT and the JNR was all transferred from public to private capital in view of the breaks caused by the privatization of these enterprises. The results of Johansen tests are shown in Table 3. These results show that the null hypothesis that private and public capital have no cointegration vector is rejected in all cases. They also suggest the possibility that there are two cointegration vectors. If two variables have two cointegration vectors, it is likely that there are interactive causal relationships between these variables, indicating the need to pay attention to an inverse causality when examining the policy effects of public investment. This point will be discussed in the end of the next section.

Table 4 shows the estimates of cointegration vectors. All estimates show positive relationships between private and public capital, indicating that these two types of capital increase together in the long-run. The results other than those in the first row of the table are all similar, with only minor differences between different estimation methods. However, as pointed out by Minotani (2007), estimates of cointegration vectors based on Johansen tests are not entirely reliable.[9] Therefore, in the following discussion, we will use OLS estimates obtained by a regression analysis performed using private capital as the dependent variable. Let it be noted that except for the results in the first row of the table, our choice has no effect on the conclusions of this paper.

[8] See Johansen (1988).
[9] See Minotani (2007), p. 711.

Table 3
Johansen Tests between Private and Public Capital

Variables	Test	Null hypothesis	Alternative hypothesis	Statistics	(P value)	Lag order
Private capital, Public capital	Trace	n = 0	n > 0	23.351	(0.003)	2
		n ≤ 1	n > 1	7.026	(0.008)	
	Maximum	n = 0	n = 1	16.325	(0.023)	
		n = 1	n = 2	7.026	(0.008)	
Private capital + NTT + JNR, Public capital − NTT − JNR	Trace	n = 0	n > 0	32.312	(0.000)	1
		n ≤ 1	n > 1	10.063	(0.002)	
	Maximum	n = 0	n = 1	22.249	(0.002)	
		n = 1	n = 2	10.063	(0.002)	

(Note 1) n represents the number of cointegration vectors.
(Note 2) The sample period is from 1955 to 2004. The lag order was determined using the Schwartz information criterion.

Table 4
Estimates of Cointegration Vectors

Variables	Method		c_0	c_1
Private capital, Public capital	Johansen test	(1)	−0.730	1.105
		(2)	1.504	0.918
	OLS	Dependent variable: Private capital	1.159	0.947
		Dependent variable: Public capital	1.111	0.951
Private capital + NTT + JNR, Public capital − NTT − JNR	Johansen test	(1)	2.583	0.839
		(2)	1.336	0.944
	OLS	Dependent variable: Private capital	2.098	0.880
		Dependent variable: Public capital	2.037	0.885

III. Crowding-in Effect Based on an Error Correction Model

III.1. Estimating the Private Investment Function with Error Correction Term

Our analysis in the preceding section indicated a strong possibility that there is a positive long-run relationship between private and public capital. Since there is an equilibrium relationship on the stock phase between private and public capital, flow variables that represent the accumulation of these two types of capital (i.e. private and public investment) cannot be free from this long-run equilibrium. If the level of private or public capital deviates from the long-run equilibrium, private or public investment will be made sooner or later in the direction to correct the deviation from the equilibrium.

Analysis based on an error correction model is useful in this case. The basic assumption of an error correction model is that if a long-run equilibrium exists between variables, these variables will move in the direction to correct any deviations from the equilibrium. Accordingly, we can rewrite the private investment function estimated in Section I as follows,

$$\Delta \ln I_t = a_0 + a_1 \Delta \ln IG_t + a_2 \Delta \ln Y_t + a_3 e_{t-1} + \varepsilon_t . \quad (4)$$

The above function is based on first order differences to ensure the series is stationary. The third independent variable in Section I that represented adjustments made in accordance with the amount of private capital stock is replaced by the deviation from the long-run equilibrium in the previous period. This independent variable denoted *e* is calculated as shown below, using the cointegration vectors estimated in section II,

$$e_t = \ln K_t - (c_0 + c_1 \ln KG_t) .$$

In other words, if the amount of private capital *K* becomes larger (smaller) than the long-run equilibrium level in comparison with public capital *KG*, the error term *e*, which represents the deviation from the equilibrium, becomes positive (negative). Since correction is made toward the long-run equilibrium under this condition, private investment will decrease (increase), causing the coefficient a_3 for error term *e* to be negative.

