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THE POSITIVE EFFECT OF PUBLIC INVESTMENT ON POTENTIAL GROWTH

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By Jean-Marc Fournier

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Johansson, A. (2016), “Public Finance, Economic Growth and Inequality: A Survey of the Evidence”, *OECD Economic Department Working Papers*, No. 1346, OECD Publishing.

Bloch, D., J.M. Fournier, D. Gonzales, and A. Pina (2016), “Trends in Public Finances: Insights from a New Detailed Dataset”, *OECD Economic Department Working Papers,* No. 1345, OECD Publishing.

ABSTRACT/RÉSUMÉ

The positive effect of public investment on potential growth

An estimated baseline convergence model capturing the long-term effect of human capital and physical investment on potential output for a panel of OECD countries is augmented with public investment and its components. The estimations suggest that public investment has a positive effect on long-term growth and on labour productivity. Public investment can also increase the speed of convergence of catching-up countries. Public investment is more beneficial in some areas than others. This is particularly the case of public investment in health and in research and development. There is also evidence that growth gains from increasing public investment may decline at a high level of the public capital stock due to decreasing returns.

JEL Codes: H54; O40

Keywords: Public investment, Growth, Health investment, Research and Development, Decreasing marginal returns

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L’effet positif de l’investissement public sur la croissance potentielle

Un modèle de convergence de base mesure l’effet à long terme du capital humain et de l’investissement physique sur la production potentielle pour un panel de pays de l’OCDE. L’investissement public et ses composantes y sont ajoutés. Les estimations suggèrent que l’investissement public a un effet positif sur la croissance et sur la productivité du travail à long terme. L’investissement public peut également accroître la vitesse de convergence des pays en voie de rattrapage. L’investissement public est plus bénéfique dans certains domaines que d’autres. C’est particulièrement le cas de l’investissement public dans la santé et dans la recherche et le développement. Il est également prouvé que les gains de croissance découlant de l’accroissement des investissements publics pourraient baisser à un niveau élevé de stock de capital public en raison de rendements décroissants.

Codes JEL : H54 ; O40

Mots clés : Investissement public, Croissance, Investissement dans la santé, Recherche et développement, Rendements marginaux décroissants

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THE POSITIVE EFFECT OF PUBLIC INVESTMENT ON POTENTIAL GROWTH

By Jean-Marc Fournier[1]

1. Introduction and main findings

1. In the aftermath of the recent economic crisis, the recovery has been lacklustre; raising the question of what policy levers can be used to raise growth prospects. At the same time, public investment has declined in most OECD countries (OECD, 2015a). As both economic theory and the empirical literature suggest that public investment can increase output, it is one policy lever to escape from the current low growth environment. However, beyond the general arguments in favour of public investment, the size of the beneficial effects can depend on specific circumstances. For instance, it can depend on the public capital stock level, and it can differ across government functions.

2. This paper sheds new light on the long-term effects of public investment, estimating the average effect and providing some insights on the specific circumstances, which make public investment particularly effective. The following findings emerge from the empirical analysis:

- Increasing the share of public investment in total government spending yields large growth gains.
- These gains are particularly strong for public investment in health (e.g. hospitals and their equipment) and for research and development spending.
- A spending shift towards public investment, away from other spending, would also speed up the convergence of lagging countries towards the income of the most advanced economies.
- The growth gains from increasing public investment may decline at a high level of the public capital stock due to decreasing returns. Still, the estimations suggest that all OECD countries, except Japan, have room for additional public investment.

2. Insights from the literature

2.1. Theoretical considerations

3. Economic theory suggests that investment can increase output as it is a production factor, and that it can have an effect either on the level or on the growth rate, depending whether the marginal return are decreasing or not. In the Solow model (Solow, 1956), the higher the investment rate, the higher the output level. In this model, investment implies no lasting growth effect because of decreasing returns.

