Chapter 2
The Productivity of Public Capital: A Meta-analysis

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Abstract The paper measures the contribution of public capital to private output using a simple meta-analysis and a meta-regression analysis based on panel data. We find an output elasticity of public capital of 0.14 in the random effects model, which is substantially smaller than the simple arithmetic average value of 0.20. Reported estimates of the output elasticity of public capital show considerable heterogeneity. We identify the type of public capital, the level of aggregation of the public capital data, the country type, the econometric specification, and publication bias as sources of variation.

Keywords Infrastructure • Meta-analysis • Meta-regression analysis • Public capital stock • Public investment

2.1 Introduction

Discussions among academics and policy makers about the contribution of the public capital stock to private output have been ongoing during the last two decades. Recently, this debate has revived within the European Union (EU), primarily driven by two developments. First, the Lisbon Agenda agreed by EU leaders in March 2000 – which aims to create a climate that stimulates economic growth, competitiveness, and innovation in Europe – has put growth issues back on the European policy agenda. The second is the renewed interest in fiscal policy rules since the inception of the Stability and Growth Pact, which applies to countries forming the

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Economic and Monetary Union. Many economists feared that the EU fiscal rules – imposing ceilings of 3 and 60% on the fiscal deficit-to-GDP and public debt-to-GDP ratios, respectively – would have a negative impact on public capital formation. Indeed, in many instances, governments find it easier to cut back on infrastructure investment rather than current expenditure, reflecting the long lags with which reductions in capital expenditures are felt. To provide input to the public capital debate, it is of importance to measure the contribution of public capital to private output.

Various authors have tried to measure the output elasticity of public capital by estimating a production function that includes the public capital stock as an input. Aschauer (1989, 1990) was one of the first to investigate this issue for the USA in an attempt to explain the productivity growth slowdown in the 1970s.[1] Indeed, public investment fell, and aggregate labour productivity growth declined slightly later, providing casual evidence of a linkage. Aschauer (1989) found in his econometric study that a 1% rise in the public capital stock increased private output by 0.39%. Since then, many studies have been undertaken for the USA and various other OECD countries. The findings of these studies generally extend from a significantly negative effect to a strongly positive effect of public capital on output.[2] So far, researchers have not attached much priority to reconciling these differences.

We quantitatively review the literature on the effects of public capital on private output by means of meta-analysis. In addition, we employ meta-regression analysis to analyze the determinants of observed heterogeneity across and between studies. Drawing on Stanley and Jarrell (1989) and Stanley (2001), meta-analysis can be defined as a body of statistical methods to summarize, evaluate, and analyze empirical results from primary studies. A problem with conventional reviews of the literature is that empirical studies are difficult to compare, owing to differences in theoretical specifications, employed empirical methodologies, and data definitions. Meta-analysis presents a more systematic and objective way to summarize empirical results. In addition, it allows us to explain the wide study-to-study variation by fundamental economic variables and the researcher's choice of research design. In this way, an estimate of the output elasticity of public capital can be derived, which researchers and policy makers can use as an input into their analyses.[3]

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[1]Mera (1973) was the first study that estimated for nine Japanese regions a production function including some form of public capital, which he refers to as "social capital." For example, transportation and communications facilities, soil and water conservation, health and educational facilities. The work of Mera was followed by two papers by Ratner (1983) and Da Costa et al. (1987).

[2]Only a small number of studies have been reported. More details on the output elasticities of public capital can be found in Table 2.1 below.

[3]Meta-analysis has a long-standing tradition in psychological and medical research. Environmental and transport economists were the first to apply meta-analysis in economics in the 1980s. Since then, it has been picked up by researchers in other fields in economics such as labour economics (e.g., Card and Krueger 1995), industrial organization (e.g., Button and Weyman-Jones 1992), and international economics (e.g., De Mooij and Ederveen 2003).

Although various authors have reviewed the literature on the productivity of public capital,[4] only one study (i.e., Button 1998) has applied a meta-regression analysis. Button's (1998) analysis covers 26 studies, which are published during 1973–1994. His analysis yields a bare minimum of 28 data points. Our paper extends Button's study in four ways. First, our sample for the meta-analysis covers all relevant studies up to and including the year 2005, giving rise to a meta-dataset of 49 studies. Our larger meta-regression dataset – also including studies not reporting any standard errors – incorporates 55 studies and encompasses 248 observations. Second, we conduct a standard meta-analysis in addition to a meta-regression analysis to arrive at a *meta* output elasticity of public capital. Third, we test for a larger set of potential determinants of differences across studies, including variables describing the functional and econometric specification of the production function, the capital stock definition, and the level of economic development. Finally, Button (1998) employs a pooled ordinary least squares (OLS) model in its meta-regression analysis,[5] whereas we exploit the panel structure of the data by taking multiple observations from the same study. We estimate various standard panel data models, namely, the fixed effects model, the random effects model, and an extended Generalized Least Squares (GLS) model, which corrects for heteroscedasticity in the error term. In view of the larger number of observations and use of more advanced estimation techniques, we expect to find more efficient and reliable estimates.

Our analysis finds an output elasticity of public capital of 0.14 in the random effects meta-analysis model, which is substantially below the simple average of 0.20 and the value of 0.39 initially found by Aschauer (1989). Reported estimates show a substantial amount of observed heterogeneity. Studies employing core infrastructure, using data at the national level, featuring publication bias, and estimating the equation in logarithmic levels find larger output elasticities of public capital. In contrast, studies using data for the USA and imposing an economies-of-scale restriction on the coefficients of the production function find smaller output elasticities of output.

The remainder of the chapter is structured as follows. Section 2.2 discusses definitions, presents the various methodological approaches used to estimate the impact of public capital on private output, and studies stylized facts. In addition, it gives an overview of the criticisms launched against the main approach, that is, the production function approach. Section 2.3 describes the meta-sample and presents the results of a simple meta-analysis. Section 2.4 formulates hypotheses to explain differences across studies and presents results of the meta-regression analysis. Section 2.5 concludes the chapter.

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[4] See the studies by Munnell (1991, 1992), Gramlich (1994), Pfahler et al. (1996), Button (1998), Sturm et al. (1998), Button and Rietveld (2000), Mikelbank and Jackson (2000), IMF (2004), and Romp and De Haan (2007).

[5] Button's (1998) analysis is basically a cross-sectional approach given the limited number of observations.

2.2 Public Capital and Private Output

What do we mean by infrastructure investment? How is this related to the public capital stock? Which concept of public capital is typically used in empirical analyses? These questions need to be addressed before we venture into the methodology of measuring the output effects of public capital.

