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Synthesizing the Empirical Evidence on the Productivity of Public Capital in Japan: A Meta-Analysis[1]

Fumiaki Ishizuka*

Abstract

Over the past few decades many attempts have been made to measure the output elasticity of public capital or infrastructure, with varying results. This paper focuses on the accumulation of empirical analyses in Japan that have been overlooked in previous meta-analyses and quantifies the impact of public capital on output in the country through a meta-analysis of 1,038 estimates from 44 studies. No significant evidence of publication bias was found. The output elasticity of infrastructure in Japan is positive at 0.146, and this value is strongly influenced by heterogeneity of infrastructure such as project entity, time frame, region, and sector. Projects undertaken solely by local governments or in non-metropolitan areas have relatively higher elasticities, but their value declines over time. Social infrastructure such as housing, sanitation, and education have relatively low elasticities compared to other sectors. These results add new insights to the debate on the productivity of public capital and provide a benchmark as the first meta-analysis of infrastructure output elasticities in Japan.

Keyword: Public capital, Infrastructure, Japan, Productivity, Output elasticity, Meta-analysis, Publication bias

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1.Introduction

Studying the impact of public capital or infrastructure on output is important for both practical and academic purposes. Many major countries increased their public spending on infrastructure as part of the fiscal stimulus measures following the 2008 global economic crisis. Many emerging economies are currently seeking to develop infrastructure through various funds, such as the international development finance institutions, based on the belief that infrastructure is an important driver of economic development. In terms of research, many macroeconomic models, such as endogenous growth models and general equilibrium models, use the output elasticity of public capital as a basic parameter (Bom and Lightart 2014). In this context, there is a need to continue to accumulate and verify the existing empirical analyses of the output elasticity of infrastructure.

The most common approach to capture the productivity of public capital in recent decades has been the estimation of production functions. One of the most famous early studies is Aschauer (1989), who attempted to examine the reasons for the slowdown in productivity growth in the United States. Subsequently, a number of analyses using similar methods were carried out in other OECD countries. Several cross-country meta-analyses of infrastructure output elasticities have also been conducted (Bom and Lightart 2014; Núñez-Serrano and Velázquez 2017; Melo et al. 2013; Foster et al. 2023). All of these have shown that, on average, positive output elasticities are observed. On the other hand, the magnitude of these values varies across countries/regions, infrastructure sectors, and project entities.

The accumulation of empirical analyses in Japan has often been overlooked in the above discussion. Starting with Mera (1973), a number of empirical analyses on the productivity of public capital have been published in Japan, especially since the 1990s, in response to the growing public debate on the effects of public investment in the context of fiscal difficulties. Most of them are written in Japanese and thus have not been included in previous meta-analyses. However, their quality and quantity are comparable to those in Europe and the United States. For example, the infrastructure stock statistics provided by the Japanese government (Cabinet Office) have covered 47 prefectures and 16 infrastructure sectors for each year since 1960. Many time series and panel data analyses have been conducted using these statistics. However, the conclusions vary widely depending on the scope of the data and the method of analysis.

The purpose of this paper is to quantify the effects of public capital on output in Japan, focusing on the accumulation of empirical analyses in Japan over the past 50 years. The focus is not on finding a single elasticity value, but on quantifying the various heterogeneities that make a difference to their effects on production. These heterogeneities include the nature of the infrastructure, such as differences in sector, region, time frame, and project unit, as well as the analytical models and econometric methods used in each analysis.

The method of analysis is a meta-analysis of empirical studies using the production function approach. The sample consists of 1,038 estimates from 44 empirical studies using the Cobb-Douglas production function, which provides comparable measures. Specifically, we use the FAT-PET-PEESE approach proposed by Stanley and Doucouliagos (2014) to test for publication bias and to estimate the value of the effect beyond this bias. Because the precision of each estimate differs, we used the weighted least squares (WLS), which uses the precision of each estimate as a weight, to pursue the efficiency of the statistical analysis.

The results showed, first, that the presence of publication bias was not significantly confirmed. Second, the output elasticity of Japanese infrastructure is positive at 0.146 when heterogeneity is not taken into account. Third, output elasticity is significantly affected by heterogeneity of infrastructure in terms of project entity, time frame, region, and sector. Projects undertaken solely by local governments have higher elasticities than those under the direct control/subsidy of the national government, and non-metropolitan areas have higher elasticities than metropolitan areas. The elasticity decreases with each passing year. Social infrastructure such as housing, sanitation and education have relatively low elasticity compared to other sectors.

The first contribution of this paper is that it sheds light on the accumulation of empirical analyses in Japan, which has been overlooked in previous meta-analyses. As noted above, the results of previous empirical studies vary widely. This meta-analysis is an attempt to integrate them, thus providing new insights into the debate on the output elasticity of public capital. Second, it is the first meta-analysis of infrastructure output elasticities in Japan and provides a benchmark for the debate on the productivity of public capital in Japan. Infrastructure productivity remains an important issue for Japan, which is facing fiscal difficulties and a shrinking population, as well as for other countries, especially emerging economies, which are vigorously developing their infrastructure.

The remainder of this paper is organized as follows. Section 2 describes the sample for the meta-analysis. This includes the sample selection procedure, descriptive statistics, and a preliminary analysis of publication bias. Section 3 sets up the model for the meta-analysis and selects the variables or moderators that affect the elasticity values of each sample. Section 4 presents the results of the meta-analysis. It includes a quantitative examination of the publication bias, the value of the output elasticity without the said bias, and a quantification of the influence of each moderator. For robustness checks, the results after adjusting the weights in the regression analysis are also shown. Section 5 discusses the results of the analysis obtained in the previous section. Finally, section 6 presents the conclusions.