1. The author is member of the Economics Department of the OECD. He thanks Falilou Fall, Peter Gal, Peter Hoeller, Catherine Mann and Jean-Luc Schneider (all of whom are members of the Economics Department) for comments and suggestions. The paper has also benefitted from comments by members of Working Party No. 1 of the OECD Economic Policy Committee. Special thanks go to Debra Bloch for statistical assistance and Celia Rutkoski for assistance in preparing this document.

Beyond this effect on the GDP level, a main conclusion in the endogenous growth literature with constant or increasing returns to scale is that long-term growth crucially hinges on the accumulation of human and physical capital (Lucas 1988; Romer 1990).

4. Turning to public investment, theory suggests that its effect is most likely positive and depends to what extent it crowds in or crowds out private investment (Aschauer, 1989). If public and private capital are complementary (e.g. roads that connect enterprises), higher public investment can spur private investment. This corresponds to cases in which the social return is above the private return, as investigated by Arrow (1962) in the case of production of knowledge, which is a public good that can benefit all. Similarly, Romer (1986) shows that in the presence of positive externalities, government intervention can lead to welfare gains. In other words, the investment return expected by the private sector reflects only private returns, so that the investment ratio without government intervention would be below the social optimum: there is a case for public investment. By contrast, if public and private capital are substitutes, a rise in public capital can decrease private investment. The crowding-out may be partial, so that aggregate investment still increases. Aggregate investment may even be unchanged if one unit of public investment crowds out one unit of private investment. This can occur if public investment is spent on specific functions that do not increase the rate of return of private investment (e.g. investment in state-owned enterprises in sectors with no specific externalities). In this crowding-out scenario, the growth effect could even turn negative if public investment is less effective than private investment.

5. These theoretical considerations are a useful reminder that there are two major conditions to make sure that public investment boosts long-term growth: the public sector should focus on investments with positive externalities and public finance management practices should ensure effectiveness. And given the theoretical ambiguities, the effect of public investment on growth is an empirical question.

2.2. Empirical evidence from the literature

6. Empirical cross-country studies estimating the impact of the structure of spending on growth generally provide evidence that the mix of spending matters for growth (see Cournède et al., 2013 or Johansson, 2016 for a literature review). Often these papers classify government spending into productive and non-productive spending, depending on whether they are included in the production function or not (e.g. Barro, 1990). For instance, investment in infrastructure and education can raise the human and physical capital stock and, in turn, long-run growth or the GDP level. Since Kneller et al. (1999), a number of papers found that productive spending affects economic growth positively, while unproductive spending does not. For instance, Gemmell et al. (2014) find that reallocating total spending towards infrastructure and education would raise GDP in the long run in OECD countries.[2]

7. One of the key insights of Kneller et al. (1999) is the importance of controlling for the government's budget constraint as failing to do so would yield biased estimates of changes in the public spending mix. Recent studies consider this constraint by controlling for the size of government, which is also the strategy used in this paper. A review by Bergh and Henrekson (2011), based on papers published in peer-reviewed journals after 2000, suggested a negative relationship between government size and economic growth in OECD countries (see Slemrod, 1995 for a review of earlier work). Likewise, a recent OECD study confirmed a negative relationship between the size of government and GDP growth (Fall and Fournier, 2015).

2. Hanushek and Woessmann (2012) find a strong impact of cognitive skills on growth. However, research tends to show only a weak relationship between the amount of educational spending and student performance (e.g. PISA scores) (Hanushek and Woessmann, 2011). Thus, policies that aim to increase education spending effectiveness are likely more effective in improving education outcomes and hence growth than increases in education spending per se.

8. Most papers focusing on the effect of public investment identify a positive effect on growth. Aschauer (1989) shows that the crowding-in effect dominates the crowding-out effect, so that an increase in public investment implies an even larger increase in total (public plus private) investment. Erenburg and Wohar (1995) find that public investment crowds-out private investment in the short run, during which the financial sector crowding-out effect dominates, and then crowds-in private investment in the medium run, as new public capital becomes available. Abiad et al. (2015) find that public investment can raise output and crowd in private investment, and that the positive effect is more pronounced when there is economic slack and monetary accommodation, and when public investment efficiency is high. Beyond the production effect, Ganelli and Tervala (2016) show that public investment also increases consumption.