Table 5 shows the results of the estimation of equation (4). We also examined the case in which the effects of the privatization of the NTT and the JNR were considered, but the basic conclusion remains the same. The results show that a_1, which represents the effect of public investment, and a_2, which represents the effect of the economic growth rate, are similar to those obtained in Section I, indicating that the public investment for the current period has a crowding-out effect as before. Meanwhile, a_3 indicating the effect which corrects the deviations from the equilibrium, is estimated to have a significantly negative sign, providing evidence that public investment also has an effect through an error correction mechanism. In other words, if an increase in public investment results in an increase in public capital, the resulting deviation from the long-run equilibrium moves in a negative direction, causing private investment to increase. This is precisely what is meant by the crowding-in effect, which is therefore considered to be produced in the long-run.

Table 5
Private Investment Function with Error Correction Term

Dependent variable	Public investment	Private capital	Public capital	a_0	a_1	a_2	a_3	R^2	*DW*
Private investment	Public investment	Private capital	Public capital	−0.0515 (−3.94)	−0.4379 (−3.65)	3.0058 (11.04)	−0.3495 (−3.07)	0.76	1.46
+ Public enterprise	− Public enterprise	+ NTT + JNR	− NTT − JNR	−0.0413 (−4.88)	−0.2638 (−3.56)	2.5361 (14.40)	−0.3243 (−5.18)	0.86	1.74

(Note1) The estimation period is from 1956 to 2004.
(Note2) The values in parenthesis are t-statistics.

III.2. Crowding-in Effect

How, then, is the crowding-in effect produced and what is the size of the effect? To answer these questions, we will use the following function as a private investment function based on the results shown in the first row of Table 5,

$$\Delta \ln I_t = -0.0515 - 0.4379\,\Delta \ln IG_t + 3.0058\,\Delta \ln Y_t - 0.3495\,e_{t-1},$$

and the following equation to represent deviations from the long-run equilibrium,

$$e_t = \ln K_t - (1.159 + 0.947 \ln KG_t).$$

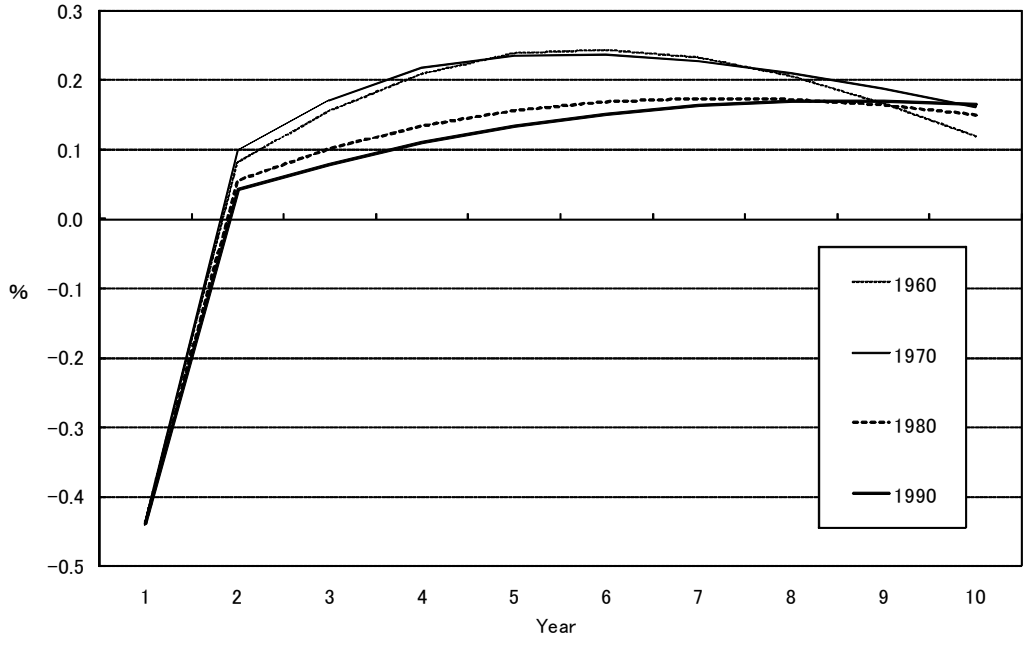
We also assume that private and public capital follow the accumulation processes shown below, where δ_t and δ^G_t represent, respectively, the depletion rates of private and public capital,

$$K_t = (1 - \delta_t)K_{t-1} + I_t,$$

$$KG_t = (1 - \delta^G_t)KG_{t-1} + IG_t.$$ [10)]