2. Meta-sample

2.1 Production Function Approach

The sample for this analysis is an empirical study that estimates the output elasticity of public capital using the production function approach. This approach adds public capital stock as a variable to the general production function that shows the relationship between private sector output and inputs. It attempts to quantify the effect of the public capital stock on output. The quantification targets the output effect from the general economic effects of public investment. Other effects of public investment related to welfare, demand creation and income redistribution need to be measured using a different approach.

The most common form of the production function approach is the Cobb-Douglas type, which is expressed by the following equation:

$$Y_{it} = A_{it}\, K_{it}^{\alpha}\, L_{it}^{\beta}\, G_{it}^{\theta} \qquad (1)$$

where Y_{it} is the total output of region/country i at time t, A_{it} is total factor productivity, K_{it} is private capital stock, L_{it} is employment (total number of workers or total hours worked), and G_{it} is public capital stock. The output elasticity of public capital is expressed by θ, which is the main interest of the analysis for each sample. By logarithmizing both sides of equation (1), we can easily estimate each parameter using standard econometric techniques.

2.2 Sample Selection

In order to collect all available literature on the productivity effect of public capital in Japan, I first consulted five survey articles on this topic that have been published to date (Ejiri et al. 2001; Murata and Ohno 2001; Iwamoto 2005; Hayashi 2003a, 2019). All academic papers and books reviewed in the above survey articles were then collected. Google Scholar was also searched for literature cited in or by these sources to ensure the collection of all literature that fit the above topic.

Next, samples for which a single elasticity value could not be obtained or for which standard errors were not reported were excluded. For example, the translog production function is more flexible than the Cobb-Douglas type in that it can estimate indirect effects through the private sector in addition to direct effects on total output, but it cannot represent the output elasticity of public capital by a single parameter. Similarly, Mera (1973), mentioned above, does not include standard errors, so it was also excluded from the meta-analysis.

2.3 Sample Overview

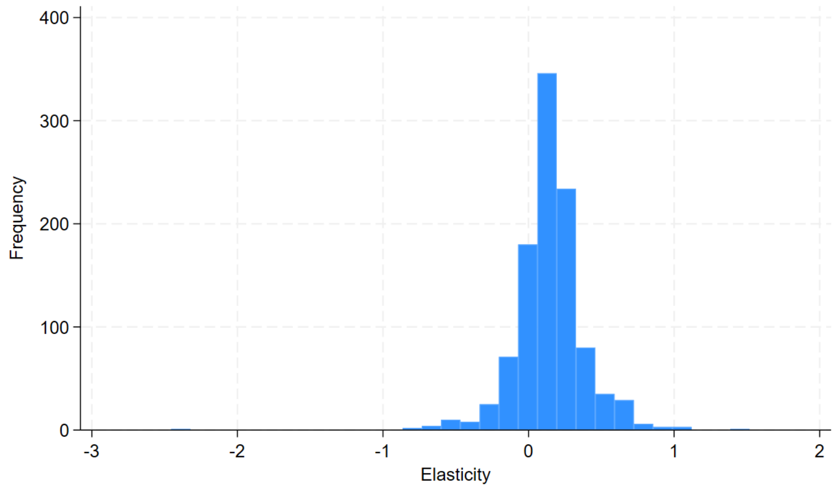
Table 1 provides an overview of the 44 studies and 1,038 samples selected using the above procedure. Of the 44 studies, 9 are in English and 35 are in Japanese. All of them were published as academic papers or academic books, but as described below, a certain number of academic papers include those that have not been externally peer reviewed or for which the existence of external peer review cannot be confirmed. The average output elasticity for all these samples is 0.146, with a minimum of -2.455 and a maximum of 1.518.

Table 1: Descriptive Statistics of the Sample

No.	Study	Estimates	Min	Max	Mean
1	Asako and Wakasugi (1984)	1	0.301	0.301	0.301
2	Hori（1989)	5	0.189	0.412	0.281
3	Iwamoto（1990)	9	0.055	0.416	0.281
4	Miyawaki and Tobita（1991)	1	0.065	0.065	0.065
5	Asako and Sakamoto（1993)	8	-0.007	0.177	0.109
6	Asako et al.（1994)	48	-0.388	1.013	0.256
7	Nishigaki（1994)	2	0.221	0.225	0.223
8	Mitsui, Takezawa and Kawauchi（1995a)	51	-0.251	0.284	0.099
9	Mitsui and Inoue（1995)	4	0.248	0.451	0.345
10	Mitsui, Takezawa and Kawauchi（1995b)	49	-0.251	0.251	0.096
11	Mitsui, Inoue and Takezawa（1995)	21	-0.162	0.394	0.133
12	Okui（1995)	19	-0.136	0.243	0.045
13	Iwamoto et al.（1996)	38	-0.560	0.580	0.082
14	Yang（1997)	9	0.112	0.255	0.143
15	Nishizu（1997)	184	-0.749	0.740	0.104
16	Kaneuchi（1998)	5	-0.068	0.123	0.030
17	Hatano（1998)	12	0.252	0.394	0.317
18	Sakamoto（1998)	45	-0.774	0.948	0.266
19	Yoshino and Nakajima （1999)	3	-0.152	0.203	0.077
20	Ida and Yoshida （1999)	87	-0.305	0.651	0.125
21	Nozaki（1999)	99	-0.646	0.733	0.246
22	Okui（2000)	51	-0.227	0.365	0.129
23	Yamano and Ohkawara (2000)	2	0.034	0.148	0.091
24	Nagashima（2000)	3	0.200	0.360	0.257
25	Ohkawara, Yamano and Kim（2001)	10	0.064	0.082	0.071
26	Tanaka（2001)	2	-0.130	0.095	-0.018
27	Asako and Noguchi (2002)	12	-0.283	0.207	0.008
28	Endo（2002)	2	0.097	0.100	0.099
29	Homma and Tanaka（2004)	4	-0.029	0.223	0.093
30	Goto（2004)	46	-0.074	0.336	0.094
31	Kataoka (2005)	4	-0.065	0.313	0.139
32	Nakahigashi (2008)	1	0.255	0.255	0.255
33	Okubo (2008)	8	-0.063	0.130	0.049
34	Miyara and Fukushige (2008)	36	0.051	1.042	0.358
35	Kameda and Lee（2008)	36	-0.139	0.242	0.096
36	Hayashi（2009)	8	-0.147	0.733	0.316
37	Kawaguchi, Ohtake and Tamada (2009)	6	-0.400	0.050	-0.178
38	Mizutani and Tanaka (2010)	2	0.073	0.074	0.074
39	Lee（2011)	3	0.141	0.198	0.178
40	Miyagawa, Kawasaki and Edamura（2013)	40	-2.455	1.518	0.140
41	Kataoka (2014)	2	-0.120	0.100	-0.010
42	Okoshi（2015)	18	-0.131	0.140	0.044
43	Nakahigashi（2017)	6	0.028	0.226	0.119
44	Kameda, Lu and Fukui （2022)	36	0.012	0.310	0.119
	Total	1038	-2.455	1.518	
	Average				0.146