9. Papers focusing on specific investment fields associated with positive externalities also find a positive effect of public investment. For instance, Fernald (1999) finds that road investment boosted productivity in the United States in the 1950s and 1960s. Other papers provide evidence of positive externalities in specific fields, implicitly supporting the case for a public initiative to increase investment. In particular, Jones and Williams (1998) show that the true social return to R&D is higher than the coefficient estimates by the earlier literature, which was already above the private rate of return to capital.

10. However, these positive effects should not be taken as granted in all circumstances. Warner (2014) finds a small and non-significant long-term effect of large infrastructure projects and public capital increases in low-income countries. He explains that case studies reveal problems with many investment projects: incentive and agency problems abound and it is difficult to obtain the critical information that should underpin investment choices. Berg et al. (2015) investigate the nexus between public investment efficiency and growth. If *past* investment was inefficient, then the existing capital stock may be inadequate and hence additional public investment can deliver large marginal returns. Policies that raise public investment efficiency deliver particularly large growth gains as high quality public goods replace low quality public goods. IMF (2015) discusses policies to improve public investment efficiency.

11. The shape of the production function is an empirical issue. Considering the whole economy, Mankiw et al. (1992) argue that one can explain much of the cross-country variation in income while maintaining the assumption of decreasing returns. As regards the government sector, an emerging literature is estimating optimal public capital stock to GDP ratios, which can be estimated if the marginal returns of public capital are decreasing. The seminal estimates of Aschauer (2000) show that in the United States, the optimal capital stock is about 60% of GDP. Kamps (2005) finds an optimal capital stock around 40% in European countries. More recently, Checherita-Westphal et al. (2014) find that the optimal public capital stock level in OECD countries is between 50% and 80% of GDP.

3. Methodology

3.1. Econometric specification

12. The empirical approach builds on the neo-classical growth theory, and is the same as the one used in Fournier and Johansson (2016). In a human capital augmented Solow model, Mankiw et al. (1992) show that in the steady state, the logarithm of GDP per capita depends linearly on the logarithm of the stock of human capital and on the logarithm of the saving rate. In the empirical implementation, the investment rate is preferred to the saving rate because in the case of persistent imbalances, it is more directly linked with the accumulation of capital. This long-term relationship is embedded in a convergence equation, where the potential growth rate of GDP per capita depends on the past potential GDP per capita

level, production factors and a set of structural indicators and other factors influencing growth. The sample is restricted to OECD countries because these countries provide better data on public spending.[3]

13. The convergence equation following Barro (2015) is augmented with the size of government and the public investment share:

$$\begin{aligned}\Delta \ln(Y_{i,t}/POP_{i,t}) = \quad & a - \phi[\ln(Y_{i,t-1}/POP_{i,t-1}) - a_1 \ln(schooling_{i,t-1} * PISA_{i,t-1}) - a_2 \ln(I_{i,t-1}/Y_{i,t-1}) - \ldots \\ & \ldots a_3 X_{i,t-1} - a_4 G_{i,t-1} - a_5 PI_{i,t-1}] + b_1 \Delta \ln(schooling_{i,t} * PISA_{i,t}) + b_2 \Delta \ln(I_{i,t}/Y_{i,t}) + v_t + \varepsilon_{i,t}\end{aligned} \quad (1)$$

where *i* indicates the country, *t* is time. *Y* is potential GDP in 2010 purchasing power parity, *POP* is the working-age population (age 15 to 74), schooling is the average years of schooling of the working age population, PISA is the mean PISA score in 2006, *I/Y* is the cyclically-adjusted private investment rate[4] and *X* is a set of control variables including openness (measured as the sum of exports and imports to GDP), rule of law, employment protection legislation, inflation (measured by consumer price inflation), population size, old-age dependency ratio and financial development (proxied by the credit to GDP ratio). *G* is the size of the government (underlying primary spending to potential GDP) to account for the budget constraint and *PI* is the share of public investment. v_t is a time fixed effect. The standard errors are adjusted for country clusters to allow for serial correlation of the residuals. In this set-up, the long-term effect of a public finance reform is an effect on the GDP level. Since it can take decades to reach the new long-run GDP level after a reform, the temporary growth effect lasts for a long time.