Figure 1 is the result of simulation based on the above equations, which shows how an increase of 1% in growth rate of public investment ($\Delta \ln IG$) in one year (first year) will affect the growth rate of private investment ($\Delta \ln I$) over the subsequent ten years in comparison with the case where there is no increase in $\Delta \ln IG$. The figure indicates that there is a crowding-out effect in the first year, when public investment is increased. This is a negative effect of public investment that appears in the private investment function. However, after the second year, the growth rate of private investment starts to rise, indicating a crowding-in effect. Due to the differences in the capital depletion rates, effects produced by a one-percent increase differ from year to year, but the basic results remain the same.

Figure 1
Effect of a One-percent Increase in Growth Rate of Public Investment on Growth Rate of Private Investment



[10)] See the Data Appendix for how the depletion rates were computed.

III.3. Causality Test

As the above results show, a long-run equilibrium relationship exists between private and public capital and there is also a possibility that an error correction mechanism exists between private and public investment. However, caution is needed when concluding from this that public investment has a crowding-in effect on private investment. As we have seen, the results of Johansen tests lead us to assume that there are two cointegration vectors between private and public capital. In this case, there is likely to be interactive causality between these variables. In other words, the most likely scenario may be that private capital accumulated through an increase in private investment causes an increase in the demand for public capital, bringing about an increase in public investment in consequence.

To compare the two possibilities, we conducted Granger causality tests between private and public capital, and between private and public investment.[11] In order to ensure stationary series, we took second-order differences for private and public capital (logarithms) and first-order differences for private and public investment (logarithms). Table 6 shows the results of these tests. The null hypothesis that no causal relationship exists in the direction shown by the arrow was accepted at a 5% significance level, only in the case where the causality from private to public capitals was assumed. In other words, causal relationships from public to private capital and from public to private investment are likely to exist. These results provide reliable evidence for the crowding-in effect discovered in our analysis. However, since the results also confirm the causality from private investment to public investment, we are unable to deny the inverse causal relationship entirely.

Table 6
Granger Causality Tests

Causal relationship	F value	(P value)
$\Delta^2 \ln KG \rightarrow \Delta^2 \ln K$	5.624	(0.007)
$\Delta^2 \ln K \rightarrow \Delta^2 \ln KG$	2.973	(0.062)
$\Delta \ln IG \rightarrow \Delta \ln I$	3.435	(0.042)
$\Delta \ln I \rightarrow \Delta \ln IG$	7.329	(0.002)

(Note) Lag orders are all 2. These orders were selected so as to minimize the P value.

IV. Conclusion

In this paper, we examined the effects of public investment on private investment based on Japanese empirical data. In previous studies, some results provided evidence for the crowding-out effect while other results provided evidence for the crowding-in effect. This is likely to be due to an improper understanding of long-run equilibrium and bias caused by inappropriate formulation of the relationship. As we have emphasized, the long-run relationship between private and public investment is not on the flow phase relationship but the stock phase

[11] See Granger (1969).

relationship. Therefore, in order to examine the relationship between private and public investment, there is a need to consider long-run stock equilibrium. Estimates made based on a model that considers such stock equilibrium clearly reveal a long-run crowding-in effect.

However, some caution is required when evaluating the analysis in this paper. First, there is a possibility of an inverse causal relationship. To examine this possibility, it is necessary to construct a model that considers the effect of private investment on public investment or private capital on public capital. When constructing such a model, there will be a need to examine the possible effects of Keynesian fiscal policies. Secondly, while we took every possible measure to avoid the effects of the privatization of the NTT and the JNR, we were unable to process data on flow variables in an appropriate manner. It will be necessary to re-examine the data creation process in order to confirm the robustness of the results obtained. Thirdly, there is a need to improve the precision of the production function. Although we adopted a Cobb-Douglas function in this paper, the expression of the long-run equilibrium would undoubtedly change if we used a more complex function. Such a sophisticated model would reveal the details of the dynamic mechanism of private investment and prove to be of great use for enabling a proper understanding of the effects of public investment.