2.2.1 Definitions

Gramlich (1994, p. 1177) defines infrastructure capital from an economic point of view as "large capital intensive natural monopolies such as highways, other transportation facilities, water and sewer lines, and communications systems." Although most of these systems are publicly owned, in some cases, they are privately owned, for example, a firm that constructs its own road to connect itself to the main highway. The literature generally defines infrastructure capital based on ownership.

Most studies employ a *narrow definition* of public capital that includes the tangible capital stock owned by the public sector, excluding military structures and equipment. More specifically, the intangible capital stock covers *core infrastructure*, hospitals, educational buildings, and other public buildings. Core infrastructure in turn consists of roads, railways, airports, and utilities such as sewerage and water facilities (Aschauer 1990). Some studies use a *broad definition* of public capital by including human capital investment (e.g., Garcia-Milà and McGuire 1992) or health and welfare facilities (e.g., Mera 1973). The latter components are hard to measure, which explains why most authors focus on narrowly defined public capital.

The concept of public capital may also differ owing to differences in the level of government at which it is measured. Various studies focus on the national public capital stock, including all levels of governments (federal, state, and local), for example, Aschauer (1989), whereas others deal only with capital stocks defined at the regional level (e.g., Garcia-Milà and McGuire 1992) or city level (e.g., Duffy-Deno and Eberts 1991). The majority of studies have a fairly comprehensive coverage including all levels of government.

2.2.2 Methodologies Employed in the Literature

The services of public capital are almost never sold on markets, except for toll fees for highway use, which makes it difficult to assess the economic value of public capital. Nevertheless, economists have estimated the stock of public capital, which is subsequently used as an input into the production function approach (see below). To measure the public capital stock, the perpetual inventory method is employed, which is based on an estimate of the initial value of the capital stock to which gross investment flows are added and from which technical depreciation of the existing stock – based on the expected lifespans of the various types of assets – is subtracted.

2.2.2.1 Four Methodological Approaches

The literature has distinguished four approaches that study empirically the link between private output and public capital: the production function, vector autoregression (VAR), behavioural, and growth regressions approach. The production function approach is the most widely known and applied.[6] This approach considers the stock of public capital either as a separate input in private production (which we call the pure production function approach) or as a factor improving multifactor productivity (which is known as the growth accounting approach, as explored by Hulten and Schwab 1991b). In both cases, public capital is assumed to be strictly exogenous.

The VAR approach analyzes the relationships between public capital, private inputs, and private output without imposing a theoretical structure a priori. The multi-equation VAR approach – generally employing the same set of variables as in the production function approach – models every endogenous variable as a function of its own lagged value and the lagged values of the other endogenous variables and can therefore assess whether there is any feedback effect from private sector variables to the public capital stock.

The remaining two approaches yield elasticities that are incomparable with the output elasticities of public capital derived by both the production function and VAR approach. First, the behavioural approach, coined as such by Sturm et al. (1998), which employs cost or profit functions to assess whether public capital reduces firms' production costs or increases firms' profits. Second, the cross-country growth regressions approach, which specifies a reduced-form equation to estimate – using cross-sectional or panel data – the relationship between per capita private output growth and the public investment-to-GDP ratio. The growth regressions approach should be distinguished from studies that embed a production function in an estimated Ramsey type growth model. We classify the latter under the pure production function approach if an output elasticity of public capital is derived.

2.2.2.2 The Production Function Approach

Because the majority of studies in our database concern the production function approach, we discuss this approach in more detail. The cornerstone of the production function approach is a production function that incorporates the stock of public capital G_t as an input:

$$Y_t = A_t F\left[K_t, G_t, L_t\right], \tag{2.1}$$

[6]The surveys of Sturm et al. (1998) and Romp and De Haan (2007) identify 54 studies employing some form of production function approach. In 2005, the other three approaches feature the following number of papers: 21 studies concern VAR studies; 26 studies deal with cost or profit functions; and 12 studies use growth regressions.

where Y_t is real aggregate private output of a jurisdiction (region or country), A_t is an index of economy-wide productivity, K_t denotes the stock of (non-residential) private fixed capital, and L_t denotes employment (generally measured by total hours worked), $F[.]$ describes a general functional form, and t denotes time. The general idea of the production function approach is that the services of public capital are proportional to the stock of public capital – which is generally assumed to be a pure public good – and in that way enhance private output. Equation (2.1) shows that public capital may affect aggregate private output in two ways. The first is a direct effect, that is, $\partial F_t / \partial G_t > 0$. Second, public capital may raise private production by increasing the economy-wide productivity index, that is, $A_t(G_t)$, with $\partial A_t / \partial G_t > 0$. Equation (2.1) assumes Hicks-neutral public capital, which is a common assumption made in the public capital literature.[7]

Most studies employ a Cobb–Douglas production function:

$$Y_t = A_t K_t^{\alpha} G_t^{\beta} L_t^{\gamma}, \qquad \alpha, \beta, \gamma > 0 \tag{2.2}$$

where $\beta \equiv dlnY_t / dlnG_t$ is the output elasticity of public capital, which is hypothesized to be positive. This specification imposes a unit elasticity of substitution between factors of production. Furthermore, public capital and private inputs are cooperative factors of production, implying that a rise in G_t increases the marginal productivity of labour and private capital.

Taking natural logarithms on both sides of (2.2) we get a linearized specification:

$$lnY_t = lnA_t + \alpha lnK_t + \beta lnG_t + \gamma lnL_t \tag{2.3}$$

Equation (2.3) can readily be estimated in logarithmic levels or first differences of logarithmic levels (i.e., growth rates) to arrive at estimates of $\alpha, \beta,$ and γ. As can be seen from (2.3), the productivity index enters the equation in an additive way. Accordingly, it does not make a difference whether public capital enters the production function directly (as a separate input) or indirectly through the technology index. Following Aschauer (1989), many studies include a constant and a time trend as a proxy for technological progress (i.e., $lnA_t = a_0 + a_1 t$, where $a_0 > 0$ and $a_1 > 0$).

Incorporating public capital into the production function raises the issue of returns to scale in production. Imposing the restriction of constant returns to scale across all inputs in (2.1), which is represented by $\alpha + \beta + \gamma = 1$, yields

$$ln(Y_t / K_t) = lnA_t + \beta\, ln(G_t / K_t) + \gamma\, ln(L_t / K_t), \tag{2.4}$$

which features decreasing returns with respect to private inputs taken together (i.e., $\alpha + \gamma < 1$). Instead of using private capital productivity $ln(Y_t/K_t)$ as the left-hand side variable, some studies subtract lnL_t from both sides of (2.3) so as to arrive at

[7]Hicks-neutral public capital enters the production in such a way that the average and marginal products of all factors increase in the same proportion.

labour productivity as the dependent variable. An alternative model assumes constant returns to scale in private inputs (represented by $\alpha + \gamma = 1$):

$$ln(Y_t / K_t) = lnA_t + \beta lnG_t + \gamma ln(L_t / K_t), \quad (2.5)$$

allowing for increasing returns to scale across all inputs (i.e., $\alpha + \beta + \gamma > 1$).

