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New Estimates of Government Net Capital Stocks for 22 OECD Countries, 1960–2001

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The issue of whether government capital is productive has received a great deal of attention recently, yet empirical analyses of public capital productivity have generally been limited to the official capital stock estimates available in a small sample of countries. Alternatively, many researchers have investigated the output effects of public investment—recognizing that investment may be a poor proxy for the corresponding capital stock. This paper attempts to overcome the data shortage by providing internationally comparable capital stock estimates for 22 Organization for Economic Cooperation and Development (OECD) countries. [JEL C82, E22, E62, H54]

The issue of whether government capital is productive has received a great deal of recent attention. In his seminal contributions, Aschauer (1989a, 1989b) found large positive output effects of government capital in the United States. His results suggested that government capital was even more productive than private capital. However, the large body of empirical literature that developed after Aschauer's early studies challenged these results. This literature—surveyed, for example, in Gramlich (1994); Sturm, Kuper, and de Haan (1998); and Seitz (2001)—concludes

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that although there is evidence for positive output effects of government capital, the magnitude of these effects is generally much smaller than Aschauer reported.

The lack of public capital stock data for a large number of Organization for Economic Cooperation and Development (OECD) member countries has forced most empirical studies to focus on the United States. Few studies have investigated the productivity of government capital for other OECD countries; examples are Ford and Poret (1991) and Evans and Karras (1994). Both studies drew their data from OECD (1997), which included capital stock series (provided by national authorities) for 12 countries over the period 1970–96. However, the OECD data were not internationally comparable, because estimation methods differed widely across countries.[1] This was one of the reasons the OECD suspended publication of the capital stock series after 1997 and cofounded the Canberra Group on Capital Stock Statistics, whose activities resulted in the publication of a manual on the measurement of capital (OECD, 2001). Thus far, only a few countries have adjusted their estimation methods, so internationally comparable capital stock data are still not available.

In spite of these constraints, the analysis of public capital productivity has continued to be an active area of research. Most recent studies use an approach based on vector autoregressive (VAR) models—for example, Mittnik and Neumann (2001), Voss (2002), and Kamps (2005)—that, unlike the earlier production function and cost function approaches, does not impose causal links among the variables under investigation. The main disadvantage of this approach is that it generally requires large data samples for conventional lag lengths. For this reason, most researchers employing the VAR approach have used data on public investment instead of data on the public capital stock. This choice has been dictated by the lack of capital stock data for a large number of countries and the fact that public investment data are usually available each quarter, whereas public capital stock data are available only once a year. One drawback of this choice is the implicit assumption that the effects of public investment are independent of the level of the corresponding capital stock. Economic theory suggests that this assumption is dubious. According to the law of diminishing returns, an increment to the public capital stock (that is, public investment corrected for fixed capital consumption) would have a small (large) output effect if the capital stock in the previous period were large (small). There is indeed evidence for a fast decline in the marginal productivity of public capital (Demetriades and Mamuneas, 2000, p. 702).

This paper provides internationally comparable annual capital stock estimates for 22 OECD countries for the period 1960–2001, calculated using the perpetual inventory method based on a geometric depreciation pattern. Capital stock data are estimated for three categories of investment: (1) private nonresidential gross fixed capital formation, (2) private residential gross fixed capital formation, and (3) government gross fixed capital formation. A sensitivity analysis explores the robust-

[1]Sturm, Kuper, and de Haan (1998, p. 382) draw attention to the problem that "most authors employ data in their analysis which are generally chosen on the ground of their availability, without analyzing whether their conclusions are sensitive not only to the concept of the public capital stock (narrow versus broad definition), but also to the way the capital stock has been constructed."

ness of the capital stock estimates by varying the main estimation assumptions for a reference country, the United States, for which public capital stock estimates from official sources are available. The results of this sensitivity analysis suggest that the benchmark capital stock estimates are robust. Finally, the paper reports and compares estimation results for the production function approach, using three alternative measures of the public capital stock: (1) the author's estimates, (2) estimates from national authorities, and (3) estimates from OECD (1997). The regression results confirm previous results in the literature based on the production function approach and show that the elasticity of output with respect to public capital is positive and statistically significant, but quite large for most countries. According to estimates based on a simple panel data model, the elasticity of output with respect to public capital is, on average, 0.2 in OECD countries.

I. Data

The basic ingredient for the estimation of capital stocks is historical data on gross investment. These data are taken from the June 2002 version of the OECD Analytical Database.[2] The estimation is carried out for the following 22 OECD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.[3] The series retrieved from this database expressed in constant prices and in national currencies are (OECD code in parentheses) total gross fixed capital formation (ITV), total private gross fixed capital formation (IPV), private nonresidential gross fixed capital formation (IBV), private residential gross fixed capital formation (IHV), and government gross fixed capital formation (IGV).

This paper uses public investment data from the OECD Analytical Database because, in addition to providing long time series for a large panel of countries, the data are categorized by institutional sector and are more comparable internationally than data from national sources. Table 1 gives details about the institutional coverage of the public investment series. This information is important because the definition of the public sector underlying the investment series varies not only across sources for a given country but also across countries for a given source. Three definitions regarding the coverage of public investment are used by the countries under investigation:[4] (1) public investment of the general government; (2) public

[2]This database includes not only investment data but also a large set of other macroeconomic variables. In addition to investment, real gross domestic product (GDPV) and employment (ET) are retrieved. Most of these data are available via the Internet at: www.sourceoecd.org.

[3]For most of these countries, the data are available for the period 1960–2001. The following OECD countries are not included in the analysis because long investment series are not available: the Czech Republic, Hungary, the Republic of Korea, Luxembourg, Mexico, Poland, the Slovak Republic, and Turkey.

[4]In OECD (1997), public entities are referred to as "producers of government services." This category, in most cases, corresponds to the definition of public activities underlying the investment series from national sources. An important difference, however, is that capital stocks in OECD (1997) were based on classifications of public activities according to the 1968 System of National Accounts, whereas recent national data are based on classifications according to the 1993 System of National Accounts.

Table 1. Coverage of Government Gross Fixed Capital Formation

Country	OECD ADB	National Data	OECD FSFC
Australia	General government	General government	PGS[4]
Austria	General government	General government	—
Belgium	General government	Public administration[1]	PGS[4]
Canada	General government	Public administration[2]	PGS[4]
Denmark	General government	General government	PGS[4]
Finland	General government	General government	PGS[4]
France	General government	—	—
Germany	General government	General government	PGS[4]
Greece	General government	—	General government
Iceland	General government	—	—
Ireland	General government	—	—
Italy	General government	Public administration[1]	PGS[4]
Japan	Public sector	General government	—
Netherlands	General government	—	—
New Zealand	Public sector	Public sector	—
Norway	General government	General government	PGS[4]
Portugal	General government	—	—
Spain	General government	Public administration[3]	—
Sweden	General government	—	PGS[4]
Switzerland	General government	—	—
United Kingdom	General government	General government	PGS[4]
United States	Public sector	Public sector	—

Sources: OECD ADB = OECD Analytical Database, which provides the investment series used in the calculation of the author's capital stock estimates. National data = government capital stock data available from national authorities (see Kamps, 2004, Appendix I for details). OECD FSFC = OECD (1997) publication *Flows and Stocks of Fixed Capital 1970–1996.*

Notes: The general government sector comprises the central, local, and state government subsectors, including social security funds. The public sector comprises the general government and nonfinancial public corporations. See IMF (2001) for details.

[1]Public administration and defense services, compulsory social security services (ISIC (International Standard Industrial Classification) category).

[2]Public administration, educational services, and health care and social assistance (ISIC category).

[3]Public administration, educational services, and health care and social assistance provided by the government (no private provision included) plus investment in infrastructure provided by public corporations.

[4]Producers of government services (PGS). The coverage of PGS is somewhat smaller than that of the general government, since the latter also includes departmental enterprises (Florio, 2001, p. 185). Moreover, capital stocks in OECD (1997) were based on classifications of government activities according to the 1968 System of National Accounts, whereas recent national data are based on classifications according to the 1993 System of National Accounts.

investment of the nonfinancial public sector (general government plus nonfinancial public enterprises (NFPEs)); and (3) investment carried out by economic units engaged in activities labeled "Public administration and defense services, compulsory social security services" (narrow definition) and "Public administration, educational services, and health care and social assistance" (broad definition) according to the International Standard Industrial Classification (ISIC). Whereas the first two definitions categorize by institutional sector, the latter two categorize by type of economic activity. The ISIC category "Public administration, educational services, and health care and social assistance" comes close to the definition of the nonfinancial public sector, but it also includes private spending on education, which may be important in some countries, such as Canada.

Figure 1 displays the evolution of the public investment–GDP ratio for the 22 countries over the period 1960–2001. The subpanels of Figure 1 for the individual countries show the public investment–GDP ratio for the data from the OECD Analytical Database as well as (if available) for data from national sources[5] and from OECD (1997). The public investment–GDP ratio has, in general, declined over the sample period. In some countries, such as Austria and Ireland, the decline has been particularly pronounced. Notable exceptions to the general pattern are Greece, Portugal, and Spain, where public investment–GDP ratios have increased considerably since their accession to the European Community in the 1980s. A comparison of data from the three sources reveals that the ratios calculated for data from the OECD Analytical Database match the ratios calculated with data from national sources except for Belgium, Canada, Italy, Japan, and Spain. The differences between data from the Analytical Database and national sources and data from OECD (1997) are quite large in most cases, partly reflecting the fact that OECD (1997) data are based on the 1968 System of National Accounts, while the other two sources rely on the 1993 System of National Accounts.[6] To a certain extent, the difference is also due to data revisions since the publication of OECD (1997). However, the most important reason for the data discrepancy seems to be different coverage of public investment.