To capture the characteristics of the above samples, a histogram was created as shown in Figure 1. The horizontal axis is the value of the output elasticity, and the vertical axis is the number of samples. As a result, many of the estimated results are concentrated around the above mean of 0.146. Most of the samples are positive, but there are a certain number of samples that are negative (indicating that public capital had a negative effect on output).

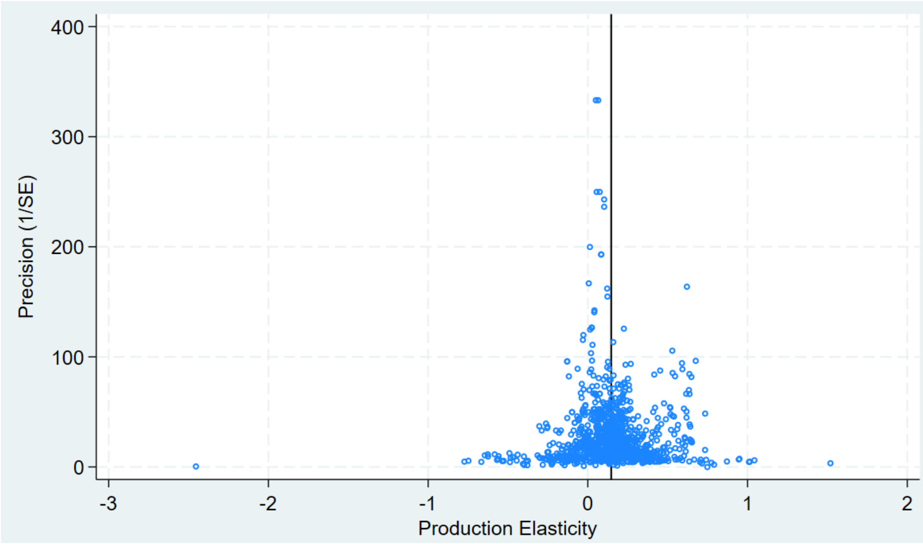
Figure 1: Histogram of the Sample



2.4 Preliminary Analysis of Publication Bias

For the above sample, a funnel plot as shown in Figure 2 was created to check for publication bias. Publication bias occurs when researchers and editors tend to report and publish more statistically significant results than those that are not. If the presence of publication bias is confirmed, the sample may not be representative of the true population of estimates. The inverse of the standard error (the precision of the parameter) is plotted on the vertical axis, the value of the output elasticity is plotted on the horizontal axis, and the mean of the effect is plotted as a solid vertical line. Overall, there is a degree of symmetry around the same mean, and no significant publication bias is visually apparent.

Figure 2: Funnel Plot



3. Methodology

3.1 Model Specification

To quantitatively examine the above publication bias and conduct a meta-analysis to address it, the FAT-PET-PEESE method was used (Stanley and Doucouliagos 2014). This method is considered to be one of the most effective in addressing publication bias in order to conduct a meta-analysis (Irsova et al. 2023).

Specifically, the Funnel Asymmetry Test (FAT; tests for the presence or absence of publication bias) and the Precision Effect Test (PET; tests for the presence or absence of effects independent of publication bias) are first performed using the following equations:

$$effect_i = \gamma_1 + \alpha_1 SE_i + \varepsilon_i \qquad (2)$$

where γ_1 is the effect without publication bias and α_1 is the degree of publication bias. The statistical significance of each is tested. If the former is significant, the existence of the effect excluding publication bias is statistically confirmed. If the latter is significant, the existence of publication bias is statistically confirmed. Since the error term in equation (2) is heteroskedastic, it is estimated using weighted least squares (WLS) weighted by the standard error of each sample (Stanley and Doucouliagos 2017).