Alternatively, various authors[8] have employed a translog specification, which nests many commonly used functional forms (including the Cobb–Douglas production function):

$$\begin{aligned} lnY_t &= lnA_t + \alpha lnK_t + \beta lnG_t + \gamma lnL_t \\ &\quad + a_k (\ln K_t)^2 + a_G (lnG_t)^2 + a_L (lnL_t)^2 \\ &\quad + b_{LK} lnL_t lnK_t + b_{LG} lnL_t lnG_t + b_{KG} lnK_t lnG_t, \end{aligned} \quad (2.6)$$

where a_i for $i = \{K, L, G\}$ and b_{jk} for $j = \{K, L\}$ and $k = \{G, K\}$ are parameters. The translog specification allows for non-unitary and non-constant elasticities of substitution between inputs. A potential problem in its use is that the second-order terms may give rise to multicollinearity. Consequently, many authors have resorted to the more restrictive Cobb–Douglas form.

2.2.3 Stylized Facts

The output elasticity of public capital can be rewritten to yield the marginal productivity of public capital, that is, $\partial Y_t / \partial G_t = \beta (Y_t / G_t)$, which is an indicator of the effective rate of return on government capital.[9] To assess whether investments in public capital are worthwhile, policy makers generally compare the marginal productivity of public capital with the marginal productivity of private capital, which equals the real rate of interest in a competitive market.

Gramlich (1994) argues that the return on public capital derived by Aschauer (1989) is too large to be credible. Indeed, depending on the year, it varies between 60 and 80%. The marginal output gain of an additional unit of private capital estimated from Aschauer's equation amounts to 30%, suggesting a difference between public and private capital of a factor two to three. Some observers (e.g., Aschauer 1990) point to the high rate of return found in R&D studies to justify the high output elasticities found in the early literature. Others (including Gramlich), however, argue that a large share of public capital is directed at less productive sectors of the economy such as waste treatment and pollution abatement, which is unlikely to contribute much to national output.

[8] Early adopters of the translog specification are, amongst others, Merriman (1990), Pinnoi (1994), and Dalamagas (1995).

[9] Here, it is assumed that public capital is remunerated based on its marginal productivity. Aaron (1990) has argued that in the presence of government pricing inefficiencies and the absence of markets, this is not a very realistic assumption.

Munnell (1992) is less pessimistic about the usefulness of empirical studies on public capital. First, studies published in the mid-1990s find lower – and thus more realistic – values of the output elasticity of public capital. Second, most studies find a positive and statistically significant output elasticity of public capital. What do the narrative surveys tell us about the evidence? The range of β estimates is wide, varying from negative values to values that are well in excess of that of private capital. The majority of studies, however, find a significantly positive elasticity (Stylized Fact 1). Ligthart (2002) derives an unweighted average of the output elasticity of public capital of 0.25 for OECD countries (if the production function is estimated in logarithmic levels), which is substantially below Aschauer's estimate.

Stylized Fact 1 *Public capital has a significant and positive effect on private output.*

The first author studying the output effect of public capital in a regional context is Mera (1973), who analyzes nine Japanese regions, employing a broad definition of public capital. Since then, various authors have found elasticities at the regional level that are much smaller than those from analyses using aggregate data for a single country (Stylized Fact 2), reflecting spillover effects.[10] Intuitively, some of the beneficial effects of public capital accrue to neighbouring regions and therefore cannot be internalized at the level of an individual region. In a Nash equilibrium – when governments set their optimal level of public goods provision given the level set by other governments – both regions end up with a less than socially optimal stock of public capital. Spillovers can be formalized as follows:

$$Y_{it} = A_{it} K_{it}^{\alpha} G_{it}^{\beta} G_{jt}^{\eta} L_{it}^{\gamma}, \qquad (2.7)$$

where G_{it} is the public capital stock of the home region i, G_{jt} is the public capital of the neighbouring region j, and $\eta > 0$ is the spillover effect.[11] The studies by Holtz-Eakin and Schwartz (1995a, b) and Boarnet (1998) find little evidence of spillover effects.

Stylized Fact 2 *The output elasticity of public capital for national-level studies is higher than that of regional-level studies.*

Aschauer (1990), and Sturm and De Haan (1995) stress that the composition of public investment matters for its effect on private production. The stock of core infrastructure (such as roads, railways, and airports) is more productive than other components of public capital such as educational and office buildings and hospitals (Stylized Fact 3). Accordingly, empirical studies that broaden the stock of public capital while staying within the boundaries of the narrow definition – thus necessarily

[10] Munnell (1990), Eisner (1991), Garcia-Milà and McGuire (1992), and Evans and Karras (1994), and Holtz-Eakin (1994).

[11] Some authors argue that spillover effects are likely to be positively related to the population size and the openness of regions, which is not reflected in the above equation.

including less productive components – find a lower β than studies focusing on core infrastructure only.

Stylized Fact 3 *Core infrastructure is more productive than other categories of narrowly defined public capital.*

Button (1998) suggests that the output elasticities derived from production function equations based on first differences of variables are lower than that of studies estimating the equation in levels of variables. However, the dummy variable representing studies based on a first differences specification is not significant in Button's analysis. In contrast, in an overview of studies for OECD countries, Ligthart (2002) reports elasticities derived from production functions estimated in first differences that are significantly higher for equations estimated in levels. No consensus has emerged yet.

2.2.4 Criticisms of the Production Function Approach

The early literature on the output elasticity of public capital has generated a substantial amount of criticism in the 1990s. Various authors have criticized Aschauer's model for being misspecified due to the omission of relevant macroeconomic variables. Tatom (1991) argues that Aschauer's approach is flawed because it omits energy prices, which should be included to account for the decline in the use of private capital induced by higher oil prices during the 1970s. Tatom (1991) and Crowder and Himarios (1997), for example, include energy prices in the production function to capture these kinds of supply shocks. Gramlich (1994), in turn, criticizes Tatom's approach for mixing production functions and cost functions. Instead of including energy prices, studies should employ a measure of the quantity of energy use in production. The study by Vijverberg et al. (1997), for instance, includes imported raw materials in the production function.