II. Methodology

The methodology applied here in the estimation of capital stock data draws in large part on OECD (2001) and the U.S. Bureau of Economic Analysis (1999). The estimation exercise is comparable to that performed by Jacob, Sharma, and Grabowski (1997), who estimate capital stocks by industrial activity according to the ISIC. Here, however, the aim is to obtain estimates by institutional sector—with a special focus on the public sector—rather than by industrial activity. Other precursors of the present study include Berndt and Hansson (1991), who estimate the public capital stock for Sweden; Sturm and de Haan (1995), who estimate the public capital stock for the Netherlands; as well as Boskin, Robinson, and Huber (1987); Munnell (1990); and Holtz-Eakin (1993), who estimate the capital stock for local and state governments in the United States. This paper employs the same estimation approach as those studies: the perpetual inventory method. The net capital stock is estimated for the three subcategories of gross investment available from the OECD Analytical Database: (1) private nonresidential gross fixed capital

[5]See Kamps (2004, Appendix I) for a description of data from national sources.

[6]For details of the 1993 System of National Accounts, see European Commission and others (1993).

Figure 1. Real Government Gross Fixed Capital Formation in 22 OECD Countries, 1960–2001
(*As a percentage of real GDP*)

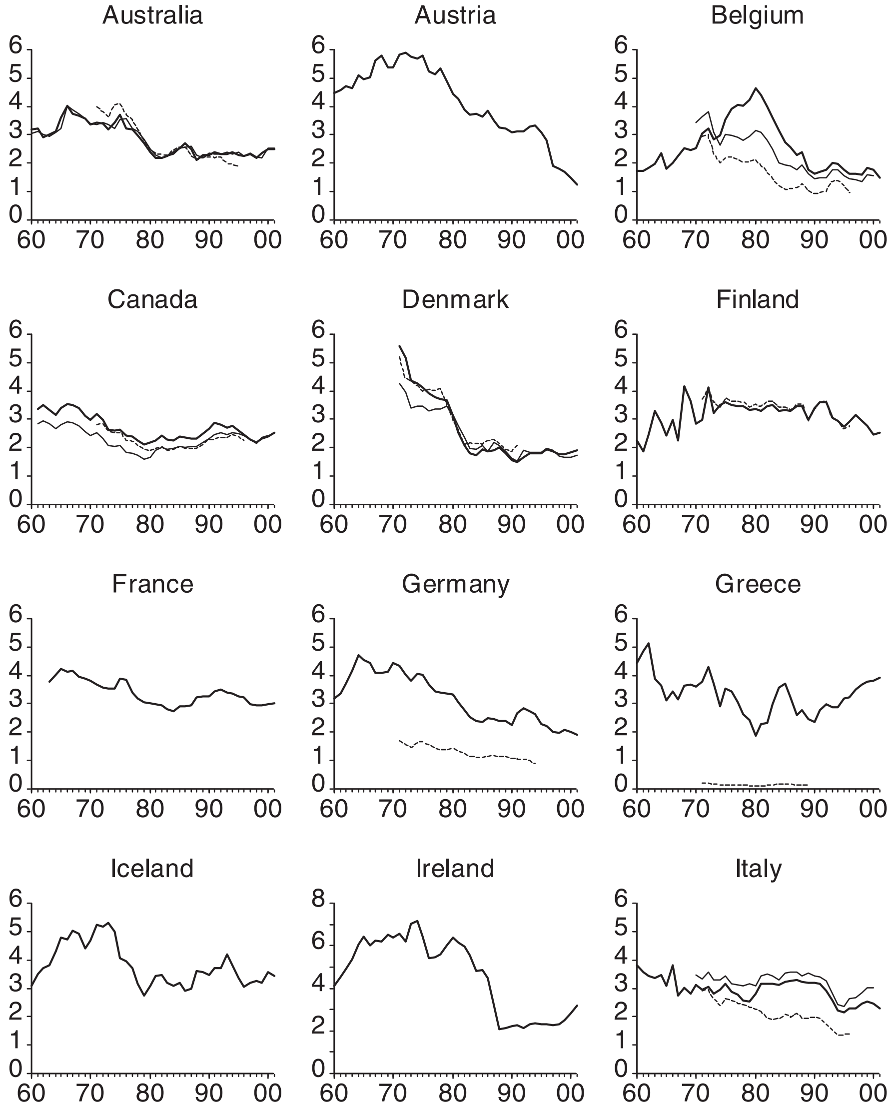
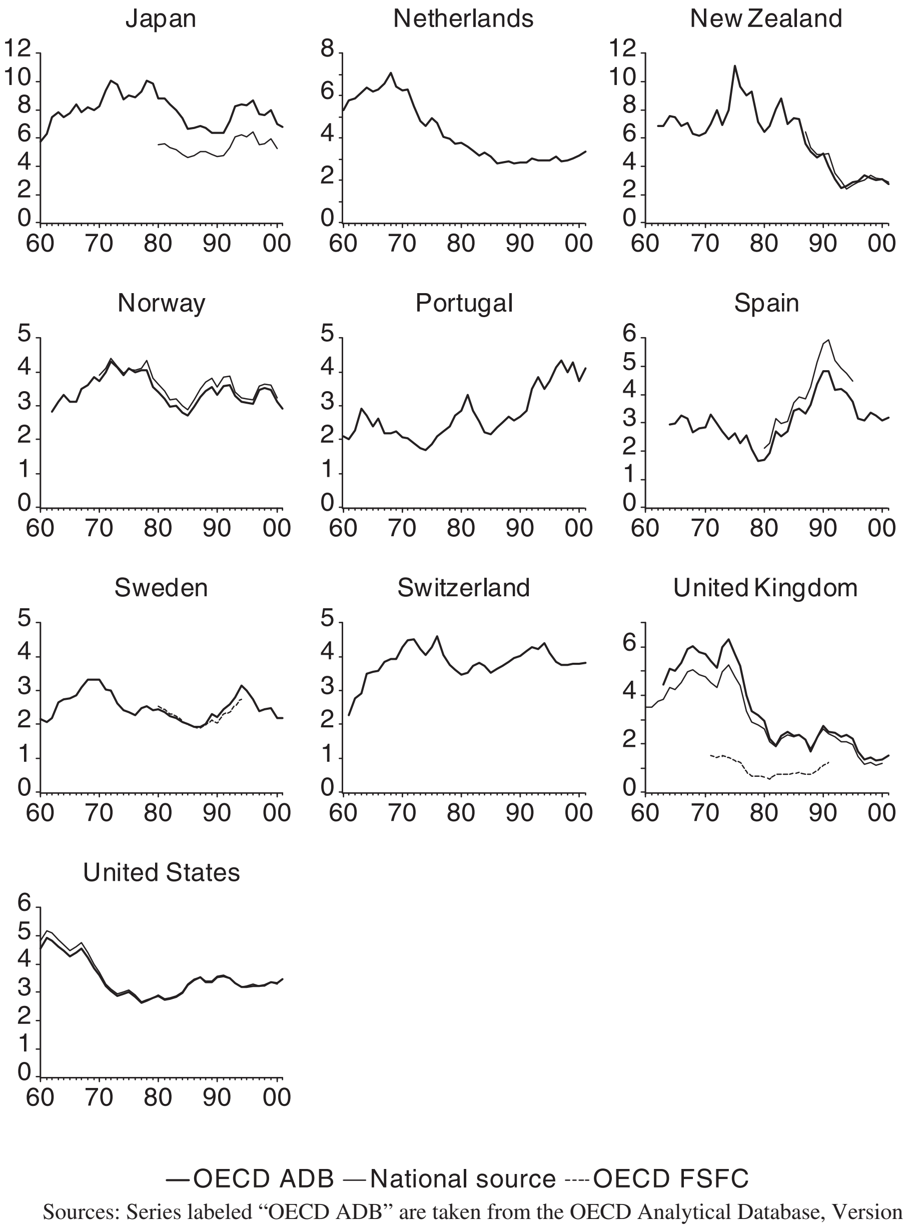


Figure 1. *(concluded)*



Sources: Series labeled "OECD ADB" are taken from the OECD Analytical Database, Version June 2002. Series labeled "National source" are estimates from national authorities. Series labeled "OECD FSFC" are calculated as follows: The gross investment series are taken from OECD (1997) and divided by GDP series taken from OECD (1998).

formation, (2) private residential gross fixed capital formation, and (3) government gross fixed capital formation.[7]

The basic idea of the perpetual inventory method is that the net capital stock at the beginning of the following period, K_{t+1}, can be expressed as a function of the net capital stock at the beginning of the current period, K_t, of gross investment in the current period, I_t, and of depreciation[8] in the current period, D_t:

$$K_{t+1} = K_t + I_t - D_t. \tag{1}$$

If one further assumes geometric depreciation (that is, the capital stock depreciates at a constant rate, δ), then the capital accumulation equation can be rewritten as

$$K_{t+1} = (1-\delta) K_t + I_t. \tag{2}$$

The method is called "perpetual" because all assets are forever part of the inventory of capital stocks. Of course, the quantity of services provided by an asset declines as it ages, but it never reaches zero. This can be seen by repeatedly substituting equation (2) for the capital stock at the beginning of period *t:*

$$K_{t+1} = \sum_{i=0}^{\infty} (1-\delta)^i I_{t-i}. \tag{3}$$

This expression shows that the capital stock at the beginning of period $t + 1$ is a weighted sum of past investment where the weights are a decreasing function of the distance between the current period and the investment period. In practice, an infinite number of past investment flows is not available, so equation (3) is replaced by the following expression:

$$K_{t+1} = (1-\delta)^t K_1 + \sum_{i=0}^{t-1} (1-\delta)^i I_{t-i}, \tag{4}$$

where K_1 is the initial capital stock at the beginning of period 1.