14. In the steady state, investment and the capital stock are linked by an identity. This can be seen with a few calculations, starting with the capital accumulation equation:

$$K_{t+1} = (1-\delta)K_t + I_{t+1} \quad (2)$$

where K_t is the level of the capital stock at date *t*, I_t the level of investment at date *t* and δ the depreciation rate of capital. Dividing by GDP gives:

$$k_{t+1} = \frac{(1-\delta)}{1+g_{t+1}} k_t + i_{t+1} \quad (3)$$

where k_t is the capital to GDP ratio, i_t the investment to GDP ratio and g_t the growth rate. In the steady state, the ratios are stable and the steady state investment rate i^* should both offset the depreciation of the steady state capital stock k^* and grow at the same rate as potential output *g*:

$$i^* \approx (\delta + g)k^* \quad (4)$$

15. This relationship suggests a rule of thumb to gauge whether public investment is above or below the level that keeps the capital stock to GDP ratio stable, building on available measures of the public capital stock, the depreciation rate and potential growth.

16. In an exogenous growth model, equation (4) provides a linear link between the capital stock and investment. This explains why one can use investment series rather than capital stock series as the determinant of potential output in the convergence equation (1).

3. Luxembourg is excluded in the estimations as the large share of cross-border workers affects the measure of the potential output to working-age population ratio.

4. The cyclically-adjusted investment rate is the residual of the regression of the investment rate on output gaps.

17. The estimation strategy follows closely Barro (2015) to ensure that the estimation of the convergence coefficient ϕ is unbiased. In this paper, the convergence coefficient is estimated with an ordinary least square estimator with year fixed effects. Country fixed effects are not included because with a small time dimension, Nickell (1981) and Arellano and Bond (1991) show that there is a Hurwicz (1950)-type bias of the estimated coefficient for the convergence term. This bias is much larger than the convergence coefficient itself according to Nickell's (1981) formula and Barro's (2015) estimates. Furthermore, Nerlove (2000) underlines that the bias of the convergence term will affect the estimates of the coefficients of all variables that are correlated with the level of GDP. Without country fixed effects, the model captures a convergence process conditional only on the control variables. Therefore, countries converge to the productivity frontier if these control variables converge to those of the country at the technology frontier.

18. Once the convergence coefficient is estimated, two different methods are used to estimate the effect of public investment on GDP per capita, following Fournier and Johansson (2016). The first approach is the ordinary least square estimator with year fixed effects, but without country fixed effects. This approach assumes that the omitted variable bias is small when a large set of control variables is included. The second approach adds country fixed effects and the convergence coefficient is constrained to be equal to the one estimated in the regression without country fixed effects. This second option has the advantage that it controls for unobserved country-specific characteristics while circumventing the risk of a Hurwicz-type bias for the convergence coefficient. Several checks reported in Fournier and Johansson (2016) confirm that the omitted variable bias in the specification without fixed effects is much smaller than the convergence bias.

19. *A priori*, the causality between public investment and GDP can run in both directions. Business cycle effects and Wagner's law (the tendency for government expenditure to be larger at higher levels of per capita GDP) are the most likely sources of endogeneity in growth regressions including the effect of public spending (Easterly and Rebelo, 1993; Kneller et al., 1999). The use of cyclically-adjusted GDP data should attenuate the effect of short-term GDP fluctuations on the investment share.[5] Wagner's law posits that a higher income results in increasing political pressure for social programmes, which are not capital intensive. This can create a negative link between the share of public investment in public spending and growth, going against the positive effect of public investment found in this paper: the effect of government investment on growth could be underestimated. As OECD countries have reached quite comparable levels of development, it is likely that Wagner's law plays a secondary role in shaping the link between government size, the government spending composition and GDP.[6] In sum, the reverse causality bias is likely to be small.