Another specification issue concerns the role of capacity utilization in the production function. Generally, production function studies incorporate a capital utilization rate – or, alternatively, the unemployment rate – to capture the effect of business cycle fluctuations on production factor use.[12] Because capacity utilization enters the productive function in an additive fashion in the logarithmic model, it does not affect the optimal capital–labour ratio. Indeed, capacity utilization affects all factor inputs across the board, which is a restrictive assumption. The majority of studies, therefore, do not include capacity utilization in the econometric specification.

Some of the early studies have been criticized for not properly accounting for common trends. Generally, time series on private output and the public capital stock contain a unit root or, in other words, they are non-stationary time series. If variables

[12]For example, Aschauer (1989), Hulten and Schwab (1991a), and Sturm and De Haan (1995) were early adopters of this specification.

are non-stationary, the usual test statistics have non-standard distributions, implying that the application of standard inference procedures gives rise to misleading results. In particular, one may find spurious relationships between inputs and outputs. Some studies have, therefore, proposed to eliminate the trend in variables by taking first differences of the time series.[13] Two criticisms were raised against first differencing. First, the growth rate of private output in a particular year is not strongly correlated with the growth rate in the capital stock during that same year, as lagged effects are likely to be important. Indeed, it may take a number of years before large construction projects are completed and become productive. Second, and related to the previous argument, first differencing may discard information on a possible long-run equilibrium relationship between a set of non-stationary time series, that is, the variables are cointegrated. Consequently, the focus of the analysis is shifted away from the long-run effects of public capital to the short-run effects. Instead of first differencing, the variables should be first tested for cointegration. If variables are cointegrated, it is justified to estimate the equation in levels of variables. In the mid-1990s, various authors have employed the Engle–Granger (1987) test and/or Johansen cointegration (1988) test (generally recognized to be superior to the former), giving rise to mixed results.

Aschauer (1989) and related studies assume that G_t is strictly exogenous, implying that the causality runs from public capital to private output. Some authors (e.g., Munnell 1992; Gramlich 1994) have pointed to the lack of attention paid to feedback effects. The direction of causality may run from output to public capital rather than the other way around. Indeed, higher output may increase the demand for public capital and generate favourable budgetary conditions to support an increase in public investment. Recently, a number of authors[14] have employed VAR models with a view to capture the dynamic interactions between output, public capital, and private capital.

Econometric studies employ very different concepts of public capital, which makes it hard to compare the results of these analyses. Some authors employ narrowly defined public capital [e.g., Canning and Bennathan (2000) study paved roads], whereas others define capital in a broad sense [e.g., Mera (1973) and Mas et al. (1996) employ social public capital]. In addition, the definition of what constitutes public capital (and core infrastructure) may differ by country.

2.3 A Simple Meta-analysis

Meta-analysis can be defined as a body of statistical methods to summarize, evaluate, and analyze results of empirical studies. In doing so, meta-analysis produces value added above and beyond conventional literature reviews, which have less of a quantitative orientation. A meta-analysis forces a researcher to be explicit

[13] See, for example, Aaron (1990), Hulten and Schwab (1991a), and Tatom (1991).

[14] Clarida (1993), Otto and Voss (1996), Batina (1998), Flores de Frutos et al. (1998), Pereira and Roca Sagales (1999), Ligthart (2002), and Pereira and Roca Sagales (2003) have employed a VAR approach amongst others.

about the weights assigned to the studies, whereas conventional literature reviews leave much more room for subjective elements in the analysis. We show that we cannot simply take an average over all studies to derive an estimate of the output elasticity of public capital. Section 2.3.2 conducts a simple meta-analysis based on the meta-sample of Sect. 2.3.1.

2.3.1 The Meta-sample

To estimate the output elasticity of public capital, we focus on studies employing the pure production function and VAR approaches. All the selected production function studies use a log-linearized production function. Consequently, they estimate a uniformly defined output elasticity of public capital, which measures the percentage change in real private output in response to a 1% increase in the public capital stock. We identified via an extensive literature search 60 studies that could potentially be included in our sample. In order to conduct a standard meta-analysis, it is necessary to collect not only the point estimates of the output elasticity but also the precision of the estimates (i.e., their standard errors). Not all studies report standard errors, particularly those employing the VAR approach,[15] which forced us to dismiss 11 studies.[16] We also excluded studies (e.g., Mera 1973) that include non-standard components in their definition of public capital. Our dataset consists of 248 measurements taken from 49 studies, of which 41 are published in academic or professional journals and eight are unpublished.[17]

Table 2.1 presents an overview of the studies included in the meta-sample. We take all relevant elasticities from each study rather than using a single estimate per study.[18] The number of elasticities per study differs, averaging to five, potentially giving rise to dependency between observations from the same study in our meta-sample.[19] Following Aschauer's work, the majority of studies deal with the USA (26 out of 49) at the national or regional level. Only 15 studies pertain to other OECD countries. The remaining eight studies cover multiple countries.

Figure 2.1 shows that there is substantial variation across output elasticities of public capital. On the order of 80% of the estimates takes on values between −0.15

[15]Many VAR studies were not considered for our potential database because they neither reported standard errors nor disclosed any output elasticities.

[16]Studies reporting output elasticities of public capital but not their standard errors are the following: Clarida (1993), Pinnoi (1994), Crihfield and Panggabean (1995), Wylie (1996), Lau and Sin (1997), Mamatzakis (1999), Pereira and Flores de Frutos (1999), Pereira and Roca Sagales (2001), Ashipala and Haimbodi (2003), Pereira and Roca Sagales (2003), and Everaert and Heylen (2004). These studies, however, have been included in the meta-regression analysis of Sect. 2.4.

[17]We could not get a hold of some of the early unpublished papers, thereby making the sample of unpublished papers less representative.

[18]This is still a controversial issue in the literature. Bijmolt and Pieters (2001) claim that all available measurements need to be included, whereas Stanley (1998) believes that only one measurement per study should be selected.

[19]No routines are available yet to measure and correct for this problem.