Second, the Precision Effect Estimate with Standard Errors (PEESE) is used to obtain the value of the effect (infrastructure output elasticity) beyond publication bias. If the results of the above

PET confirm the existence of the effect beyond publication bias, the squared term is more desirable to approximate the relationship between each effect and standard errors (Stanley and Doucouliagos 2014). Therefore the following equation in which the standard error in the second term on the right side of equation (1) is replaced by the variance is used:

$$effect_i = \beta_1 + \alpha_2 \, SE_i^2 + \varepsilon_i \qquad (3)$$

where β_1 is the value of the effect beyond publication bias. Equation (3) is also estimated by the WLS, taking into account the heteroskedasticity of the error term and weighted by the variance of each estimated effect.

Third, to examine the factors that cause differences in the results of each estimate, PEESE is run with variables or moderators representing the type of infrastructure and estimation methods in each empirical study added to equation (3) above:

$$effect_i = \beta_1 + \sum_k \delta_k Z_k + \alpha_2 \, SE_i^2 + \varepsilon_i \qquad (4)$$

where β_1 is the value of the effect beyond publication bias and moderator effects and δ_k is the effect of moderator Z_k. To deal with the problem of multicollinearity, we estimate the variables for each moderator after centralizing them.

In estimating the above parameters, clustered (and robust to heteroskedasticity) standard errors for each study were used to deal with the possibility that the error terms in each estimation result within the same study may be correlated. Also, to deal with extreme outliers, thresholds (1 percentile) are set at the top and bottom of the data for the effect (output elasticity) and standard errors, and values above the thresholds are replaced with the thresholds.

3.2 Selection of Moderators

As moderators (factors that contribute to differences in production elasticities), differences in the nature of the infrastructure and analysis methods of each sample are concentrated on and 32 variables are selected in eight categories: (1) model specification; (2) target industry; (3) region; (4) infrastructure sector; (5) project entity, (6) econometric method, (7) data, and (8) publication. Of these, only two variables, YM and Date, are continuous variables, while the others are dummy variables. The description of each variable and the corresponding number of samples are shown in Table 2. In addition, the description of each category is as follows:

(1) Model specification: The moderator CRSAll is set for the samples that assume constant returns to scale for all factors of production, including public capital, while CRSPriv is set for those that assume constant returns to scale only for private capital and labor, excluding public capital. To account for infrastructure spillovers, some samples either integrate the neighboring prefecture's infrastructure stock into the study prefecture's stock or include the neighboring prefecture's infrastructure stock as a separate variable in the model. The SOa and SOd moderators are set for the former and the latter, respectively. In addition, CU is set for those who added private capital use as a separate variable to control for the effects of business cycle fluctuations.

(2) Target industry: Many of the samples use the real gross product of the country/regional bloc/prefecture as the explanatory variable. Regarding the scope of real gross product, there are cases that include both the private and public sectors, and cases that exclude the public sector and include only private sector production. The moderator Pri was set to those that fall under the latter case. First, Second, and Third are set for samples covering only the so-called primary (agriculture, forestry, and fisheries), secondary (manufacturing, mining, and construction), and tertiary (services, distribution, finance, and commerce) sectors of the private sector, respectively.

(3) Region: Each sample consists of either national-level macro data, prefectural data, or regional block data, which is a grouping of several prefectures. Eight prefectures (Tokyo, Saitama, Kanagawa, Chiba, Aichi, Osaka, Kyoto, and Hyogo) correspond to the three metropolitan areas of Tokyo (the capital), Nagoya, and Osaka (Kansai). These eight prefectures account for about one-third of Japan's infrastructure and more than half of Japan's gross domestic product. The moderator Urban is selected for the sample of the above eight prefectures or regional blocs including the above eight prefectures. Rural is selected for the sample of the remaining 39 prefectures or regional blocs not including the above eight prefectures.

(4) Infrastructure sector: Public capital or infrastructure can be divided into four sectors according to its main purpose. These are: 1) production infrastructure (roads, ports, airlines, telecommunications), 2) social infrastructure (housing, sanitation, education, parks), 3) land conservation infrastructure (erosion control, flood control, coastal protection), and 4) infrastructure for agriculture, forestry, and fisheries. Each of the above categories corresponds to that of the infrastructure stock statistics provided by the Japanese government. The sample for these specific sectors is only constructed using the Prod, Social, Disas, and Agri moderators, respectively.

(5) Project Entity: The project entity for public capital is generally divided between the central government (national government) and local governments. As an intermediate, there are projects that are implemented with subsidies from the central government to local

governments with certain restrictions on the use of funds. Kameda et al. (2022) show that the output elasticity of public capital under the jurisdiction of local governments is relatively high. To examine the effects of these different project entities, the moderators Cent, Sub, and Local moderators were set up for the sample of projects under the direct control of the central government, projects subsidized by the central government, and projects undertaken solely by local governments, respectively.

(6) Econometric method: In empirical analyses dealing with regional/prefectural panel data, it is common practice to control for region/prefecture-specific and year-specific effects. Unit and Time moderators for the sample were set using models that include these fixed effects, respectively. Trend, Multi, and SC were set for those that included the annual trend as a separate variable, those that attempted to address multicollinearity through ridge regression, and those that addressed serial correlation in the error term by adding autoregressive variables, respectively. In statistical analysis of macro data, cointegration tests have become the norm in order to eliminate the possibility of spurious regression. The Coint moderator was thus set to the one that confirmed the cointegration relationship among variables by such tests. In Japan's empirical analyses, the issue of simultaneity or reverse causality effects has traditionally been raised, given the institutional background in which public investment has been prioritized in regions/prefectures with relatively low production. This point is addressed using instrumental variable (IV) or simultaneous estimation with the public investment function. The moderator End is set for the sample that falls under this category.