Data Appendix

We used fiscal years and adopted values at the end of each year for stock series. We had no choice but to use estimated data on many series in order to extend the observation period. Also, with regard to both investment series and capital series, there were breaks in the data due to the privatization of the *Nippon Telegraph and Telephone Public Corporation* (NTT) in 1985 and the *Japanese National Railways* (JNR) in 1987. In some of the cases, we transferred the capital owned by these two enterprises before privatization from public capital to private capital for the analysis in order to examine the impacts of these breaks. For details of the analysis, see the main text.

(1) System of National Accounts

We used mainly the following four series in the real terms, (i) gross domestic expenditure, (ii) gross fixed capital formation for non-residential investment of private sectors, (iii) gross fixed capital formation for non-residential investment of public sectors, (iv) gross fixed capital formation of general government. We also used deflators for non-residential investment of private sectors. As data for private investment, we used (ii), and as data for public investment, we used the sum of (iii) and (iv). In some analyses, however, we used the sum of (ii) and (iii) as data for private investment, and we used only (iv) as data for public investment to avoid the impacts of the breaks caused by the privatization of the NTT and the JNR.

In the 1993SNA, the latest 2000 price series are available only for years after 1994, and the 1995 price series only for years after 1980. To overcome this setback, we used the following method to extrapolate the time series. Data for the years from 1955 to 2004 was made available by this method.

1) Based on the 1980 values of 1995 price series in the 1993SNA, we estimated data back to 1955 using the annual growth rate of the 1968SNA series.

2) From 1980 until 1994, we used the values of 1995 prices in the 1993SNA.

3) After 1995, we used series extrapolated from the 1994 values using the annual growth rate of the 1993SNA series at 2000 price.

(2) Private Capital

We used tangible fixed assets for all industries including the construction in progress in *Gross Capital Stock of Private Enterprises* published by the Economic and Social Research Institute (Cabinet Office, Government of Japan). Since these are quarterly data, values at the end of the first quarter of calender year *t+1* are used as values at the end of fiscal year *t*. However, time-series data based on the 1993SNA (2000 prices) are available only for the period after the first quarter of 1980. Therefore, we used the following method to estimate data before 1979. Data from 1955 to 2005 are made available by this method.

1) Using time series data based on the 1968SNA (1990 prices), we extrapolated the annual growth rate of the same quarter periods backwards.

2) Using this annual growth rate, we estimated data back to the first quarter of 1955 based on the 1993SNA series for the first quarter of 1980.

3) To adjust values in accordance with the base year of public capital, we transformed the capital stock extrapolated by the above method using deflators for non-residential investment of private sectors.

Finally, the depletion rate for year *t* was calculated as follows.

$$\delta_t = I_t / K_{t-1} - (K_t - K_{t-1}) / K_{t-1}.$$

(3) Public capital

We used the statistical data of the Cabinet Office (2002). Time series provided by these data are available for the years from 1953 to 1998 at 1995 prices. We used the following method to estimate more recent data. Data for the years from 1953 to 2004 was made available by this method.

1) We added gross fixed capital formation for non-residential investment of public sectors to gross fixed capital formation of general government.

2) We estimated capital depletion before 1998 by subtracting the increase of public capital (net investment) from gross investment which was calculated as above, and divided the gap by the public capital in the previous year to compute the capital depletion rate.

3) Using the simple arithmetic mean of the capital depletion rates from 1988 to 1998, the mean is 2.58%, we calculated the public capital for the period after 1999 as

$$KG_t = (1 - 0.0258) KG_{t-1} + IG_t.$$

The reason why we used the simple arithmetic mean of the capital depletion rates from 1988 to 1998 was that the NTT was privatized in 1985 and the JNR was privatized in 1987, causing breaks in estimated depletion rates. The depletion rate for year *t* was calculated as follows.

$$\delta_t^G = [IG_t - (KG_t - KG_{t-1})] / KG_{t-1}.$$

References

Argimón, I., J. M. González-Páramo and J. M. Roldán (1997), "Evidence of Public Spending Crowding-out from a Panel of OECD Countries," *Applied Economics* 29: pp.1001-1010.

Aschauer, D. A. (1989), "Does Public Capital Crowd out Private Capital?" *Journal of Monetary Economics* 24: pp.171-188.