According to equation (4), the application of the perpetual inventory method requires the following inputs. First, a time series on gross investment flows is needed. The estimations in this paper rely on investment data from the OECD Analytical Database. Second, the estimations necessitate an initial capital stock; in our case, the capital stock at the beginning of 1960. Third, an assumption must be

[7]All series are expressed in the constant prices of 1995. For countries with a different base year (Australia 1999/2000; Canada, 1997; Iceland, 1990; Norway, 1997; Switzerland, 1990; and the United States, 1996), the series were rebased to 1995.

[8]The terms "depreciation" and "consumption of fixed capital" are used interchangeably in this paper. This is common in economic literature. Note, however, that "depreciation" as used here differs considerably from its use in company accounts, where it is calculated on the basis of historic costs rather than market prices.

made of the size and the time profile of the depreciation. Finally, a depreciation method must be chosen. This study relies on geometric depreciation.

There is no official information on the magnitude of the initial capital stock for any country except the United States. This paper follows an approach similar to that used by Jacob, Sharma, and Grabowski (1997, p. 567) to estimate the initial capital stock. For that purpose, an artificial investment series for the period 1860–1959 is constructed for each country by assuming that investment increased by 4 percent a year during this period, finally reaching its observed level in 1960.[9] The rationale for this assumption is that total gross investment in the 22 OECD countries under consideration grew by 4 percent a year on average during the period 1960–2001. It is, of course, highly improbable that investment in the earlier period grew at the same rate or that investment growth was the same for all countries. However, as historical information—especially on public investment—is not available for most of the countries under consideration, this study opts for an equal treatment of all countries.[10] The results of a sensitivity analysis described in Section IV suggest that the assumption on the initial capital stock does not affect the dynamics of the resulting capital stock series to a great extent. Also, the importance of the initial capital stock to the level of the capital stock series fades over time. Its contribution to the level of the capital stock at the end of the sample is less than 10 percent for the average OECD country.

This assumption implies that investment and the capital stock grew smoothly over the period 1860–1960, a simplification that needs to be justified, especially since some countries in the sample experienced severe damage during World War II.[11] The question arises as to whether the effects of war damage on the capital stock were persistent enough to affect our estimate of the initial capital stock at the beginning of 1960. There are at least two reasons why war damage might have had little effect by 1960. First, the countries that experienced the most war

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[9]An exception to this general rule applies in the case of the United States. The U.S. Bureau of Economic Analysis (BEA) provides investment series starting in 1914. This information is used by chaining the OECD data, which are available for 1960–2001, with the BEA growth rates for 1914–60.

[10]Maddison (1995) estimates gross capital stocks for six OECD countries based on investment series that in some cases start in the 19th century. However, he acknowledges that the assembly of the investment series is a major problem, because historical series for different periods have to be linked and because these series rely on different weighting bases. Also, there are generally breaks in the historical investment series. However, most important for our purpose is that historical series on investment in general do not include a measure of government investment but only measures of private investment. An exception relates to the influential works of Feinstein (for example, 1972), who provides investment series for the public sector in the United Kingdom starting in 1856. However, the definition of the public sector in his studies differs considerably from that underlying the OECD series.

[11]In his estimation of nonresidential capital stocks for six OECD countries, Maddison (1991, pp. 284–92) assumed that the loss in capital stock caused by war damage amounted to 3 percent in the United Kingdom, 8 percent in France, 10 percent in the Netherlands, 16 percent in Germany, and 25.7 percent in Japan. These figures are subject to a large margin of uncertainty, though, and the war damage to productive capacities may well have been lower. For example, Ritschl (2003, p. 414) reports that the industrial capital stock in Germany in 1945 exceeded prewar levels by a third. This capital stock was often composed of multipurpose machinery and, thus, was available for civil production. Likewise, Giersch, Paqué, and Schmieding (1992, p. 17) and Eichengreen and Ritschl (1998, p. 8) note that war damage to the capital stock in Germany was quite limited.

damage grew much faster after World War II than the countries that suffered little or no war damage.[12] Thus, real GDP in countries subject to severe war damage might well have returned to its long-run trend by 1960.[13] Second, the strong rise in GDP after World War II in these countries was accompanied by fast increases in investment and in the capital stock.[14] As a consequence, the capital stock might also have returned to its long-run trend by 1960.[15] All in all, there are hints that the effects of war damage on the capital stock in countries that were most severely affected had disappeared by 1960, the starting year for our capital stock estimates. The strong growth performance in the quarter century following World War II (often referred to as a "growth miracle") was distributed unevenly among OECD countries. As Broadberry (1988, p. 26) notes, the countries most hit by war damage, such as Japan and Germany, grew much faster than countries that were hardly affected by war damage, such as the United Kingdom and the United States. The evidence presented in Maddison (1982, p. 55) and Eichengreen and Ritschl (1998, p. 32) further suggests that by 1960 real GDP in OECD countries was close to the level implied by its long-run growth path. Moreover, the analysis in Eichengreen and Ritschl (1998, p. 8) shows that the strong growth performance in Germany was not impaired by a lack of capital resulting from war damage. On the basis of these considerations, we chose not to correct the capital stock estimates at the beginning of 1960 for war damage.

The next assumption in the estimation relates to the size and the time profile of the depreciation rate. In this study, it is assumed that the depreciation rate is time-varying for the public capital stock and the private nonresidential capital stock and constant for the private residential capital stock.[16] This assumption allows us to

[12]Maddison (1987, p. 650) reports that between 1950 and 1973, real GDP grew by 9.4 percent a year on average in Japan and by 5.9 percent in Germany, whereas the average annual growth rate was only 3 percent for the United Kingdom and 3.7 percent for the United States.

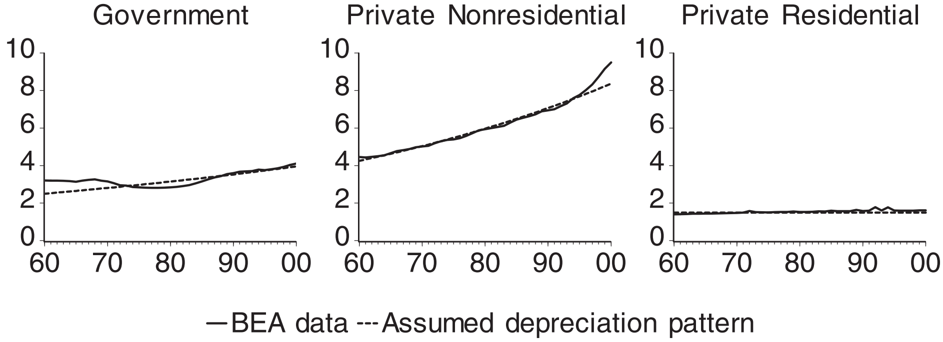
[13]For example, long-run growth in real GDP was remarkably stable in West Germany, despite the disruptions caused by World War II. Calculations based on historical GDP figures drawn from Ritschl and Spoerer (1997) reveal that real GDP grew by 2.9 percent a year on average between 1938 and 1960 and by 3.1 percent between 1960 and 1990. Of course, real GDP did not grow smoothly in the first subperiod. Real GDP in 1946 was lower than in 1938 by roughly 60 percent. However, real GDP growth over the period 1946–60 was extremely strong, averaging almost 12 percent a year.

[14]Maddison (1987, p. 657) reports that between 1950 and 1973, the private capital stock on average grew in Japan by 9.5 percent a year and in Germany by 7.2 percent. Calculations based on Luetzel (1977, p. 66) show that the total net capital stock in Germany grew by 7.9 percent a year on average between 1950 and 1960. Calculations based on Mitchell (1975) show that net investment in Germany grew by 9.7 percent a year on average between 1950 and 1960.

[15]The fall in capital stocks as a result of wartime disruptions was less pronounced than the fall in output (Maddison, 1982, p. 55), implying that the gap between capital stock levels at the end of World War II and their long-run trend was lower than was the case for output.

[16]This paper assumes that the time profile of the depreciation rates is the same across countries. Official estimates of capital stocks for different countries are, in general, based on different assumptions about depreciation rates. This is appropriate insofar as country-specific factors influence service lives. However, only a few countries have investigated service lives with particular care, among them the United States (OECD, 2001, p. 99). Therefore, it seems preferable to assume identical depreciation rates across countries for the purpose of international comparisons. Such a standardized approach is also adopted by Maddison (1995) and O'Mahony (1996).

Figure 2. Implicit Scrapping Rates for Net Capital Stocks in the United States, 1960–2000
(*In percentage*)



Sources: U.S. Bureau of Economic Analysis (BEA) and author's calculations.

take into account the empirically observed pattern of aggregate depreciation rates.[17] Figure 2 shows the implicit scrapping rate for the real government net capital stock, the real private nonresidential net capital stock, and the real private residential capital stock in the United States for the period 1960–2000. The implicit scrapping rate is calculated as the quotient of depreciation in period t and the net capital stock at the beginning of period t (data from the BEA):

$$s_t = \frac{D_t}{K_t} 100. \tag{5}$$

Figure 2 reveals that the implicit scrapping rates differ considerably across the three types of capital. The implicit scrapping rate is highest for private nonresidential capital and lowest for private residential capital. Whereas the scrapping rate for private residential capital has remained roughly constant over the period 1960–2000, the scrapping rates for private nonresidential capital and government capital have tended to rise over time. The increase is especially pronounced in the case of the private nonresidential capital stock, its scrapping rate having risen from about 4.5 percent in 1960 to about 9.5 percent in 2000.

Two developments may partly explain the rise in the scrapping rate. First, it may reflect an increasing weight of assets with relatively short asset lives, and second, it may reflect to a certain extent a shortening of asset lives. Both developments are characteristic of ICT-related assets that are part of the private nonresidential

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[17]National authorities usually estimate the contribution of investment to the net capital stock for a large number of individual assets (BEA, 1999). For most of these assets, national authorities assume constant depreciation rates, except for assets related to information and communication technology (ICT). At the same time, they assume different depreciation rates for different types of assets. As the relative importance of different assets changes with time, so does the average depreciation rate. The latter will increase over time if assets with relatively short asset lives gain in importance. This paper tries to capture this phenomenon by assuming a time-varying aggregate depreciation rate.

capital stock and—to a lesser extent—of the government capital stock. A similar pattern for implicit scrapping rates can be observed for other countries. For example, Canadian and Australian data reveal that implicit scrapping rates of private nonresidential and government capital have also risen since the 1960s.