(7) Data: For the type of data, the median year of data covered by each sample is first set as the moderator YM to examine the impact of differences based on time frame. In addition, as moderators for the different attributes of the data, Dif was set for those who use first-difference data instead of level data, Cross for those who use cross-sectional data, Pref for those who use prefecture data, and Reg for those who use data by regional block, respectively.

(8) Publication: To account for differences by publication type for each sample, the Pub moderator was first set for those published as peer-reviewed academic journals or academic books, excluding journals whose peer-review status cannot be confirmed. In addition, the moderator Date is set to the year of publication for each sample.

Table 2: Selected Moderators

Category		Moderator	Estimates	Note
Model Specification	CRSAll	Constant Return to Scale for All Sector	354	Constant returns to scale restriction across all inputs (private capital + labor + public capital)
	CRSPriv	Constant Return to Scale for Private Sector	212	Constant returns to scale restriction across private inputs (private capital + labor)
	SOa	Spillover Effect (aggregated)	53	Infrastructure stock of neighboring prefectures integrated into the infrastructure stock of the study prefecture
	SOd	Spillover Effect (disaggregated)	30	Infrastructure stock of neighboring prefectures included as a separate variable
	CU	Capital Utilization	175	Capital utilization rate (or its proxy variable, e.g., electricity consumption, unemployment rate) included as a separate variable
Industry	Pri	Private Sector Production	281	Production effects of the private sector (excluding the public sector)
	First	Agriculture, Forestry and Fishery Industry	67	Production effects of primary industry (agriculture, forestry, and fisheries)
	Second	Manufacturing, Mining and Construction Industry	26	Production effects of secondary industries (manufacturing, mining, and construction)
	Third	Service, Logistics, Finance and Commerce Industry	23	Production effects of tertiary industries (services, distribution, finance, and commerce)
Region	Urban	Urban Region	96	Effects on eight prefectures (Tokyo, Saitama, Chiba, Kanagawa, Osaka, Kyoto, Hyogo, Aichi) or regional blocs including these eight prefectures
	Rural	Rural Region	375	Effects on the remaining 39 prefectures or regional blocs not including the above eight prefectures
Sector	Prod	Production Infrastructure	138	Effects of production infrastructure (roads, ports, airlines, telecommunications)
	Social	Social Infrastructure	119	Effects of social infrastructure (housing, sanitation, education, parks)
	Disas	Disaster Prevention Infrastructure	88	Effects of land conservation infrastructure (erosion control, flood control, coastal protection)
	Agri	Agriculture, Forestry and Fishery Infrastructure	77	Effects of agriculture, forestry, and fisheries infrastructure
Project Entity	Cent	Projects Implemented by the Central Government	24	Effects of projects under direct control of the central government
	Sub	Projects Subsidized by the Central Government	24	Effects of projects subsidized by the central government
	Local	Projects Implemented only by the Local Governments	24	Effects of projects undertaken solely by local governments
Econometric Method	Unit	Unit Specific Effect	329	Unit (prefecture/regional block) effects included as separate variables
	Time	Time Specific Effect	193	Time (year) effect included as a separate variable
	Trend	Time Trend	185	Time trend included as a separate variable
	Multi	Multicollinearity	135	Ridge regression is used to address multicollinearity
	SC	Serial Correlation	98	Addressing serial correlation of error terms by adding an autoregressive variable, etc.
	Coint	Cointegrating Relationship	36	Eliminating the possibility of spurious regression by conducting a cointegration test
	End	Endogeneity	178	Addressing simultaneity or reverse causality by using instrumental variables or simultaneous estimation with public investment functions
Data	YM	Sample Year Median	-	Median of time frame or years covered (e.g., "1990" for data from 1980 to 2000)
	Dif	First Difference	25	Using first-difference (not level) data
	Cross	Cross-section Data	153	Using cross-section data
	Pref	Prefectural Data	901	Using prefectural data
	Reg	Regional Block Data	33	Using regional block data that aggregated prefectural data
Publication	Pub	Published in a Peer-reviewed Journal or Book	536	Published as peer-reviewed academic journals or academic books (excluding journals whose peer-review status is not confirmed)
	Date	Date of the Study (in Years)	-	Year of publication

4. Results

4.1 Verification of Publication Bias

The results for FAT-PET (WLS using the inverse of the standard error of each effect as weights) are shown in the first column of Table 3. For robustness checks, the results of OLS (column 2) and WLS using the inverse of the number of estimates per study as weights (column 3) are also reported.

Table 3: FAT-PET results

	WLS weighted by the inverse of the standard error	**OLS**	**WLS weighted by the inverse of the number of estimate reported per study**
Standard Error	-0.210	-0.271	-0.146
(publication bias)	(0.654)	(0.312)	(0.375)
Constant	0.162**	0.167***	0.149***
(effect beyond bias)	(0.055)	(0.030)	(0.023)
Observations	1,038	1,038	1,038

Notes: Robust standard errors, clustered at the study level, are reported in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01.

The results (column 1) show that publication bias (row 1) is not statistically significant. This is also true for the other estimated results (columns 2 and 3). The results confirm the funnel plot above, in which no large publication bias was found.

The effect excluding publication bias (row 2) is positive and statistically significant at 0.162. This positive sign and statistical significance remain the same in the other estimation results (rows 2 and 3). This confirms the existence of a positive output elasticity for Japanese infrastructure, even after accounting for the possibility of publication bias.

4.2 Output Elasticity of Japan's Infrastructure

The results for PEESE (WLS using the inverse of the variance of each effect as weights) are shown in the first column of Table 4. For robustness checks, the results of OLS (column 2) and WLS (column 3) using the inverse of the number of estimates per study as weights are also reported.