Table 2.1 Summary statistics of the studies in the meta-dataset

			Output elasticities				
	Authors	Jurisdiction	Number	Mean	Median	Minimum	Maximum
1	Ratner (1983)	USA	2	0.057	0.057	0.056	0.058
2	Aschauer (1989)	USA	1	0.400	0.400	0.400	0.400
3	Ram and Rasmey (1989)	USA	1	0.240	0.240	0.240	0.240
4	Merriman (1990)	US (48 states) and Japan (9 regregions)	4	0.418	0.445	0.200	0.580
5	Munnell (1990)	USA	2	0.360	0.360	0.330	0.390
6	Eisner (1991)	USA (national and 4 regions)	17	0.027	0.064	–0.491	0.383
7	Ford and Poret (1991)	10 OECD countries	20	0.378	0.395	–0.340	0.770
8	Tatom (1991)	USA	2	0.087	0.087	0.042	0.132
9	Berndt and Hansson (1992)	Sweden	1	0.687	0.687	0.687	0.687
10	Garcia-Milà and McGuire (1992)	USA (48 states)	2	0.105	0.105	0.045	0.165
11	Bajo-Rubio and Sosvilla-Rivero (1993)	Spain	1	0.190	0.190	0.190	0.190
12	Finn (1993)	USA	2	0.010	0.010	–0.138	0.158
13	Munnell (1993)	USA (national and 4 regions)	9	0.155	0.120	–0.004	0.380
14	Eisner (1994)	USA	1	0.270	0.270	0.270	0.270
15	Evans and Karras (1994)	7 OECD countries	7	–0.005	0.033	–0.175	0.182
16	Holtz-Eakin (1994)	USA (48 states and 8 regions)	13	0.009	–0.050	–0.130	0.348
17	Ai and Cassou (1995)	USA	4	0.308	0.308	0.295	0.321
18	Baltagi and Pinnoi (1995)	USA (48 states)	16	0.073	0.070	–0.110	0.390
19	Dalamagas (1995)	Greece	1	0.532	0.532	0.532	0.532
20	Holtz-Eakin and Schwartz (1995a)	USA (48 states)	6	0.010	–0.069	–0.022	0.054

21	Holtz-Eakin and Schwartz (1995b)	USA (48 states)	2	0.004	0.004	–0.038	0.046
22	Sturm and De Haan (1995)	The Netherlands and USA	8	0.635	0.540	0.260	1.150
23	Garcia-Milà et al. (1996)	USA (48 states)	18	0.023	–0.011	–0.071	0.370
24	Hulten (1996)	USA	1	0.317	0.317	0.317	0.317
25	Mas et al. (1996)	Spain (17 regions)	4	0.050	0.067	–0.021	0.086
26	Otto and Voss (1996)	Australia	2	0.232	0.232	0.168	0.296
27	Crowder and Himarios (1997)	USA	6	0.291	0.294	0.168	0.382
28	Kavanagh (1997)	Ireland	1	0.495	0.495	0.495	0.495
29	Vijverberg et al. (1997)	USA	1	0.119	0.119	0.119	0.119
30	Batina (1998)	USA	1	–0.110	–0.110	–0.110	–0.110
31	Boarnet (1998)	USA (State of California)	4	0.083	0.056	–0.016	0.236
32	Flores de Frutos et al. (1998)	Spain	1	0.210	0.210	0.210	0.210
33	Ramirez (1998)	Mexico	2	0.315	0.315	0.040	0.590
34	Delorme et al. (1999)	USA	1	0.276	0.276	0.276	0.276
35	Canning and Bennathan (2000)	97 countries	2	0.084	0.084	0.083	0.085
36	Charlot and Schmitt (2000)	France (22 regions)	6	0.229	0.253	0.070	0.321
37	Nourzad (2000)	24 countries	5	0.469	0.445	0.397	0.553
38	Vanhoudt et al. (2000)	15 EU countries	4	0.042	0.050	–0.093	0.161
39	Yamano and Ohkawara (2000)	Japan (47 regions)	1	0.034	0.034	0.034	0.034
40	Yamarik (2000)	USA (48 states)	4	0.087	0.081	0.025	0.160
41	Stephan (2001)	France (21 regions) and Germany (11 states)	6	0.100	0.099	0.083	0.128
42	Yilmaz et al. (2001)	USA	1	0.032	0.032	0.032	0.032
43	Kemmerling and Stephan (2002)	87 German cities	3	0.169	0.169	0.169	0.170

(continued)

Table 2.1 (continued)

			Output elasticities				
	Authors	Jurisdiction	Number	Mean	Median	Minimum	Maximum
44	Ligthart (2002)	Portugal	18	0.189	0.194	0.022	0.371
45	Dodonov et al. (2002)	13 Eastern European countries	2	0.525	0.525	0.450	0.600
46	Song (2002)	Australia	1	0.005	0.005	0.005	0.005
47	Stephan (2003)	Germany (11 states)	3	0.659	0.651	0.547	0.779
48	Kamps (2005)	22 OECD countries	23	0.452	0.551	–0.568	1.265
49	La Ferrara and Marcellino (2005)	Italy (4 regions)	5	0.017	–0.139	–0.148	0.367
			248	0.200	0.136	–0.568	1.265

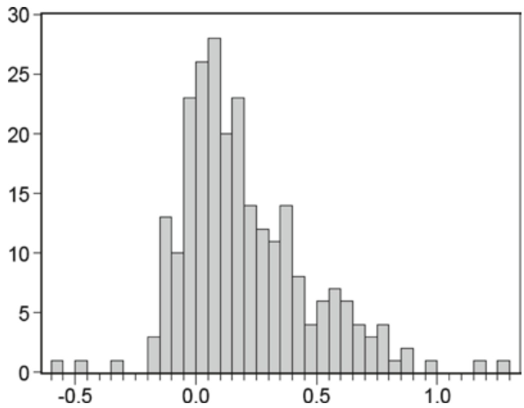

Fig. 2.1 Distribution of the output elasticity of public capital. Notes: The horizontal axis measures the output elasticity of public capital and the vertical axis the frequency

and 0.40. The multi-country study of Kamps (2005) reports both the largest elasticity (1.26 for Denmark) and the smallest elasticity (–0.57 for Portugal). Roughly 21% (52 out of 248) of the output elasticity estimates have a negative sign, of which 75% (39 out of 52) is statistically significant at the 5% level. The small percentage of significantly negative output elasticities in our sample provides a quantitative underpinning of Stylized Fact 1.

The simple (or arithmetic) average of the output elasticity of public capital in our meta-sample is 0.20, whereas the median elasticity amounts to 0.13, reflecting a distribution that is skewed to the right. Of course, the mean of the distribution is just a naive estimate that does not take into account the difference in precision with which the output elasticities are estimated. The sample consists of 13 outliers (5% of total) that are two standard deviations (i.e., two times 0.265) above or below the mean. If these extreme values were deleted, the simple mean would fall to 0.175, a decline of only 12.5%, which is sufficiently small to leave the outliers in.

2.3.2 Results of the Meta-analysis

If estimates of the effect size (i.e., β) are considered to be homogeneous – and thus differences between estimates are due to purely random variation – a fixed effects model is the appropriate specification. However, often there are systematic differences between effect size estimates, in which case they are considered to be heterogeneous. In case of heterogeneity of effect size estimates, a random effects model should be selected.[20] The random effects specification assumes that there is unobserved heterogeneity across observations.