On the basis of this evidence, this paper makes the following assumptions about the time profile of the depreciation rates. For the period 1860–1960, the depreciation rate is assumed to be 2.5 percent for government assets, 4.25 percent for private nonresidential assets, and 1.5 percent for residential assets. For the period 1960–2001, it is assumed to increase gradually from 2.5 percent to 4 percent for government assets and from 4.25 percent to 8.5 percent for private nonresidential assets,[18] and to be a constant 1.5 percent for private residential assets (see Figure 2). Equation (6) formalizes the time profile of the depreciation rates:

$$\delta_t^j = \delta_{\min}^j \left(\left(\frac{\delta_{\max}^j}{\delta_{\min}^j} \right)^{\frac{1}{41}} \right)^{t-2001+41} \qquad \text{for all } t = 1960, 1961, \ldots, 2001. \tag{6}$$

where $\delta^j_{\min}$ is the depreciation rate of asset type j in 1960 and $\delta^j_{\max}$ is its depreciation rate in 2001.

Finally, the real net capital stock at the beginning of period $t + 1$ for investment category j can be expressed (see also BEA, 1999, p. M-5) as

$$\begin{aligned} K_{t+1}^j &= \sum_{i=1860}^{t-1} \left[\prod_{k=i+1}^{t} \left(1-\delta_k^j\right) \right] \left(1-\frac{\delta_i^j}{2}\right) I_i^j + \left(1-\frac{\delta_t^j}{2}\right) I_t^j \\ &= \left(1-\delta_t^j\right) K_t^j + \left(1-\frac{\delta_t^j}{2}\right) I_t^j \qquad \text{for all } t = 1860, 1861, \ldots, 2001. \end{aligned} \tag{7}$$

Note that the capital stock at the beginning of the initial period, K_{1860}, is set equal to zero. Equation (7) differs from equation (4) in two respects in order to increase the realism of the estimates. First, as discussed earlier, the equation incorporates time-varying depreciation rates. Second, new investment is assumed to be placed in service at midyear instead of at the end of the year as implied by equation (4). Investment typically occurs throughout the year, not only at the end of the year. Equation (7), in conjunction with the assumptions about the depreciation patterns, serves to estimate net capital stocks for government assets and for private nonresidential and private residential assets.

To sum up, the application of the perpetual inventory method requires three important assumptions. First, an initial capital stock must be constructed; in our

[18]Figure 2 shows that the implicit scrapping rate calculated for BEA data sharply accelerated after 1995. To some extent, this probably reflects the growing importance of ICT assets characterized by asset lives that are much shorter than those of other assets. Because the importance of the ICT sector is considerably lower in most other industrial countries than in the United States (OECD, 2002a), we chose a flatter depreciation profile for the years 1995–2001 than that implicit in U.S. data.

case, for the beginning of 1960. This study uses artificial investment series for the period 1860–1959 as an input for the estimation of the initial capital stock. Second, an assumption must be made on the level and the time profile of the depreciation rate. This paper assumes that the depreciation rate is time-varying and different across the three types of investment considered, but the same for all countries. Third, a depreciation method must be chosen. This study relies on geometric depreciation. Section IV analyzes in detail the importance of each of these assumptions for the resulting capital stock estimates.

III. Capital Stock Estimates for 22 OECD Countries, 1960–2001

Figure 3 displays the evolution of the ratio of the public net capital stock and GDP, both at 1995 prices, for the 22 OECD countries over the period 1960–2001.[19] The graphs for the individual countries plot not only the author's own estimates of the public capital stock but also—where available—estimates from national authorities and from OECD (1997). For seven countries, there is no benchmark against which the author's estimates could be assessed.[20] The same holds for Greece, in view of the very low capital stock estimate reported by OECD (1997) owing to a narrow definition of public investment. For the countries for which alternative estimates are available, the general picture is that in most cases the dynamics of the author's estimates resemble those of the alternative estimates. In some cases, the level of the public capital–GDP ratios is also similar, but in general there are significant differences. This, in part, reflects the fact that the initial level of the author's estimates depends on the artificial investment series assumed for the period 1860–1959. Yet, there are two other reasons for the differences: (1) for some countries, the investment series shown in Figure 1 differ sharply from each other (Greece); and (2) many different methods are used by national authorities to construct capital stock estimates. An attractive feature of the author's estimates is that they rely on the same methodology and homogenous investment data across countries, a condition that is not satisfied for the alternative estimates.

Table 2 shows the value of the public capital–GDP ratio for three reference years: 1980, 1990, and 2000. The average ratio for the 22 OECD countries has declined by six percentage points over the period 1980–2000. Public capital as a share of GDP has declined in 13 countries since the early 1980s; it has slightly increased in 4 countries and strongly risen in Greece, Japan, Portugal, Spain, and Switzerland. It does not come as a surprise that Greece, Portugal, and Spain are in this group, because these countries are known to have made substantial efforts to

[19]A special problem in the estimation of capital stocks relates to German reunification. The OECD investment and GDP series cover only West Germany for the period 1960–90, but they include East Germany from 1991 on. Since there is no information on the magnitude of the East German capital stock at the beginning of 1991, this paper assumes that the ratio of the East German capital stock to the West German capital stock equaled the ratio of East German and West German GDP in 1991 (8 percent). In the estimation, the German capital stock at the beginning of 1991 is thus increased by 8 percent for the three asset types considered. From 1991 on, this additional capital stock depreciates at the same rate as the other assets.

[20]Austria, France, Iceland, Ireland, the Netherlands, Portugal, and Switzerland.

Figure 3. Real Government Net Capital Stock
in 22 OECD Countries, 1960–2001
(*As a percentage of real GDP*)

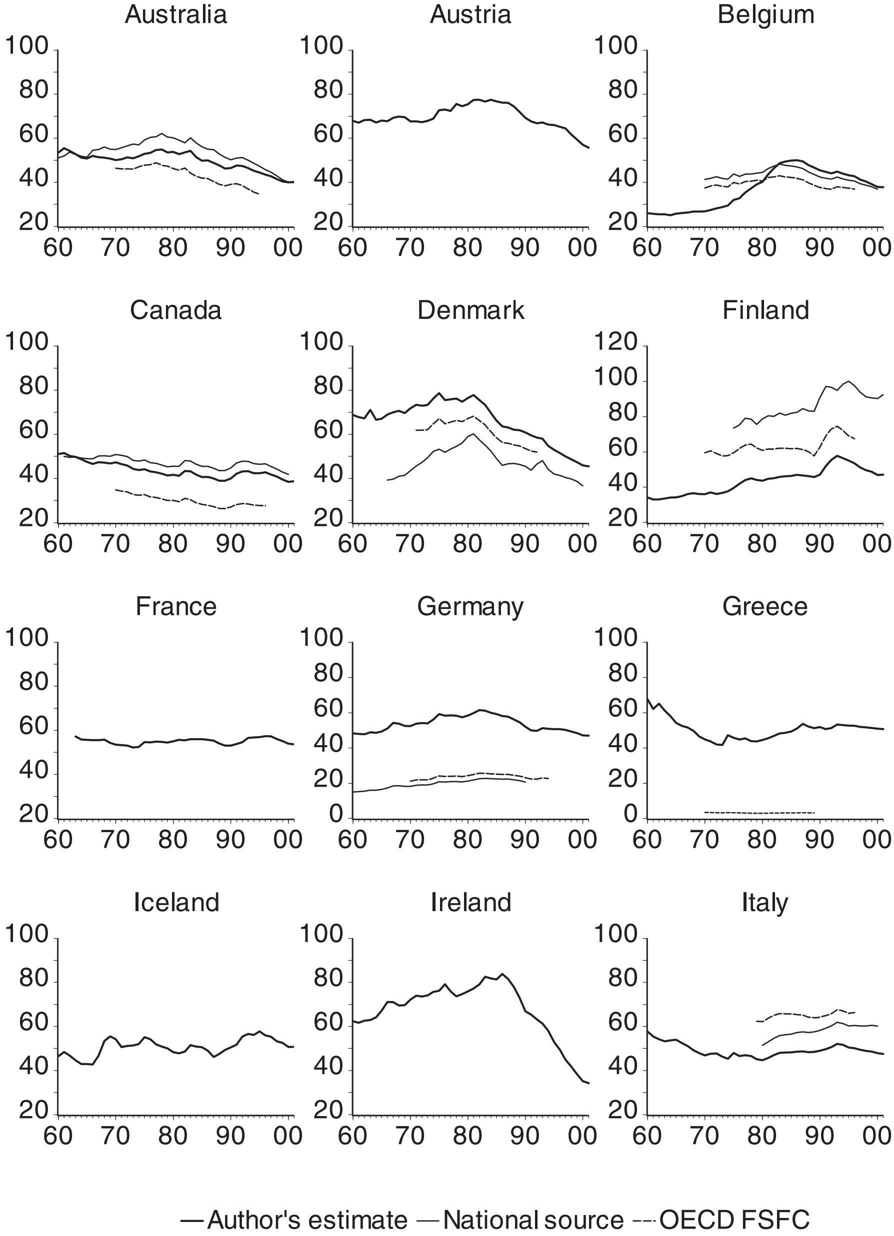
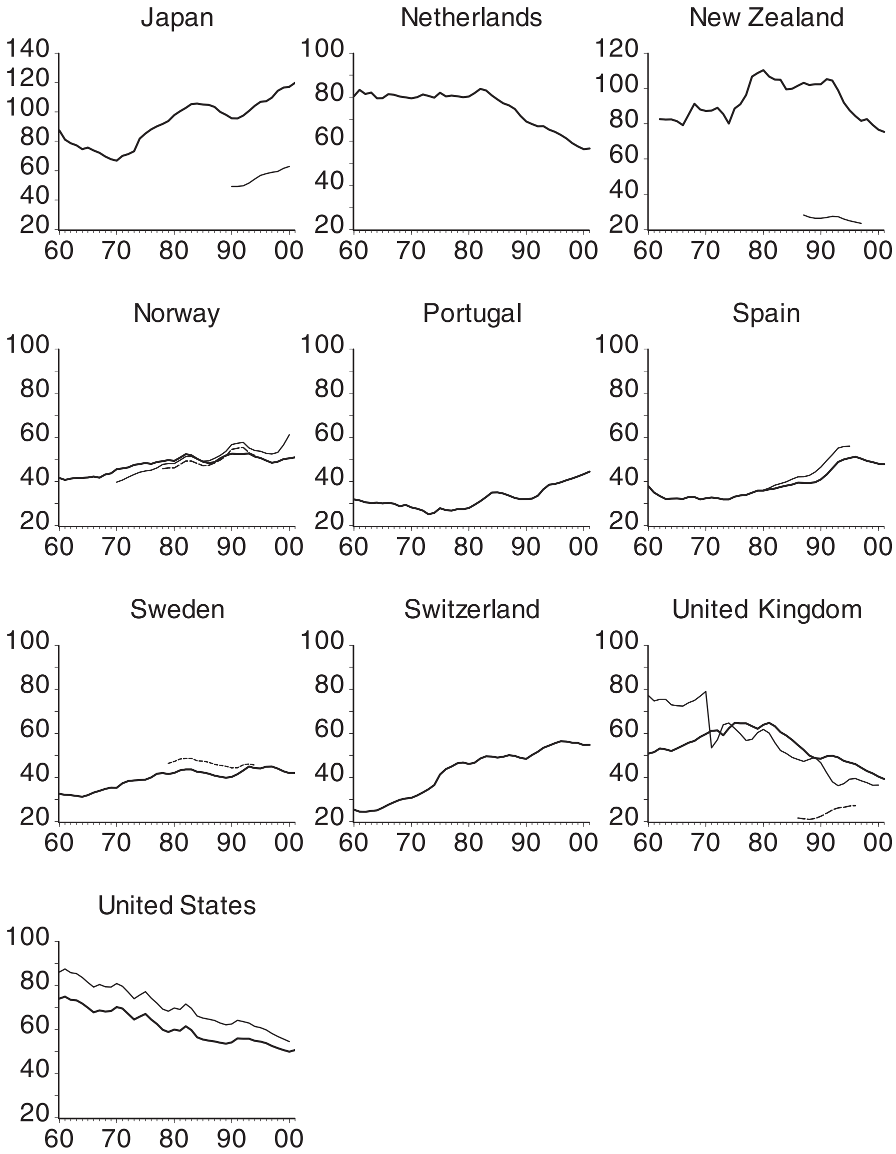