3.2. Data

20. The OECD Economic Outlook November 2015 database is the source for the macroeconomic variables (see Table A1.1 for details). The quality of education is measured as the average of reading,

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5. The benefits of minimising the reverse causality bias due to short term effects is most likely outweighing the drawbacks of potential output measurement errors. First, potential output measurement errors mainly affect the end points, as explained by Orphanides and van Norden (2002) among others. Measurement errors in the dependent variable can increase the standard errors, but do not induce a bias, if they are not correlated with the explanatory variables.

6. This paper does not provide estimates with instrumental variables because of the lack of suitable instruments. Indicators of the political orientation of governments could be considered. Unfortunately, the correlation between this instrument and public investment is very weak.

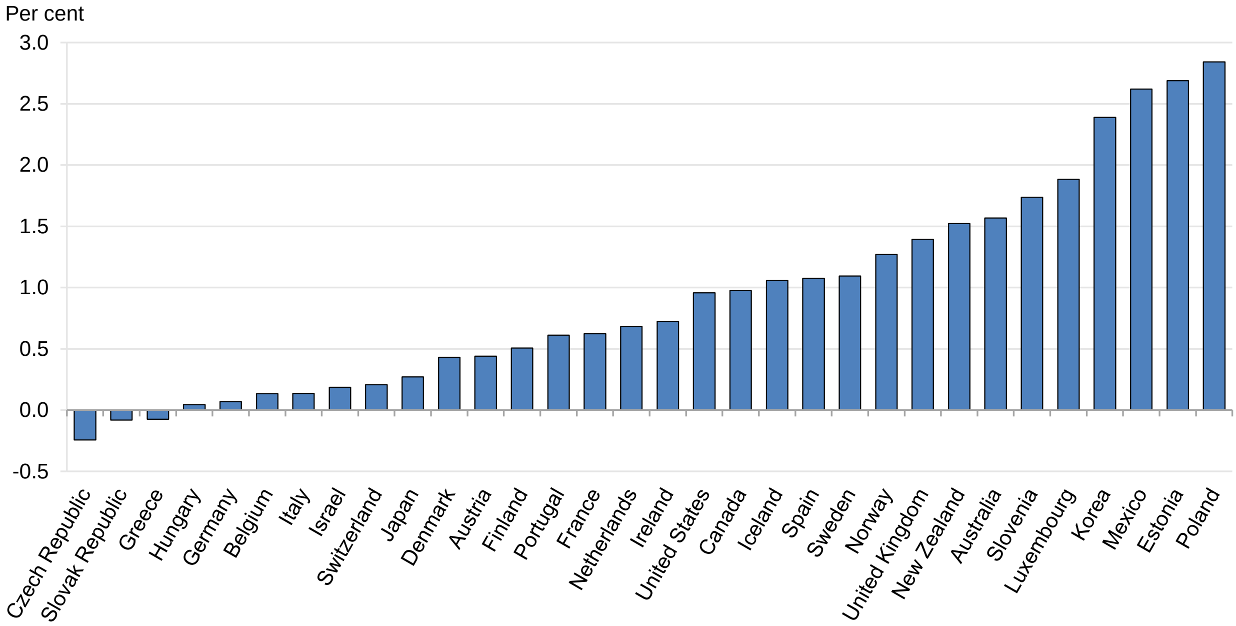
science and math PISA scores in 2006.[7] This is a proxy for the quality of education since in most countries average PISA scores have remained fairly stable over time. The source of average years of schooling of the working-age population is the OECD Long-term Economic Outlook database. The rule of law indicator is from the Worldwide Governance Indicator (WGI) database of the World Bank. Employment protection legislation (EPL) is the protection for regular contracts based on the second edition of this OECD indicator. For these two slow-moving indicators, the average value over the available years is used in the regressions.[8] The stock of public capital is from the IMF's Investment and Capital Stock Dataset. The credit to GDP ratio is from the World Bank Global Financial Development database, with some adjustments made as in Cournède and Denk (2015).

21. The OECD Economic Outlook data includes cyclically-adjusted variables following the methodology of Price et al. (2015). Public investment is not cyclically-adjusted as its variation reflects discretionary choices, rather than automatic stabilisers.[9] In order to focus on long-term structural effects, public investment is expressed as a ratio to potential GDP.