Bairam, E. and B. Ward (1993), "The Externality Effect of Government Expenditure on Investment in OECD Countries," *Applied Economics* 25: pp.711-716.

Cabinet Office, Government of Japan (ed.) (2002), *Public capital of Japan* (*Nihon no Shakai Shihon*), National Printing Bureau (in Japanese).

Dickey, D. A. and W. A. Fuller (1979), "Distribution of the Estimators for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association* 74: pp.427-431.

Dickey, D. A. and W. A. Fuller (1981), "Likelihood Ratio Statistics for Autoregressive Time Series with A Unit Root," *Econometrica* 49: pp.1057-1072.

Erenburg, S. J. (1993), "The Real Effects of Public Investment on Private Investment," *Applied Economics* 25: pp.831-837.

Erenburg, S. J. and M. E. Wohar (1995), "Public and Private Investment: Are There Casual Linkages?" *Journal of Macroeconomics* 17: pp.1-30.

Granger, C. W. J. (1969), "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods," *Econometrica* 37: pp.424-438.

Hatano, Toshiya (2004), *Macroeconomic Analysis of Fiscal Deficits and Public Investment* (*Zaisei Akaji to Kokyo Toshi no Makuro Keizai Bunseki*), Doctoral Thesis, Hitotsubashi University (in Japanese).

Johansen, S. (1988), "Statistical Analysis of Cointegration Vectors," *Journal of Economic Dynamics and Control* 12: pp.231-254.

Kalyvitis, S. (2003), "Public Investment Rules and Endogenous Growth with Empirical Evidence from Canada," *Scottish Journal of Political Economy* 50: pp.90-110.

Kawade, Masumi, Arata Ito and Toru Nakazato (2004), "Effects and Changes of Fiscal Policies after 1990," in Toshihiro Ihori (ed.), *Fiscal Deficits of Japan* (*Nihon no Zaisei Akaji*), Iwanami Shoten, Chapter 5: pp. 105-123 (in Japanese).

Kitaoka, Takayoshi (2002), "Efficiency of Public Investment: Comparison of Japan and Australia," *Oceanian Economy (Taiyoshu Keizai)*, No. 10: pp. 45-62 (in Japanese).

Maddala, G. S. and In-Moo Kim (1998), *Unit Roots, Cointegration, and Structural Change*, Cambridge University Press.

Minotani, Chiohiko (2007), *Econometrics (Keiryo Keizaigaku Taizen)*, Toyo Keizai Shinposha (in Japanese).

Mitsui, Kiyoshi, Yasuko Takezawa and Shigeru Kawachi (1995), "Crowding-in Effect of Public Investment and Welfare Analysis," in Kiyoshi Mitsui and Kiyoshi Ota (eds.), *Productivity of Public capital and Public Financial System* (*Shakai Shihon no Seisansei to Kouteki Kinyu*), Nihon Hyoronsha, Chapter 4: pp. 67-96 (in Japanese).

Monadjemi, M. S. (1993) "Fiscal Policy and Private Investment Expenditure: A Study of Australia and the United States," *Applied Economics* 25: pp.143-148.

Monadjemi, M. S. (1996) "Public Expenditure and Private Investment: A Study of the UK and the USA," *Applied Economics Letters* 3: pp.641-644.

Monadjemi, M. S. and H. Huh (1998), "Private and Government Investment: A Study of Three OECD Countries," *International Economic Journal* 12: pp.93-105.

Murata, Osamu and Yasushi Ohno (2000), "The Survey on the Productivity of Public Capital Stock in Japan," *The journal of economics of Kwansei Gakuin University* (*Keizaigaku Ronkyu*) 54: pp. 97-130 (in Japanese).

Otto, G. D. and G. M. Voss (1996), "Public Capital and Private Production in Australia," *Southern Economic Journal* 62: pp.723-738.

Pereira, A. M. (2001), "On the Effects of Public Investment on Private Investment: What Crowds in What?" *Public Finance Review* 29: pp.3-25.

Phillips, P. C. B. and P. Perron (1988), "Testing for a Unit Root in Time Series Regression," *Biometrika* 75: pp.335-346.

Voss, G. M. (2002), "Public and Private Investment in the United States and Canada," *Economic Modelling* 19: pp.641-664.