Figure 3 *(concluded)*



—Author's estimate —National source ---OECD FSFC

Sources: Series labeled "National source" are estimates from national authorities. Series labeled "OECD FSFC" are calculated as follows: the capital stock series are taken from OECD (1997), and divided by GDP series taken from OECD (1998).

Table 2. Government Net Capital Stock in 22 OECD Countries
(As a percentage of GDP, both at 1995 prices)

	1980		1990		2000		
Country	Ratio[1] (1)	Rank[2] (2)	Ratio[1] (3)	Rank[2] (4)	Ratio[1] (5)	Rank[2] (6)	Reliability[3] (7)
Australia	53.8	11	46.5	17	40.0	19	91.5
Austria	75.4	6	69.3	3	57.0	3	90.8
Belgium	40.2	20	45.5	18	37.9	21	94.4
Canada	41.6	19	40.0	21	38.4	20	91.5
Denmark	76.4	4	60.8	6	45.9	15	85.7
Finland	43.7	17	47.1	16	46.9	14	94.6
France	55.0	10	53.0	8	54.0	6	91.3
Germany	58.4	9	52.0	10	47.1	13	91.4
Greece	44.4	16	51.9	11	51.0	7	92.3
Iceland	48.4	13	50.5	12	50.7	8	94.8
Ireland	75.9	5	66.8	5	35.2	22	92.9
Italy	44.7	15	49.0	13	47.9	12	90.8
Japan	97.7	2	95.7	2	117.1	1	97.0
Netherlands	80.2	3	68.9	4	56.4	4	89.0
New Zealand	110.3	1	102.4	1	76.6	2	89.1
Norway	49.3	12	52.5	9	50.5	9	94.6
Portugal	27.9	22	32.0	22	43.3	16	96.2
Spain	35.8	21	40.9	19	48.0	11	95.7
Sweden	42.1	18	40.2	20	42.0	17	92.4
Switzerland	46.1	14	48.4	15	54.7	5	94.7
United Kingdom	63.9	7	48.5	14	40.3	18	86.8
United States	59.9	8	54.1	7	50.0	10	89.4
Average[4]	57.8		55.3		51.4		92.1
Standard deviation	20.6		17.0		17.1		3.0

Source: Author's estimates and calculations.

[1]The columns labeled "Ratio" give the ratio of the government capital stock and GDP (in percent).

[2]The columns labeled "Rank" give the ranking of the countries according to the size of their capital to GDP ratio; the country with the highest ratio ranks first.

[3]The column labeled "Reliability" gives the contribution of government investment in the period 1960–99 to the net capital stock at the beginning of 2000 (in percent). The difference between 100 percent and this figure reflects the contribution of government investment in the period 1860–1959, for which official data are not available.

[4]Unweighted average.

improve their infrastructure after joining the European Community. Furthermore, it is well known that during the 1990s the Japanese government repeatedly attempted (in vain) to reinvigorate the country's sluggish economy with the help of large spending programs focusing on construction. According to the estimates, in 2000 Japan had by far the largest public capital–GDP ratio among the OECD countries considered in this study, while Ireland had the lowest. The large decline in the public capital–GDP ratio in Ireland during the 1990s mirrors the strong fall of public investment as a share of GDP during this period. Fitz Gerald, Kearney, and

Morgenroth (1999) state that the Irish government viewed the lack of infrastructure as one of the major impediments to growth.

The last column of Table 2 shows the contribution of government investment in the period 1960–2000 to the government net capital stock in the year 2000. As explained in the previous section, assumed investment data for the period 1860–1959 are used to estimate the initial capital stock at the beginning of the year 1960. The contribution of the assumed investment data to the initial capital stock is 100 percent, but their influence gradually fades and is quite small at the end of the sample. The capital stock estimates for the year 2000 are largely unaffected by the assumption on investment during the period 1860–1959, for which no data from official sources are available. Investment from 1960 onward contributes an average 92 percent to the net capital stock in the year 2000, implying that the average contribution of the assumed investment data is only 8 percent.[21]

Another way to compare the government capital stock across countries is to look at its absolute value for each person. For an international comparison of real capital stock, three conditions must be met (OECD, 2002c, p. 8). First, the definition of the capital stock must be the same. This condition is fulfilled, since for all countries the investment data used in the capital stock estimations are compiled according to the 1993 System of National Accounts. Second, the capital stock must be expressed in the same currency; and third, the price level at which the capital stock is valued must be the same. The second and third conditions are not fulfilled, since the capital stock estimates are expressed in national currency and valued at the national price. These data can be converted to a common currency and revalued at a common set of prices using so-called purchasing power parities (PPPs). Unfortunately, PPPs for the public capital stock are not available. Instead, we must use a proxy for this measure. The OECD (2002c) provides PPPs for GDP and for total gross fixed capital formation. In the following paragraph, PPPs for gross fixed capital formation are used to convert the public capital stock estimates to U.S. dollars.[22]

Table 3 gives the real per capita public net capital stock expressed in 1999 PPPs for gross fixed capital formation in U.S. dollars for the years 1980, 1990, and 2000. The average capital stock for each person for the 22 OECD countries has increased by 32.2 percent over the period 1980–2000 (that is, by 1.4 percent a year). This growth rate has been lower than that of real GDP, implying that the public capital–GDP ratio has declined on average during this period in the OECD, as shown in Table 2. A comparison across countries reveals that the public capital stock per capita is by far the highest in Japan, exceeding the average by around 180 percent in the year 2000. Regarding the ranking of the countries, the United

[21]The contribution of the initial capital stock varies between 14.3 percent in the case of Denmark and 3.0 percent in the case of Japan. The differences in contributions across countries are mainly caused by differences in the level of public investment–GDP ratios over the sample period. For instance, the contribution of the initial capital stock is lowest in Japan because the public investment–GDP ratio there was the highest among the considered countries over the period 1960–2001.

[22]The most important qualitative results reported in the following paragraph are unaffected if PPPs for GDP are used instead. See Kamps (2004, Table 3) for results based on PPPs for GDP.