Table 4: PEESE results without moderator

	WLS weighted by the inverse of the variance	**OLS**	**WLS weighted by the inverse of the number of estimate reported per study**
Variance	-0.273	-0.768	-1.141
	(4.527)	(0.606)	(0.789)
Constant	0.149**	0.154***	0.150***
(effect beyond bias)	(0.053)	(0.019)	(0.016)
Observations	1,038	1,038	1,038

Notes: Robust standard errors, clustered at the study level, are reported in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01.

The results (column 1) show that the effect excluding publication bias (row 2) is 0.149 and statistically significant. For the other estimated results (rows 2 and 3), the effect values are generally around 0.15. Thus, the output elasticity of public capital infrastructure in Japan is 0.149, excluding the effects of the moderators discussed below.

4.3 Factors that Make a Difference in the Elasticity

The estimation results for PEESE with all moderators added (unrestricted model) are shown in the first column of Table 5. The estimation results for PEESE with only 11 of these moderators that were statistically significant (restricted model) are shown in the fourth column of the same table. In both cases, the results of OLS (columns 2 and 5) and WLS using the inverse of the number of estimates per literature as weights (columns 3 and 6) are also reported for robustness checks.

Table 5: PEESE results including moderators

	Unrestricted			Restricted		
	WLS weighted by the inverse of the standard error	**OLS**	**WLS weighted by the inverse of the number of estimate reported per study**	**WLS weighted by the inverse of the standard error**	**OLS**	**WLS weighted by the inverse of the number of estimate reported per study**
CRSAll	-0.026 (0.027)	0.008 (0.023)	0.029 (0.021)			
CRSPriv	0.184*** (0.046)	0.16 (0.097)	-0.009 (0.039)	0.201*** (0.059)	0.13 (0.081)	0.012 (0.042)
SOa	0.076** (0.027)	0.140*** (0.034)	0.155*** (0.033)	0.132*** (0.038)	0.090* (0.044)	0.005 (0.035)
SOd	-0.024 (0.023)	0.002 (0.040)	0.009 (0.030)			
CU	0.023 (0.047)	0.086* (0.034)	0.125*** (0.034)			
Pri	-0.058* (0.026)	0.01 (0.043)	0.055 (0.030)	-0.087** (0.032)	-0.023 (0.047)	0.026 (0.038)
First	0.057 (0.054)	0.166*** (0.046)	0.210*** (0.041)			
Second	0.065 (0.053)	0.012 (0.060)	0.114*** (0.028)			
Third	0.06 (0.061)	0.039 (0.054)	0.078 (0.043)			
Urban	0.121* (0.055)	0.092 (0.047)	0.127*** (0.035)	0.119*** (0.031)	0.132* (0.053)	0.081* (0.039)
Rural	0.159* (0.068)	0.032 (0.051)	0.080* (0.034)	0.151** (0.048)	0.082 (0.051)	0.047 (0.040)
Prod	0.003 (0.065)	0.042 (0.055)	-0.036 (0.027)			
Social	-0.099*** (0.020)	-0.054* (0.025)	-0.034 (0.024)	-0.083*** (0.016)	-0.044 (0.043)	-0.049 (0.040)
Disas	-0.047 (0.045)	-0.089 (0.050)	-0.053 (0.029)			
Agri	-0.047 (0.030)	0.027 (0.047)	0.009 (0.036)			
Cent	-0.011 (0.044)	-0.054 (0.064)	-0.057 (0.050)			
Sub	-0.034 (0.049)	-0.002 (0.067)	-0.003 (0.053)			
Local	0.181*** (0.041)	0.130* (0.063)	0.128** (0.048)	0.192*** (0.031)	0.105** (0.037)	0.109*** (0.029)
Unit	-0.021 (0.038)	-0.028 (0.029)	-0.002 (0.021)			
Time	-0.064* (0.027)	-0.083** (0.027)	-0.083* (0.037)	-0.049* (0.025)	-0.046 (0.027)	-0.052 (0.054)
Trend	-0.015 (0.043)	-0.043 (0.061)	-0.038 (0.043)			
Multi	-0.066 (0.034)	0.023 (0.057)	-0.084 (0.055)			
SC	-0.099 (0.091)	0.052 (0.061)	-0.009 (0.028)			
Coint	0.128 (0.113)	-0.014 (0.092)	-0.051 (0.059)			
End	0.001 (0.017)	0.046 (0.039)	0.031 (0.032)			
YM	-0.003** (0.001)	-0.004 (0.003)	-0.005** (0.002)	-0.003* (0.001)	-0.002 (0.003)	-0.002 (0.003)
Dif	0.171 (0.196)	0.133 (0.090)	0.126 (0.083)			
Cross	-0.014 (0.038)	-0.121** (0.044)	-0.152*** (0.041)			
Pref	0.029 (0.086)	0.178 (0.106)	-0.068 (0.044)			
Reg	0.074 (0.128)	0.161 (0.123)	-0.07 (0.053)			
Pub	0.040* (0.020)	0.06 (0.032)	-0.025 (0.024)	0.029 (0.021)	0.062* (0.028)	0.042 (0.027)
Date	-0.008** (0.003)	-0.005 (0.004)	0.001 (0.002)	-0.006*** (0.002)	-0.002 (0.003)	-0.002 (0.002)
Variance	-3.314 (2.605)	-1.005* (0.500)	-1.204** (0.443)	-1.89 (2.195)	-0.751 (0.508)	-0.872 (0.632)
Constant	0.180*** (0.017)	0.157*** (0.014)	0.150*** (0.010)	0.166*** (0.018)	0.154*** (0.016)	0.157*** (0.016)
Observations	1038	1038	1038	1038	1038	1038

Notes: Robust standard errors, clustered at the study level, are reported in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01. All variables are centered, except Variance.