22. Average net public investment is below one percent of GDP in OECD countries, with a wide cross-country heterogeneity (Figure 1). With an average potential growth of about 1.6% in the OECD in recent years according to OECD estimates, this average net investment ratio does not suffice to bring the public capital stock to the optimal level estimated in this paper.

Figure 1. Net public investment in OECD countries

Net investment as a percentage of potential GDP, average 2009-13



Source: OECD (2015) "OECD Economic Outlook No. 98 (Edition 2015/2)", OECD Economic Outlook: Statistics and Projections (database), DOI: http://dx.doi.org/10.1787/bd810434-en.

7. The year 2006 is chosen because it is the earliest PISA vintage in which the science performance scale is the same as the one used in the following vintages (OECD, 2014). In the case of the United States, the 2009 average is used as the 2006 reading score is not available.

8. Replacing the average rule of law with the time-varying indicator yields broadly unchanged results (assuming that the index pre-1996 is equal to the value in 1996).

9. The significant positive effect of public investment also holds with a cyclically-adjusted share of public investment.

4. Empirical results

4.1. A positive average effect of public investment on output

23. Table 1 presents a parsimonious baseline growth regression with significant positive effects of the production factors on growth and plausible convergence rates (column 1). The estimated long-term effect of education on GDP per capita is significant and is not significantly different from unity (e.g. in line with Arnold et al., 2011).[10] As expected, the investment rate is positive and significant. According to the "iron law of convergence", countries are expected to converge to the productivity frontier at a 2% rate per year (Barro, 2015), which is roughly the rate estimated here. By contrast, the education variable is not significant in regressions with many controls. As the effect of education on growth can partly be an indirect effect via the influence of the level of education on other factors such as the quality of institutions (Krueger and Lindahl, 2001), regressions with a large set of controls or with fixed effects miss these important indirect effects and hence cannot capture the overall education effect. These regressions with more controls are preferred here to assess the effect of public investment as they reduce the risk of omitted variable bias.

24. Public investment is added on top of this baseline regression. This reveals that the overall effect of public investment is positive (columns 3 and 8). This may be an effect on labour productivity: the coefficients are quite similar, if one replaces GDP per capita by GDP per employee in the specification without country fixed effect (column 4). This is in line with theory that posits that an increase in the level of capital should increase the output to labour ratio. This also implicitly means that public investment has no visible impact on employment ratios. However, the effect on productivity is not robust to the inclusion of country fixed effect. The difference between the GDP effect and the labour productivity effect in regressions with country fixed effects suggests that a change in public investment within countries can also be associated with employment gains (column 9). Finally, an interaction between the convergence term and public investment reveals that public investment can speed up the pace of convergence (column 5).

25. The effect of public investment is large. Increasing the share of public investment in primary spending by one percentage point (offset by a reduction in other spending) would increase the long-term GDP level by about 5%. As the average share of public investment in primary spending is close to 8%, this effect corresponds to a rise of public investment by 12.5% (i.e. 1/8). According to the Solow (1956) model, the long-term elasticity of GDP per capita to the investment ratio is $\alpha/(1-\alpha)$, where α is the capital share in the production function. Assuming that in the steady state the rise of public investment is associated with a similar rise of private investment (assumption of complementarity of public and private capital) and the capital share is 30%, then the theoretical effect would be roughly equal to 5% (the long-term effect is $12.5*0.3/(1-0.3)$%).[11] The convergence effect is also sizeable. For instance, all else equal, the estimate implies that a country that is among the top 25% in terms of the level of public investment would converge to the productivity frontier about one-third faster than a country among the bottom 25% in terms of public investment.

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10. The Uzawa (1965) and Lucas (1988) growth models predict that the coefficient on the level of education (as a proxy for human capital) should be equal to one in the long run.

11. At a high public capital level, the assumption of complementarity between public and private capital may not hold. Empirical work reported in Table 4 suggests an absence of a significant positive effect of public investment on GDP at a high public capital stock level. In this case, it may be difficult to find investment projects that meet the needs of firms.