Table 3. Government Net Capital Stock Per Capita in 22 OECD Countries
(At 1999 PPPs in U.S. dollars)

	1980		1990		2000	
Country	Capital[1]	Rank[2]	Capital[1]	Rank[2]	Capital[1]	Rank[2]
Australia	8,003.7	11	8,176.0	15	8,817.5	16
Austria	10,856.7	7	12,359.1	5	12,188.5	4
Belgium	5,866.2	19	8,059.0	16	8,050.2	17
Canada	8,166.6	10	9,124.8	12	10,387.4	10
Denmark	11,809.9	4	11,343.6	7	10,361.4	11
Finland	7,004.6	15	9,809.3	10	11,629.0	8
France	7,615.3	13	8,805.9	13	10,317.5	12
Germany	10,415.8	8	11,273.6	8	10,242.9	13
Greece	3,828.0	20	4,562.3	21	5,412.1	21
Iceland	8,344.7	9	10,224.3	9	11,913.5	5
Ireland	6,219.7	18	7,589.3	18	7,449.7	19
Italy	6,259.3	17	8,531.9	14	9,566.1	14
Japan	16,396.7	1	22,717.8	1	31,147.2	1
Netherlands	11,280.2	6	11,387.6	6	11,623.0	9
New Zealand	12,008.5	3	13,403.4	4	11,697.7	7
Norway	7,170.4	14	9,329.5	11	11,844.4	6
Portugal	1,909.5	22	3,001.8	22	5,254.9	22
Spain	3,320.0	21	4,891.5	20	7,334.8	20
Sweden	6,742.0	16	7,766.6	17	9,322.4	15
Switzerland	11,798.3	5	14,434.3	2	16,591.4	2
United Kingdom	7,702.0	12	7,451.6	19	7,498.1	18
United States	12,640.2	2	14,230.5	3	16,397.4	3
Average[3]	8,425.4		9,930.6		11,138.5	
Standard deviation	3,440.8		4,115.1		5,313.1	

Source: Author's estimates and calculations.

[1]The columns labeled "Capital" give the level of the government net capital stock per capita at 1999 purchasing power parities (PPPs) for gross fixed capital formation in U.S. dollars. PPPs for gross fixed capital formation in national currency per U.S. dollar are taken from OECD (2002c). Population figures are taken from the OECD Analytical Database, Version June 2002.

[2]The columns labeled "Rank" give the ranking of the countries according to the level of public capital per capita; the country with the highest level ranks first.

[3]Unweighted average.

States ranks considerably higher than in Table 2, whereas Greece, Portugal, and Spain rank much lower. This discrepancy can be explained by the level of and change in real GDP. Output growth in the United States was very fast in the second half of the 1990s, implying a decreasing public capital–GDP ratio during the 1990s, even though public capital expanded substantially at the same time. In Greece, Portugal, and Spain, both public capital per capita and real GDP per capita remain low in the international comparison.[23] However, public capital per capita

[23]In 2000, real GDP per capita amounted to 66.3 percent of the OECD average in Greece, 72.4 percent in Portugal, and 79.5 percent in Spain (OECD, 2002b, p. 339).

has increased on average much faster in these countries than in OECD countries over the period 1980–2000, reflecting strong efforts to enhance public infrastructure in connection with accession to the European Community.

IV. Robustness of the Public Capital Stock Estimates

The following are the key assumptions made in the construction of the public capital stock estimates: (1) investment in the period 1860–1959 is assumed to have grown by 4 percent a year to finally reach its observed level in 1960, (2) the depreciation rate is time-varying and assumed to increase gradually for all asset types except residential assets, and (3) depreciation is assumed to be geometric. This section assesses the effect of the first two assumptions.[24] For that purpose, alternative public capital stock series are estimated for a reference country, the United States, modifying in turn each of the two assumptions. These alternative estimates are then compared with the benchmark estimates and with estimates from official sources. The results of this exercise are shown in Figure 4.

Figure 4a shows public capital stock estimates for alternative assumptions on the initial capital stock in 1960 for the United States, as well as the official capital stock estimate from the U.S. Bureau of Economic Analysis. The benchmark public capital stock estimate relies on the public investment series provided by the BEA for the period 1914–60 and assumes that public investment grew by 4 percent in the period 1860–1914.[25] The figure also shows an estimate that relies on the assumption that (as is assumed for all other countries) public investment in the United States grew by 4 percent in the period 1860–1959. In addition, Figure 4 shows an estimate that differs in the way the initial capital stock is constructed. This estimate of the initial public capital stock is constructed directly following a "steady-state approach" (Fuente and Doménech, 2002, p. 47). It follows from equation (2) that the growth rate of the capital stock can be expressed as

$$g_t^K = \frac{K_{t+1} - K_t}{K_t} = -\delta + \frac{I_t}{K_t}. \tag{8}$$

Thus, the capital stock at the beginning of period t can be calculated as investment in period t divided by the sum of the depreciation rate and the growth rate of the capital stock in period t:

$$K_t = \frac{I_t}{\delta + g_t^K}. \tag{9}$$

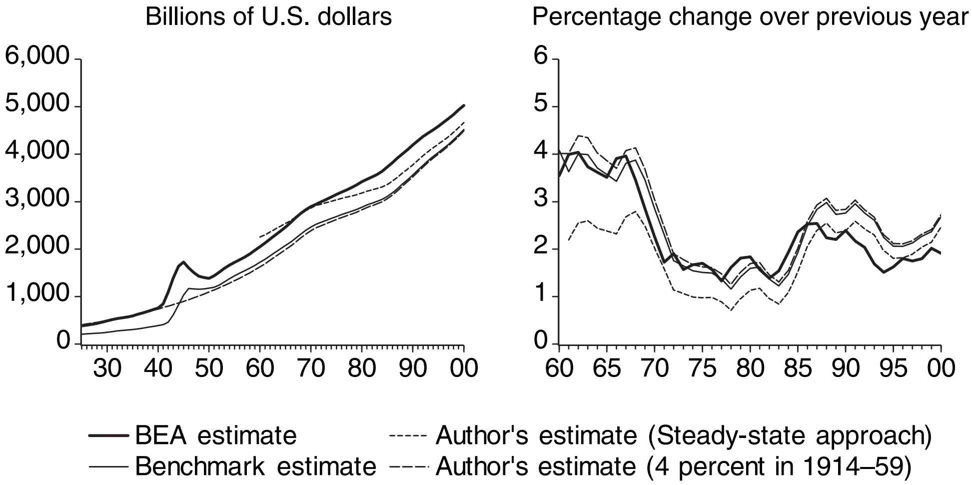
As the growth rate of the capital stock is unknown a priori, an assumption about its magnitude is needed. Neoclassical growth theory suggests that invest-

[24]See Kamps (2004, Section V) for an illustration of the influence of alternative depreciation methods for Canadian data, based on official estimates provided by Statistics Canada.

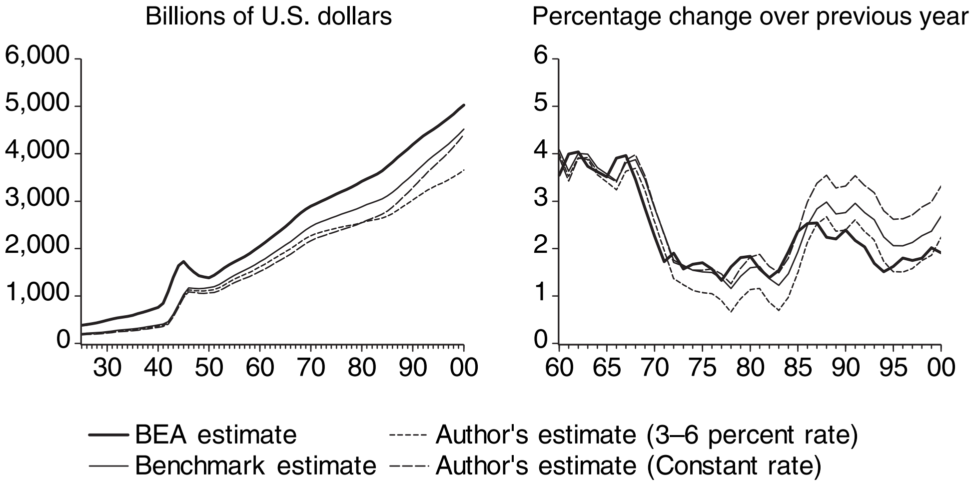
[25]The official growth rates provided by the BEA for the period 1914–60 are chained with the OECD investment series available for 1960–2001.

Figure 4. Estimates of Government Net Capital Stocks for the United States for Alternative Estimation Assumptions

(a) Alternative assumptions on the initial capital stock in 1960



(b) Alternative assumptions on depreciation rates



Source: Series labeled "BEA estimate" are from the U.S. Bureau of Economic Analysis (BEA).

ment and capital grow at the same rate in the steady state. Thus, the growth rate of capital can be approximated by the growth rate of investment. As it is improbable that the U.S. economy was in a steady state in 1960, the growth rate of capital is instead approximated by the average growth rate of investment over the period 1960–2001. This growth rate was 2.7 percent for government investment, 5.4 percent for private nonresidential investment, and 2.5 percent for private residential investment. Finally, the investment series is filtered using a Hodrick-Prescott filter to remove its cyclical component.

Figure 4a shows that assuming a constant 4 percent growth rate of public investment over the period 1914–59 instead of using the historical BEA investment growth rates does not significantly affect the resulting public capital stock series. For the period of interest, 1960–2000, the levels and dynamics of both series are almost indistinguishable. Pronounced differences occur over the period 1940–50 only because the public capital stock based on BEA investment takes into account the large increase in public investment during World War II, whereas the alternative estimate does not. However, the effect of this difference is short-lived. The figure also reveals that although the level of the public capital stock estimates is lower than the capital stock series reported by the BEA, the dynamics are very similar, as witnessed by the strong co-movement of the growth rates of the public capital stock series.

Furthermore, formal tests for equality between the means and the variances of the author's estimates and the BEA series fail to reject the null hypothesis of equality.[26] Figure 4a also shows the author's estimate of the public capital stock relying on the steady-state approach. The time profile of this estimate differs considerably from that of the other series shown in the figure. While the level of the initial capital stock at the beginning of 1960 is higher than that of the BEA reference series, its level at the beginning of 2000 is comparable to that of the author's estimate and thus lower than that of the BEA series. Furthermore, the dynamics of this estimate are significantly different from that of the other series, as can be seen in the figure. This visual impression is confirmed by a formal test for equality between the means and variances of the growth rates of this estimate and the BEA series. These results suggest that the benchmark assumption on the initial capital stock made in this paper is a reasonable way to proceed.