[20]The causes of heterogeneity can be assessed by means of a meta-regression analysis. See Sect. 2.2.4.

Table 2.2 Meta-analysis for various study characteristics and specifications

Study category	Sample size	Mean 1/	Confidence interval	
			Lower bound	Upper bound
(a) Fixed effects				
All studies	248	0.039	0.037	0.040
Aggregation level				
National-level study	137	0.014	0.012	0.016
Regional-level study	111	0.049	0.046	0.052
Econometric specification				
Variables in logarithmic levels	136	0.023	0.022	0.025
First differences of logarithms	112	0.037	0.030	0.043
(b) Random effects				
All studies	248	0.139	0.125	0.154
Aggregation level				
National-level study	137	0.200	0.177	0.224
Regional-level study	111	0.092	0.075	0.109
Econometric specification				
Variables in logarithmic levels	136	0.133	0.118	0.147
First differences of logarithms	112	0.169	0.135	0.203

1/ Weighted mean

Table 2.2 shows the results of the meta-analysis for both the fixed effects and random effects meta-analysis model.[21] To determine which model to use, we have applied Cochran's (1954) Q test:

$$Q \equiv \sum_{i=1}^{n} \omega_i T_i^2 - \frac{\left(\sum_{i=1}^{n} \omega_i T_i\right)^2}{\sum_{i=1}^{n} \omega_i}, \tag{2.8}$$

where T_i is the estimate of the "true" effect in study i (i.e., our β), ω_i is the weight of study i, and n is the total number of β estimates. In the fixed effects model, ω_i is the inverse of the variance of the ith estimate (or "within study" variation). In the random effects model, ω_i is the inverse of the sum of the "within" and "between" study variance. The Q value amounts to 10,017. Comparing this value with the critical value of a $\chi^2(248)$ distribution leads us to conclude that we can reject the null hypothesis of no heterogeneity. Consequently, differences between point estimates of studies are not purely random but are the result of observed heterogeneity across studies. This result is not surprising given that the studies differ considerably in the type of public capital considered, the countries covered, and the functional and econometric specifications employed.

[21] See Hedges (1994) for an exposition of how this terminology differs from that used in the panel data literature.

The random effects estimate of the output elasticity of public capital of the full sample is 0.14, which falls within the calculated 95% confidence interval [panel (b) of Table 2.2]. As we can see from panel (a) of Table 2.2, the fixed effect estimator is quite small (β is 0.04), but it is an incorrect estimator in view of the results of the Q test. Note that both the fixed and random effects estimators are much smaller than the arithmetic average, reflecting the effect of the weighting scheme. Panel (b) of Table 2.2 shows that the weighted average estimate of the output elasticity for national-level studies is 0.20, which is substantially larger than that of regional-level studies, and thus supports Stylized Fact 2. In addition, the output elasticity for studies estimating variables in levels is 0.13, which falls short of the elasticity estimate of a model employing first differences.

2.4 Meta-regression Analysis

Our goal is to analyze the effects of fundamental variables (such as country characteristics and definitions of public capital) and of different functional and econometric specifications on the output elasticity of public capital. In the meta-regression, we try to verify the stylized facts of Sect. 2.3.2 and various hypotheses that are set out in Sect. 2.4.1. After presenting the hypotheses and meta-regression model, we discuss the econometric results.

2.4.1 Hypotheses

Hulten and Schwab (1991a), Button (1998), and Button and Rietveld (2000) have pointed to the potential differential impact that public investment may have on output depending on the size of the capital stock that has already been installed. In view of the law of diminishing returns in factor accumulation, economies that have already accumulated a large stock of public capital experience a smaller output elasticity. Given that data on capital stocks are not readily available, we proxy a country's capital stock by the level of per capita Gross domestic product (GDP). Therefore, we hypothesize to find a lower β in more developed countries (as measured by a high per capita GDP).

Hypothesis 1 *The output elasticity of public capital depends negatively on the level of development of an economy as measured by its per capita GDP.*

In view of the above, we expect countries other than the USA – which has been the main focus of the public capital literature – to have a larger output elasticity than that of the USA (Corollary 1).

Corollary 1 *Studies for the USA produce a lower* β *than studies for other countries.*

Estimates of the output elasticity are likely to be sensitive to the specification of the production function. As argued in Sect. 2.3.2, various authors have imposed restrictions on the coefficients of the production function to force, for example, constant returns to scale with respect to all inputs [(2.4)] or constant returns to scale in private inputs [(2.5)]. We expect these restrictions to reduce the absolute size of the estimated output elasticity of public capital (Hypothesis 2).

Hypothesis 2 *Studies imposing a constant-returns-to-scale restriction on the parameters of the production function yield a smaller* β *than studies not imposing any restrictions.*

Estimates of the output elasticity of public capital are likely to be sensitive to the econometric specification of the equation to be estimated. In view of the results of Ligthart (2002) and those from the meta-analysis in Sect. 3.2, we hypothesize to find a larger β for studies estimating equations in first differences [Hypothesis 3(a)]. In addition, the size of the output elasticity is also affected by the type of dataset employed, that is, panel or cross-sectional data vs. time-series data [Hypothesis 3(b)]. Because cross-sectional studies are generally conducted at the regional level, we expect both study characteristics to be positively correlated.[22] Hence, in view of Stylized Fact 2, we anticipate to find a smaller β in cross-sectional studies than in single-country time-series studies.

Hypothesis 3 *A smaller* β *results for studies: (a) estimating variables in logarithmic levels rather than in first differences of logarithms, and (b) employing panel data or cross-sectional data.*

Some authors of meta-regression analyses (e.g., De Mooij and Ederveen 2003) have tried to identify the presence of publication bias, which is the tendency to publish only significant results supporting the hypothesis put forward.[23] In our case, we expect to find a larger β in published studies than in unpublished manuscripts [Hypothesis 4(a)]. Because we experienced difficulties in getting a hold of all unpublished papers that we are aware of – possibly biasing the publication dummy variable – we also include an indicator of the significance of the estimated β [Hypothesis 4(b)]. Furthermore, unpublished manuscripts may be published in the near future, which is particularly relevant for recently issued manuscripts containing high-quality research. Alternatively, we include the number of observations to measure publication bias. Intuitively, studies based on a larger sample yield more efficient estimates – and thus more often yield significant parameter estimates – and are therefore less likely to be subject to publication bias [Hypothesis 4(c)].