The PEESE results with all moderators added (column 1) show that the value of the output elasticity after accounting for publication bias and the effect of all moderators is 0.180, which is statistically significant. The other estimation results adjusted for weights (columns 2 and 3) have a slightly lower value but have a positive sign and are statistically significant. The results for the coefficient for each moderator in the PEESE results (column 1) are as follows:

(1) Model specification: The coefficient of CRSAll (including the public sector) is negative (but insignificant) and the coefficient of CRSPriv (excluding the public sector) is significantly positive with respect to the constant returns to scale restrictions. The results indicate that output elasticity increases when there is no restriction on the size of public capital as an externality, which is consistent with intuition. The coefficient of SOa (integrating the stock of neighboring prefectures) on the spillover effect is significantly positive, while the coefficient of SOd (adding the stock of neighboring prefectures as a separate variable) is negative but insignificant. This confirms the existence of regional infrastructure spillovers. The coefficient of CU (including the capital utilization rate) is insignificant.

(2) Target industry: The coefficient of Pri (excluding public sector output) is negative and significant. This indicates that the output elasticity is lower when public sector output is excluded, which is consistent with intuition. None of the industry-specific variables (First, Second, Third) are significant.

(3) Region: The coefficients are positive and significant for both urban (metropolitan) and rural (non-metropolitan) areas, with the coefficient being higher for rural areas. Given the overall level of output per infrastructure stock in Japan's metropolitan areas, productivity per unit (not elasticity) may be higher in metropolitan areas; the above difference in elasticity alone cannot be used to determine the priority of regional allocations of public investment.

(4) Infrastructure sector: The coefficients for Prod (production infrastructure), Disas (land conservation infrastructure) and Agri (agriculture, forestry and fisheries infrastructure) are insignificant, while those for Social (social infrastructure) are significantly negative. This indicates that the output elasticity of the social infrastructure sector is relatively low compared to other sectors, which is consistent with intuition. The main purpose of the social infrastructure sector is not production, but rather welfare; the above productivity difference alone cannot be used to determine the priority of public investment allocation among sectors.

(5) Project entity: The coefficients for Local (projects undertaken solely by the local government) are large, positive, and significant, while those for Cent (national government projects) and Sub (projects subsidized by the national government) are insignificant. This supports the argument in the above literature that local governments may have a relatively better capacity to make productive public investments in their respective regions.

(6) Econometric methods: The coefficient of Unit (unit effect) was insignificant, while the coefficient of Time (year effect) was negative and significant. The coefficients of Trend (annual trend), Multi (ridge regression), SC (serial correlation), Coint (cointegration test), and End (simultaneity) are all insignificant.

(7) Data: The coefficient of YM (median year of data) was slightly negative and significant. This suggests the possibility of a slight but gradual decline in infrastructure productivity during the postwar economic growth and subsequent stabilization period. A model with a quadratic term of YM was also tested, but the coefficient of the quadratic term was not significant, indicating the robustness of the linear trend. The coefficients for Dif (first difference), Cross (cross section), Pref (prefecture), and Reg (regional block) are all insignificant.

(8) Publication: The coefficient on Pub (peer-reviewed academic journal or academic book) is positive and significant. This suggests that better empirical analyses in general may have estimated relatively high elasticity values. The coefficient on Date (year of publication) is negative and significant. This suggests that the estimated production elasticities may have gradually declined over time due to effects related to the data and the analysis methods that were not fully accounted for by the other moderators above.

Looking at the results of the restricted model (column 4), in which only the statistically significant moderators are variables among those mentioned above, the value of the output elasticity after accounting for publication bias and the effect of the selected moderators is 0.166, which is statistically significant. The difference in values with the other estimation results (columns 5 and 6) is smaller than in the case where all moderators are added (unrestricted model). The coefficients of the selected moderators are also all significant except for Pub (peer-reviewed academic journal or academic book). Based on the above, this estimated result (column 4) is the benchmark model for this paper.

4.4 Estimation of the Elasticity According to Heterogeneity

Using the above benchmark model (column 4 of Table 5), the output elasticity of Japan's infrastructure according to heterogeneity in terms of project entity, time frame, and region can be estimated, as shown in Table 6. Columns 1 and 2 show the output elasticity of projects undertaken by the national government or projects subsidized by the national government, while columns 3 and 4 show the output elasticity of projects undertaken solely by local governments. As an additional classification, output elasticities are also shown for metropolitan areas and non-metropolitan areas, respectively. Specifically, Urban (metropolitan area), Time (time effect), and Pub (externally peer-reviewed academic journal or academic book) are set to one, Date (year of publication) is set to a maximum value (the latest year: 2022), moderators other than the above are set to zero, and YM (median year of data) has been adjusted for each year (rows 1 to 6) in the first column. Column 2 is based on this, with Urban set to zero and Rural (non-metropolitan) set to one. Columns 3 and 4 show the results of columns 1 and 2, with Local (projects undertaken solely by local government) changed to one.