Figure 4b shows public capital stock estimates for alternative assumptions on the time profile of the depreciation rate and contrasts these estimates with the BEA estimate. The benchmark estimate assumes a time-varying depreciation rate increasing from 2.5 percent to 4 percent, as explained in Section II. Figure 4b shows the public capital stock for a depreciation rate that—based on implicit scrapping rates for the total capital stock—gradually increases from 3 percent to 6 percent over the period 1960–2001. It also shows the public capital stock for a depreciation rate that is constant over time and equal to the average implicit scrapping rate empirically observed for the United States (3.5 percent for government assets).

The figure reveals that these two estimates exhibit dynamics that differ significantly from those of the BEA series and of the benchmark estimate. The reason is that the estimate assuming a constant depreciation rate considerably overestimates the growth of public capital in the 1990s, whereas the estimate relying on a steeper time profile of the depreciation rate underestimates the growth of public capital in the 1970s and early 1980s. All in all, the benchmark assumption on the depreciation rates based on empirically observed implicit scrapping rates for the United States seems to be the most sensible approach, given the alternatives.

[26]Detailed results are available upon request. These tests are carried out for the growth rates of the series, because unit root tests indicate that the public capital stock series are nonstationary.

This section has shown the effect of various assumptions on public capital stock estimates. Visual inspection and tests for equality between the benchmark estimates and reference series reported by the BEA reveal that the benchmark estimates of public capital seem quite plausible. The properties of the capital stock estimates based on the various assumptions are further explored in the next section, where these estimates are used as explanatory variables in regressions according to the so-called production function approach.

V. Evidence for the Production Function Approach

This section uses alternative capital stock measures to estimate the elasticity of output with respect to public capital, applying the production function approach. The first subsection presents regression results for the various capital stock estimates for the United States and, thus, supplements the sensitivity analysis presented in the previous section. The second subsection presents regression results for 22 OECD countries for capital stock estimates from different sources (i.e., the author's benchmark estimates, estimates from national sources, and estimates from OECD, 1997).

The production function approach is one of three main approaches that have been employed in the empirical literature on the macroeconomic effects of public capital. The other approaches are the cost function approach and the vector autoregressive (VAR) approach.[27] This study concentrates on the production function approach because it is the simplest of the three and because it remains widely applied in the empirical literature. Even recent studies relying on the less restrictive VAR approach often provide additional estimates according to the production function approach as a benchmark against which to evaluate the VAR results (Ligthart, 2002). Thus, there is ample evidence against which the regression results of this study can be evaluated.

The starting point of empirical applications relying on the production function approach is an aggregate production function of the form $Y = AF(L, K^P)$, where Y is output, L is labor input, K^P is the private capital stock, and A is an index representing multifactor productivity. This expression is extended by including the public capital stock, K^G, so that the aggregate production function can be written as $Y = AF(L, K^P, K^G)$. Using the Cobb-Douglas form, the production function can be expressed as $Y = AL^{\alpha}(K^P)^{\beta}(K^G)^{\gamma}$, where the parameters α, β, and γ can be interpreted as elasticities of output with respect to the factors of production. The empirical literature in general investigates the production function in intensive form, imposing constant returns to scale in private inputs, in order to avoid multicollinearity problems.[28] Dividing both sides by K^P yields the production function

[27]See Sturm, Kuper, and de Haan (1998) for a discussion of the three approaches and an overview of empirical studies.

[28]Multicollinearity among the regressors is frequently cited as a problem in the empirical literature estimating production functions and cost functions for individual countries (see the survey by Sturm, Kuper, and de Haan, 1998). An alternative way to deal with this problem is to exploit the cross-sectional dimension of the data and estimate panel data models instead of carrying out individual-country regressions. This is done in the second subsection.

in intensive form, $Y/K^P = A(L/K^P)^{\alpha}(K^P)^{\alpha+\beta-1}(K^G)^{\gamma}$. Finally, imposing constant returns to scale in private inputs ($\alpha + \beta = 1$) and taking the natural logarithm yields the regression equation that is typically employed in empirical studies relying on the production function approach:

$$\left(y_t - k_t^P\right) = a_0 + a_1 t + \alpha\left(l_t - k_t^P\right) + \gamma k_t^G + \varepsilon_t, \tag{10}$$

where y_t is the log of GDP, k_t^P is the log of private capital, l_t is the log of labor input, k_t^G is the log of public capital, and ε_t is a disturbance term. As in Aschauer (1989b), a constant, a_0, and a time trend, t, are introduced as a proxy for multifactor productivity.

An important issue raised by this specification is that of potential nonstationarity of the variables included in the regression. A large number of alternative unit root tests are designed to discriminate between nonstationary and stationary processes. We use the popular Dickey and Fuller (1979, 1981) test to determine whether the model variables are nonstationary. This test is applied to a total of 188 variables that are used in the individual-country regressions reported in the two subsections.[29] The test results indicate that the vast majority of variables is nonstationary; only 13 variables appear to be stationary in level. Among the variables that are nonstationary, many seem to be integrated of order 2 rather than of order 1, according to the test results. Yet it is well known that unit root tests have low power to discriminate between unit root and near unit root processes. This problem is especially pronounced for small samples. One way to alleviate the problem is to make use of the cross-sectional dimension of the data and apply panel unit root tests to the variables. The results of two popular panel unit root tests suggest that the variables are integrated to the first order.[30] The individual-country regressions are also based on this finding.

Since the variables are nonstationary, estimation of equation (10) makes sense only if the variables are co-integrated. There are many alternative methods that can be used to test for co-integration. In this paper, the two-step procedure initially proposed by Engle and Granger (1987) is applied. In the first step, equation (10) is estimated by ordinary least squares (OLS); in the second step, an augmented Dickey-Fuller test is performed on the residual sequence $\{\hat{\varepsilon}_t\}$ to determine whether it has a unit root. The null hypothesis of the test is that the residual sequence has a unit root or, in other words, that the variables are not co-integrated. Note that the critical values of the Engle-Granger test are larger in absolute value than those of

[29]Detailed results are available upon request. We use the so-called augmented Dickey-Fuller test, which is asymptotically valid in the presence of serial correlation in the errors, including two additional lags of the respective variable. The test is first carried out for the variables in levels. In this case, the test equation includes a constant and a linear time trend. If the null hypothesis of a unit root cannot be rejected at the 5 percent significance level, the test is also carried out for the variables in first differences. In this case, the test equation includes a constant. If the null hypothesis of a unit root still cannot be rejected, the test is also carried out for the variables in second differences. Small-sample critical values are derived from MacKinnon (1991).

[30]We use the panel unit root tests proposed by Levin, Lin, and Chu (2002) and Im, Pesaran, and Shin (2003). Detailed results are available upon request.

the standard Dickey-Fuller test, because the sequence $\{\hat{\varepsilon}_t\}$ is generated from a regression equation. The appropriate small-sample critical values can be derived from MacKinnon (1991). If the variables are co-integrated, the OLS estimates from regression (10) will be superconsistent. However, if the variables are not co-integrated, estimating equation (10) in levels might give rise to a spurious-regression problem. Instead, it is appropriate to difference the variables in order to induce stationarity. In this case, the regression equation takes the form

$$\left(\Delta y_t - \Delta k_t^P\right) = a_1 + \alpha\left(\Delta l_t - \Delta k_t^P\right) + \gamma \Delta k_t^G + \upsilon_t, \tag{11}$$

where Δ is the first-difference operator and υ_t is a disturbance term.

Estimates of Public Capital Productivity for Alternative Capital Measures

This subsection supplements the sensitivity analysis and reports estimates of the elasticity of output with respect to public capital for the United States, using the various public capital stock estimates discussed in Section IV. Real GDP and employment data are taken from the OECD Analytical Database; public and private capital stocks are estimates calculated using the alternative assumptions on the initial capital stock and the depreciation rate considered in Section IV. The private capital stock is the sum of private nonresidential and private residential capital. The private capital stocks are estimated using exactly the same method as that used to estimate government capital. The benchmark estimation assumes that the depreciation rate increases from 4.25 percent to 8.5 percent for private nonresidential assets, although it is assumed to be constant for private residential assets (1.5 percent). Two alternatives are considered regarding the time profile of the depreciation rate. The first alternative assumes that the depreciation rate increases from 3 percent to 6 percent over the period 1960–2001 for all assets. The second alternative assumes that the depreciation rate is time-invariant and—based on average implicit scrapping rates for the United States—is equal to 6 percent for private nonresidential capital and 1.5 percent for private residential capital.

Table 4 reports estimates of the elasticity of output with respect to public capital for the United States using the various public capital stock estimates. Figures in bold indicate whether the elasticity is taken from the model in levels or first differences, depending on the results of the test for co-integration. Table 4 shows that the Engle-Granger test statistic is lower in absolute value than the 5 percent critical value in all cases. The test results, thus, suggest that there is no co-integration among the variables and, by implication, that the production function as formalized in equation (10) does not constitute a stable long-run relationship. As a consequence, all estimates are based on the model in first differences.[31] The estimated

[31]As the usual inference procedures are inappropriate in the presence of nonspherical disturbances, the t-statistics reported in Tables 4 and 5 are based on the Newey and West (1987) heteroskedasticity and autocorrelation consistent covariance estimator.

Table 4. Elasticities of Output with Respect to Public Capital for the United States for Alternative Capital Stock Measures[1]

		Elasticity		Cointegration Test[2]
Model	Sample	Levels	Differences	Test statistic
(a) United States: Alternative assumptions on the initial capital stock				
Benchmark	1960–2001	0.839	**0.788***	–2.792
		(7.144)	(2.885)	
Steady-state approach	1960–2001	0.878	**0.850***	–3.558
		(5.060)	(2.354)	
4% growth rate[3]	1960–2001	0.795	**0.747***	–2.565
		(7.681)	(2.996)	
BEA capital stock	1960–2001	0.991	**0.830***	–1.619
		(6.486)	(3.083)	
(b) United States: Alternative assumptions on depreciation rates				
3%–6% for all assets	1960–2001	0.736	**0.372**	–2.552
		(7.162)	(1.112)	
Constant[4]	1960–2001	0.723	**0.723***	–3.518
		(5.355)	(2.672)	

Source: Author's estimates and calculations.