Hypothesis 4 *(a) Published studies are expected to report a larger* β*; (b) The significance of* β *and its size are positively related; and (c) Studies containing a large number of observations are less likely to suffer from publication bias and thus report a smaller* β*.*

[22] In the meta-regression analysis, we include both types of study characteristics.

[23] Note that authors may not report unsatisfactory results, which, of course, cannot be measured by a meta-analysis.

2.4.2 Meta-regression Model

2.4.2.1 Methodology

We employ an unbalanced panel consisting of N studies each of which covers J_i estimates of the output elasticity β. The panel is unbalanced because the number of estimates differs by study. The model to be estimated is as follows:

$$Y_{ij} = \pi + \sum_{k=1}^{K} \theta_k X_{ij}^k + \sum_{l=1}^{L} \varphi_l D_{ij}^l + \varepsilon_{ij}, \qquad i = 1,\ldots,N, \qquad j = 1,\ldots,J_i, \tag{2.9}$$

where Y_{ij} is the jth output elasticity of public capital reported in study i, π is an intercept, X_{ij} is a set of K continuous variables (X^1 is per capita GDP of the country for which elasticity estimate j of study i was obtained and X^2 is the number of observations of that study), D_{ij}^l is a set of L dummy variables, and ε_{ij} is an i.i.d. error term. The parameters θ_k and φ_l measure the impact on the output elasticity of study characteristics k and l, respectively.

The following L dummy variables are included (1) D^1 is 1 for core infrastructure and 0 for all other types of public capital (including the total public capital stock), (2) D^2 is 1 for studies pertaining to the USA and 0 otherwise, (3) D^3 is 1 for national-level studies and 0 otherwise, (4) D^4 is 1 if the variables in the study are estimated in levels and 0 otherwise, (5) D^5 is 1 if a returns-to-scale restriction on the coefficients of the production function is imposed and 0 otherwise, (6) D^6 is 1 if panel data are used and 0 otherwise, (7) D^7 is 1 if cross-sectional data are used and 0 otherwise, (8) D^8 is 1 if the coefficient is significant (at the 1 or 5% level) and 0 otherwise, and (9) D^9 if the study is published and 0 otherwise. Based on the stylized facts and hypotheses, the expected signs are as follows: $\theta_1 < 0$, $\theta_2 < 0$, $\varphi_1 > 0$, $\varphi_2 < 0$, $\varphi_3 > 0$, $\varphi_4 < 0$, $\varphi_5 < 0$, $\varphi_6 < 0$, $\varphi_7 < 0$, $\varphi_8 > 0$, and $\varphi_9 > 0$.

2.4.2.2 Data

Our meta-regression sample consists of 282 observations. We took the 49 studies from our meta-analysis sample (see Sect. 2.3.1), from which we dropped five cross-country studies[24] because these could not be matched to a particular country. We have added back in the 11 studies not reporting any standard errors – which are not used in the meta-regression analysis – to obtain 55 studies.[25] In the panel data models, we have grouped the observations by study. The average group size

[24]The cross-country studies are as follows: Evans and Karras (1994), Canning and Bennathan (2000), Nourzad (2000), Vanhoudt et al. (2000), and Dodonov et al. (2002).

[25]Of course, we could have also used the standard errors in weighting the observations. To maximize the number of observations, we decided against this. Any references to "fixed effects" and "random effects" pertain to the standard panel data methods rather than the terminology as employed by meta-analysts.

amounts to 5.1 observations with a maximum number of 2 observations. Alternatively, if we had grouped the observations by country – which allows for an analysis of country-fixed effects – the number of groups would have become relatively small (i.e., only 13 countries).

2.5 Results

Table 2.3 summarizes the empirical findings. We have employed various estimation methodologies: (1) pooled OLS, (2) panel fixed effects, (3) panel random effects, and (4) feasible GLS. The pooled OLS results in column 1 – which forces a common slope and intercept – show that only a few of the explanatory variables are significant. The intercept is significant taking on a value closely in line with the unweighted average found in the meta-analysis. Only the dummies for the USA, panel studies and significance are statistically significant, which is roughly in line with the analysis of Button (1998), who finds only a significant and negative US dummy. Studies on the USA tend to find, ceteris paribus, lower output elasticities than studies conducted for other countries or geographical areas (Corollary 1), reflecting the large stock of infrastructure installed in the USA. We cannot find, however, evidence of a negative relationship between the per capita GDP and the size of the output elasticity.

By pooling reported estimates we cannot analyze unobservable study-specific fixed effects that are likely to be relevant. Therefore, a panel fixed effects model is estimated as shown in column 2 of Table 2.3. The F test for the significance of the fixed effects cannot reject the null hypothesis of insignificant study-specific fixed effects.[26] The panel fixed effects model performs poorly. Only the significance dummy is statistically significant. The results for the panel random effects model – presented in column 3 – are not much better, which is not surprising given the presence of heteroscedasticity in the residuals.[27] Consequently, the fixed effects and random effects models are inappropriate. In the extended GLS model (see columns 4 and 5), the standard errors are reduced, making a larger number of variables statistically significant.

Table 2.4 reports the correlation coefficients between the dependent and the various explanatory variables. We can see that there is a strong negative correlation (about −0.73) between the panel dummy and the dummy for national-level studies,

[26]The F test amounts to $F(54,217)=1.91$, which exceeds the critical value.

[27]We could not find any evidence of autocorrelation in the residuals. We have performed a likelihood ratio (LR) test to check for the presence of cross-panel heteroscedasticity. The LR test is based on the difference between the unrestricted model, which allows for heteroscedasticity, and the restricted model, which assumes a constant variance of the residuals. The LR test in Table 2.3 shows that the unrestricted model performs better, implying that the error structure is heteroscedastic.