Table 6: Estimated production elasticities according to heterogeneity

	Central Government		Local Government	
Year	Metropolitan Areas	Non-metropolitan Areas	Metropolitan Areas	Non-metropolitan Areas
1960	0.108	0.140	0.300	0.332
1970	0.076	0.109	0.268	0.300
1980	0.044	0.077	0.236	0.268
1990	0.012	0.045	0.204	0.237
2000	-0.020	0.013	0.172	0.205
2010	-0.051	-0.019	0.140	0.173

From the above table, it can be seen that the output elasticity of infrastructure in Japan is highly dependent on heterogeneity such as project entity, time frame, and region (metropolitan/non-metropolitan). When a project is undertaken solely by local government the elasticity is 0.192, higher than for national government projects or projects subsidized by the national government. The elasticity is 0.032 higher in non-metropolitan areas than in metropolitan areas, but it is necessary to compare the absolute value of each region's infrastructure stock and output when considering the regional allocation of public investment. Moreover, the value of the elasticity gradually decreases over time.

5. Discussion

The first notable point to emerge from the above analysis is that the sample considered here does not significantly confirm the existence of publication bias. One interpretation is that the growing skepticism about the effects of public investment since the 1990s may not have prevented researchers from publishing results showing small or negative production elasticities. In addition, although our sample includes published academic papers and books, a significant number of them were not peer-reviewed or could not be confirmed as peer-reviewed, which may have contributed to weakening any publication bias found.

Second, the overall output elasticity of Japanese infrastructure is confirmed as significantly positive when heterogeneity is not taken into account. This is generally consistent with the conclusions of previous qualitative survey literature on the subject and confirms the prevailing view that infrastructure has had a positive impact on Japan's economic growth to date. The value of the elasticity is 0.149, which roughly approximates the average output elasticity found in the previous literature that reported on cross-country meta-analyses.[2]

Third, however, the above output elasticity values are highly sensitive to heterogeneity of infrastructure such as project entity, time frame, region, and sector. Projects undertaken solely by local governments have higher elasticities than those under the direct control/subsidy of the national government, and non-metropolitan areas have higher elasticities than metropolitan areas. In addition, the time frame of the data shows that the elasticity decreases with each passing year. This may be due to the fact that infrastructure, like other factors of production, generally has the property of reducing marginal productivity, or it may be that Japan's recent infrastructure investment has not been driven by production efficiency alone. As a result, it is possible that the sign of the elasticity has been negative in recent years for projects directed or subsidized by the central government. The relatively low elasticity observed for social infrastructure is a reasonable result considering that the main purpose of this infrastructure sector is not production but welfare. This suggests the need to evaluate the impact of infrastructure from perspectives other than production.

6. Conclusion

This study attempted to quantify the impact of public capital on output in Japan by focusing on the accumulation of empirical analyses that have been overlooked in previous meta-analyses. While addressing the possibility of publication bias, a meta-analysis of the past empirical analyses (1,038 samples) was conducted to identify the output elasticity of public capital in Japan and its heterogeneity (factors that make a difference in the effects).

As a result, first, as noted the existence of publication bias was not significantly confirmed. Second, it was confirmed that the output elasticity of Japanese infrastructure is positive at 0.146 when heterogeneity is not taken into account. Third, this output elasticity is significantly affected by heterogeneity of infrastructure in terms of project entity, time frame, region, and sector. Projects undertaken solely by local governments have higher elasticities than those under the

[2] Bom and Lightart (2014) found long-run output elasticities of infrastructure of 0.145 (local government) and 0.122 (central government), respectively, Núñez-Serrano and Velázquez (2017) found a long-run output elasticity of 0.16, and Foster et al. (2023) also found an output elasticity of infrastructure in the absence of a moderator of 0.161.

direct control/subsidy of the national government, and non-metropolitan areas have higher elasticities than metropolitan areas. The elasticity decreases with each passing year. Social infrastructure such as housing, sanitation and education have relatively low elasticity compared to other sectors.

Based on the above, the following two points should be considered in the future. The first is the need to analyze the impact of infrastructure using different scales. It is desirable to evaluate social infrastructure in terms of welfare, which is the main objective of such infrastructure. Although there is some previous literature on this point (Akagi 1998; Hayashi 2003b; Karaki et al. 2006; Kondo 2008), no meta-analysis has been conducted. In addition, a comprehensive evaluation of the effects of infrastructure, including the effects of demand creation and income redistribution through the flow of public investment, which requires analysis using a macroeconomic structural model, is another future task.

The second is to draw lessons for other countries. Japan, after a period of rapid postwar growth followed by a period of stable growth, is now facing challenges such as fiscal difficulties, population decline, and aging infrastructure. By comparing Japan's experience and the results of this study with the context of other countries, especially those emerging economies that are vigorously promoting infrastructure development, it may be possible to extract policy suggestions for other countries in environments similar to Japan's past and present.

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Abstract in Japanese

要　約

公共資本／インフラの生産弾力性を測定する試みは過去数十年にわたり数多くなされてきたが、その結果は多様である。本稿では、過去のメタ分析で見過ごされてきた日本における実証分析の蓄積に焦点を当て、44 の先行研究による 1,038 の推定値のメタ分析を通じ、日本における公共資本の生産への影響を定量化した。その結果、出版バイアスの有意な証拠は確認されなかった。日本におけるインフラの生産弾力性は 0.146 と正であり、この値は事業主体、時期、地域、分野などの対象インフラの異質性に強く影響されている。地方自治体が単独で行うプロジェクトや大都市圏以外のプロジェクトは相対的に弾力性が高いが、その値は時間の経過とともに低下する。住宅、衛生、教育などの社会インフラは、他分野と比べ相対的に弾力性が低い。これらの結果は、公共資本の生産性に関する議論に新たな示唆を与えるとともに、日本におけるインフラの生産弾力性の最初のメタ分析としてベンチマークを提供するものである。

キーワード: 公共資本、インフラ、日本、生産性、生産弾力性、メタ分析、出版バイアス