[1] *t*-values based on the Newey and West (1987) heteroscedasticity and autocorrelation consistent covariance estimator in parentheses. *denotes statistical significance at the 5 percent level. Elasticities in the column labeled "Levels" are set in bold if the variables are co-integrated; otherwise, the elasticity for the corresponding model estimated in first differences reported in the column labeled "Differences" is set in bold.

[2] This paper uses the so-called augmented Engle-Granger test, performing an augmented Dickey-Fuller test on the residuals of the model in levels (equation (10)). The MacKinnon (1991) 5 percent critical value for rejection of the null hypothesis of no co-integration is –4.795 for the sample 1960–2001.

[3] The growth rate of investment in the period 1914–59 is assumed to be 4 percent a year. The benchmark estimates, instead, rely on historical growth rates of investment reported by the U.S. Bureau of Economic Analysis (BEA).

[4] The depreciation rate is assumed to be constant over time. Based on the average implicit scrapping rate over the period 1960–2000, the depreciation rate is assumed to be 3.5 percent for government capital, 6 percent for private nonresidential capital, and 1.5 percent for private residential capital.

elasticities of output with respect to public capital are statistically significant in all cases but one and have the expected (positive) sign. The estimates are, however, very high, ranging from 0.37 to 0.85 and thus implying what Aschauer (1995, p. 91) has called "supernormal" returns to public capital. However, this is a common finding in the literature. For example, Sturm and de Haan (1995, p. 64) report elasticities of output with respect to public capital of 0.67 and 0.71 for the United States for a model estimated in first differences similar to equation (11).

The regressions reveal another problem associated with the production function approach: the difficulty of interpreting the regression results as representing the input elasticities of output. The estimates of the coefficient on labor input are larger than 1 in all regressions, implying a negative elasticity of output with respect to private capital.[32] Taken at face value, these results suggest not only that public capital is much more productive than private capital but also that private capital is not productive at all. Again, such a finding is not uncommon in the literature. For example, Sturm and de Haan (1995, p. 64) report that their estimates for the United States imply a large negative elasticity of output with respect to private capital. There are several reasons to be cautious in interpreting this finding: (1) the assumed functional form of the production function may not be an appropriate description of the data, (2) the exogeneity assumptions underlying the production function approach may not be satisfied, and (3) the regressions may suffer from a small-sample problem. One way to deal with this problem is to exploit the cross-sectional dimension of the data and estimate panel data models instead of carrying out individual-country regressions. The panel estimation reported in the next subsection yields a more plausible value for the elasticity of output with respect to private capital.

Estimates of Public Capital Productivity for 22 OECD Countries

Table 5 reports estimates of the elasticity of output with respect to public capital for the 22 OECD countries for equation (10) using public capital stock estimates from three alternative sources: first, the author's estimates; second, estimates from national sources; and third, estimates from OECD (1997). The table reveals the main advantage of the author's capital stock estimates, which is that equation (10) can be estimated for 22 countries. The alternative sources allow for only 10 and 11 individual-country regressions, respectively. The estimates of the elasticity of output with respect to public capital are based on the model in first differences, as the augmented Engle-Granger test fails to reject the null hypothesis of no co-integration in all cases. Most of the coefficients are statistically insignificant for the estimations based on data from other sources. This result is similar to that of Ford and Poret (1991), who estimated models based on the production function approach for 11 OECD countries using capital stock data from an earlier volume of OECD (1997). In contrast, most of the coefficients stemming from estimations based on the author's capital stock estimates are statistically significant. However, in those cases where the elasticity of output with respect to public capital is significant, it is again quite large. Moreover, for some countries, the coefficient on labor input—not reported in the table—is larger than 1, making it difficult to interpret the estimated coefficients as parameters of a Cobb-Douglas production function.

The last row of Table 5 reports the elasticity of output with respect to public capital for a panel consisting of all 22 OECD countries. This estimate is based on the pooled regression equation

$$\Delta y_{it} = a_1 + \alpha \Delta l_{it} + \beta \Delta k_{it}^P + \gamma \Delta k_{it}^G + \upsilon_{it}, \tag{12}$$

[32]These estimates are not reported in Table 4. Detailed results are available upon request. The coefficient of labor input is statistically significant in all cases.

Table 5. Elasticities of Output with Respect to Public Capital for 22 OECD Countries for Capital Stock Estimates from Different Sources[1]

	Author's Estimates		National Source		OECD (1997)	
Country	Sample	Elasticity	Sample	Elasticity	Sample	Elasticity
Australia	1960–2001	0.270 (1.836)	1960–2001	0.115 (1.034)	1970–95	–0.280 (–0.949)
Austria	1965–2001	0.437* (2.705)				
Belgium	1960–2001	0.224* (2.477)	1970–2000	0.471* (3.365)	1970–95	0.601* (3.043)
Canada	1960–2001	0.478* (2.350)	1961–2001	0.396* (3.594)	1970–95	0.381 (0.988)
Denmark	1960–2001	0.478* (2.894)			1971–92	0.321 (1.707)
Finland	1960–2001	0.313 (1.074)			1970–96	–0.330 (–1.433)
France	1965–2001	1.106* (3.872)				
Germany	1960–2001	0.028 (0.202)	1960–90	0.786* (4.920)	1970–94	–0.311 (–1.341)
Greece	1961–2001	0.167 (0.283)			1970–89	0.759* (4.421)
Iceland	1967–2001	–0.014 (–0.035)				
Ireland	1960–2001	–0.116 (–0.414)				
Italy	1960–2001	0.190 (0.791)	1980–2000	–0.206 (–0.591)	1979–96	–0.375 (–0.693)
Japan	1960–2001	0.835* (2.710)	1990–2000	–0.091 (–0.271)		
Netherlands	1969–2001	0.535* (2.524)				
New Zealand	1962–2001	–0.050 (–0.199)	1987–97	–0.849 (–0.761)		
Norway	1960–2001	0.024 (0.128)	1970–2000	0.017 (0.165)	1978–94	0.054 (0.496)
Portugal	1960–2001	–0.492 (–1.131)				
Spain	1961–2001	0.388* (2.088)	1980–95	–0.087 (–0.820)		
Sweden	1960–2001	0.293* (2.378)			1979–94	0.019 (0.037)
Switzerland	1960–2001	0.503* (3.809)				
United Kingdom	1960–2001	0.175 (1.264)			1986–96	0.407 (0.981)
United States	1960–2001	0.788* (2.885)	1960–2000	0.830* (3.082)		
OECD (Panel)	1960–2001	0.223* (4.835)				

Source: Author's estimates and calculations.

[1] *t*-values based on the Newey and West (1987) covariance estimator in parentheses. *denotes statistical significance at the 5 percent level. The model is estimated in first differences in all cases, based on the results of Engle-Granger tests for cointegration.

where the index i represents the countries considered. Compared with equation (11), the pooled regression does not impose the restriction of constant returns to scale a priori. The panel analysis, unlike the individual-country regressions, should not be subject to multicollinearity problems, because it exploits the cross-sectional variation in the data. Another obvious advantage of the panel regression over the individual-country regressions is the much larger number of observations: While most individual-country regressions have 37 degrees of freedom, the panel regression has more than 800 degrees of freedom. Consequently, the parameters of interest can be estimated much more precisely.

The estimation results for the panel model indicate that the elasticities of output with respect to public capital (0.22), private capital (0.26), and labor input (0.57) take on sensible values.[33] According to these estimates, private and public capital are roughly equally productive. Finally, based on the estimation results, it is not possible to determine whether the production function exhibits constant returns to scale in private inputs only or in all inputs. A test for constant returns to scale in private inputs and a test for constant returns to scale in all inputs both fail to reject the null hypothesis.

VI. Conclusion

This paper provides new estimates of the government net capital stock for 22 OECD countries for the period 1960–2001. This data set has several attractive features compared with existing alternatives. First, the same estimation approach is used across all countries, ensuring a maximum degree of international comparability. Second, the estimates are based on investment data (compiled by the OECD) that are homogenous across countries. Third, these investment data have been compiled according to the 1993 System of National Accounts, whereas the data reported in OECD (1997) were compiled according to the old 1968 System of National Accounts. Finally, the data set covers 22 countries and 42 years for each country and is, thus, much larger than any existing alternative.

The public capital stock estimates reveal that public capital–GDP ratios have tended to decline in most OECD countries since the late 1970s. The estimates further show that a considerable disparity exists in the public capital endowment of OECD countries, even though some convergence has taken place in the past two decades. A sensitivity analysis regarding the main estimation assumptions suggests that the benchmark estimates of public capital stocks are reasonable when they are compared with estimates from official sources for the United States. Regression results based on the production function approach indicate that the elasticity of output with respect to public capital is positive and statistically significant in many countries. This is confirmed by the results of a simple panel regression showing that public capital is productive, on average, in OECD countries.

The capital stock data may prove useful for applied research on the macroeconomic effects of public capital in several respects. First, they may allow an assessment of public capital productivity for countries for which such estimates

[33]The elasticities of output with respect to private capital and labor input are not reported in the table. All elasticities are significant at the 5 percent level. Detailed results are available upon request.

have not been available in the past because of a lack of public capital stock data. Moreover, they can be used in the estimation of models based on dynamic panel regression techniques aiming to uncover the average effect of public capital in OECD countries. Finally, they can be employed in the estimation of VAR models—the most commonly used framework in the recent empirical literature.

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