Table 2.3 Results of the meta-regression analysis 1/ 2/

		Pooled OLS	Fixed effects	Random effects	Feasible GLS	
					Model A	Model B
Explanatory variables		(1)	(2)	(3)	(4)	(5)
Constant		0.184***	–	0.149	0.169***	0.043
		(0.073)		(0.095)	(0.049)	(0.044)
GDP per capita	X^1	0.152	0.082	0.090	0.034	–0.004
		(0.190)	(0.276)	(0.212)	(0.114)	(0.123)
Number of observations	X^2	–0.00004	–0.00010	–0.00004	–0.00003***	–0.00004***
		(0.00002)	(0.00017)	(0.0003)	(0.00001)	(0.00001)
Dummy core infrastructure	D^1	0.041	–0.009	0.023	0.050**	0.068***
		(0.040)	(0.063)	(0.046)	(0.022)	(0.022)
Dummy USA	D^2	–0.210***	–0.139	–0.188***	–0.170***	–0.142***
		(0.038)	(0.104)	(0.049)	(0.019)	(0.024)
Dummy national	D^3	0.006	–0.069	–0.002	–0.010	0.065***
		(0.051)	(0.094)	(0.060)	(0.020)	(0.022)
Dummy levels	D^4	–0.021	0.084	0.017	0.005	0.053***
		(0.038)	(0.061)	(0.043)	(0.013)	(0.015)
Dummy restriction	D^5	–0.075	–0.046	–0.042	–0.062***	–
		(0.040)	(0.069)	(0.047)	(0.017)	
Dummy panel	D^6	–0.136***	0.475	–0.136	–0.161***	–
		(0.052)	(0.296)	(0.071)	(0.027)	
Dummy cross section	D^7	–0.079	0.146	0.016	–0.091	–0.032
		(0.092)	(0.113)	(0.099)	(0.074)	(0.068)
Dummy significance	D^8	0.212***	0.192***	0.196***	0.191***	0.143***
		(0.050)	(0.055)	(0.049)	(0.017)	(0.024)
Dummy published	D^9	0.041	–	0.063	0.029	0.002
		(0.045)		(0.067)	(0.033)	(0.036)

(continued)

Table 2.3 (continued)

	Pooled OLS	Fixed effects	Random effects	Feasible GLS	
				Model A	Model B
Explanatory variables	(1)	(2)	(3)	(4)	(5)
Number of observations	282	282	282	282	282
Adjusted R^2	0.229	0.005	0.242	–	–
F-test	8.57	2.01	–	–	–
Probability > F	0.0000	0.0334	–	–	–
Wald Chi^2 test	–	–	45.2	–	–
Probability > Chi^2	–	–	0.0000	–	–
Log likelihood	–	–	–	89.27	86.75
Likelihood ratio test	–	–	–	193.74	197.66
Probability > Chi^2	–	–	–	0.0000	0.0000

1/ Standard errors are in parentheses
2/ *** and ** indicate statistical significance at the 1 and 5% level, respectively

Table 2.4 Correlation matrix

	Output elasticity	GDP per capita	Number of observations	Core infrastructure	Cross	Levels	National	Panel	Published	Restriction	Significance	US
Output elasticity	1.00											
GDP per capita	0.07	1.00										
Number of observations	–0.22	0.26	1.00									
Core infrastructure dummy	0.23	0.11	–0.15	1.00								
Cross-sectional dummy	–0.06	–0.06	–0.09	–0.03	1.00							
Levels dummy	–0.10	0.04	0.16	–0.03	0.13	1.00						
National dummy	0.22	–0.11	–0.39	0.22	–0.02	–0.45	1.00					
Panel dummy	–0.24	0.14	0.50	–0.25	–0.18	0.29	–0.73	1.00				
Published dummy	–0.17	–0.12	–0.06	–0.38	0.11	0.26	–0.11	0.12	1.00			
Restriction dummy	0.11	–0.03	–0.20	0.11	–0.08	–0.27	0.48	–0.39	0.09	1.00		
Significance dummy	0.16	0.08	0.08	–0.06	–0.05	0.05	–0.01	0.21	0.14	0.19	1.00	
US dummy	–0.38	–0.17	0.09	–0.38	0.15	0.09	–0.12	0.10	0.53	–0.11	0.04	1.00

reflecting that most regional studies employ panel data. In addition, the strong positive correlation between the returns-to-scale restriction dummy and the dummy for national-level studies indicates that restrictions are more prevalent in national-level studies. To take into account this collinearity, we have estimated two models (labeled A and B), where model B leaves out the restriction and panel dummies.

Columns 4 and 5 of Table 2.3 present the extended GLS results for models A and B. Besides the significance of the US dummy, five additional explanatory variables are significant in model A. Core infrastructure is shown to be more productive than other types of infrastructure (Stylized Fact 3). Restrictions on the coefficients of the production function reduce the output elasticity of public capital, which is in line with Hypothesis 2. In addition, studies employing panel data yield a smaller output elasticity of public capital. Accordingly, Hypothesis 3(b) is supported, but no collaborating evidence for Hypothesis 3(a) can be found. Studies with a significant β give rise to a larger output elasticity of public capital, which supports Hypothesis 4(b). Finally, we also see that studies with a larger number of observations give rise to a smaller value of β, also suggesting that publication bias may be present. Note that the dummy for national-level studies is insignificant.

Model B shows that the dummies for logarithmic-level and national-level studies are significantly positive if the restriction and panel dummies are dropped from the benchmark equation (model A), supporting the results found in the simple meta-analysis. Compared to model A, it can be seen that the absolute size of the dummy for the USA drops somewhat, whereas the regression intercept falls substantially to a negligible small level and becomes insignificant. The dummy for published studies is insignificant in both models.

2.6 Conclusions

We have used meta-analytical tools to estimate the output elasticity of public capital. The sample features a substantial degree of (observed) heterogeneity. In view of this, we employ a meta-regression analysis to explain the differences between output elasticities of public capital within and between empirical studies.

Our analysis finds an output elasticity of public capital of 0.14 in the random effects model, which is substantially below the simple average of 0.20 and the value of 0.39 initially found by Aschauer. These results suggest a marginal productivity of public capital of 27.5% (assuming a public capital-to-GDP ratio of 51%, like in the USA in the early 2000s). This return is substantially above the marginal productivity of private capital – which is typically reflected in the long-term real rate of interest – suggesting that investment in public capital should be encouraged from a macroeconomic point of view. These results should be interpreted with care given that the simple meta-analysis is just a partial analysis that does not control for other relevant factors. The analysis has not been controlled for observed study heterogeneity yet. The composition of public capital among other factors plays an important role;

more of the same type of public capital does not necessarily boost public capital productivity. In addition, the financing method of public investment spending is not taken into account. Therefore, a careful cost–benefit analysis should precede any additional expenditures on public capital.

The meta-regression analysis – which controls for observed heterogeneity across estimates of the output elasticity of public capital – shows that studies employing core infrastructure, using public capital data at the national level, featuring publication bias, and estimating the equation in logarithmic levels find larger output elasticities of public capital. Studies pertaining to the USA and imposing an economies-of-scale restriction on the coefficients of the production function find smaller output elasticities of public capital.

Our study can be extended in three directions. First, additional explanatory variables could be included in the meta-regression analysis, such as a country's per capita stock of public capital, type of modeling approach (VAR vs. single equation), and type of estimation method. Second, instead of grouping the variables by study in the panel, they could be grouped by country, which allows us to run a meta-regression analysis with country-specific fixed effects. Finally, all observations can be weighted by (a transformation of) the degrees of freedom of the primary study.

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