Table 1. Baseline estimation results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable: change in ln of potential GDP per capita (columns 1 to 3, 5 to 8) and ln of labour productivity (columns 4 and 9).									
Production function									
$\ln(Y_{it-1}/POP_{it-1})$	-0.021***	-0.020***	-0.017***	-0.020***	-0.015***	-0.021	-0.021	-0.021	-0.021
	(0.0046)	(0.0064)	(0.0049)	(0.0061)	(0.0049)	(c)	(c)	(c)	(c)
$\ln(PISA_i * schooling_{it-1})$	0.019**	0.0016	0.00076	0.0018	-0.0077	-0.015	-0.027	-0.014	-0.024
	(0.0074)	(0.0090)	(0.0062)	(0.0084)	(0.0062)	(0.026)	(0.026)	(0.026)	(0.025)
$\ln(I_{it-1}/Y_{it-1})$	0.014*	0.023***				0.0050	0.015		
	(0.0071)	(0.0059)				(0.0094)	(0.0093)		
$\ln(Private\ Invt_{it-1}/Y_{it-1})$			0.0080	0.011**	0.0080			0.015	0.012**
			(0.0056)	(0.0051)	(0.0055)			(0.0090)	(0.0056)
Short-term dynamic									
$\Delta\ln(PISA_i * schooling_{it})$	0.35	0.24	-0.12	-0.0095	-0.37*	0.33	0.33	0.32	0.43**
	(0.31)	(0.29)	(0.21)	(0.22)	(0.21)	(0.24)	(0.32)	(0.28)	(0.18)
$\Delta\ln(I_{it}/Y_{it})$	0.017***	0.0071				0.012**	0.0033		
	(0.0061)	(0.0052)				(0.0047)	(0.0058)		
$\Delta\ln(Private\ Invt_{it}/Y_{it})$			0.00066	-0.00077	0.00049			0.0049	0.0022
			(0.0044)	(0.0053)	(0.0043)			(0.0058)	(0.0051)
Additional variables									
$Openness_{it-1}$	0.0084*	0.011**	0.0080***	0.0080**	0.0081***	-0.00026	0.0078	0.011	0.00078
	(0.0044)	(0.0042)	(0.0029)	(0.0035)	(0.0028)	(0.0062)	(0.0069)	(0.0067)	(0.0059)
$\ln(population\ size)_{it-1}$	-0.00021	0.00097	0.00086	0.00095	0.00074		0.031	0.055**	0.031
	(0.00079)	(0.00086)	(0.00073)	(0.00093)	(0.00073)		(0.023)	(0.023)	(0.019)
Average rule of law_i		0.0071**	0.0051*	-0.00087	0.0038	0.018**	0.047**		
		(0.0032)	(0.0025)	(0.0027)	(0.0024)	(0.0080)	(0.020)		
Average employment $protection_i$		-0.0033	-0.00082	-0.0027	-0.0026		0.0071		
		(0.0030)	(0.0022)	(0.0032)	(0.0021)		(0.016)		
$Inflation_{it-1}$		-0.027**	-0.0029	0.017	0.0082		-0.033***	-0.032***	-0.039*
		(0.010)	(0.022)	(0.029)	(0.021)		(0.0086)	(0.011)	(0.021)
Credit $ratio_{it-1}$		-0.0052**	-0.0068**	-0.0023	-0.0061**		-0.0074	-0.0055	0.0022
		(0.0023)	(0.0029)	(0.0022)	(0.0027)		(0.0055)	(0.0052)	(0.0022)
Old-age dependency $ratio_{it-1}$		-0.012	-0.022	-0.044*	-0.011		0.014	0.075*	-0.00034
		(0.030)	(0.023)	(0.026)	(0.022)		(0.044)	(0.039)	(0.035)
Public spending									
Spending to GDP $ratio_{it-1}$			0.0019	0.048***	-0.0030			-0.038**	0.0052
			(0.015)	(0.012)	(0.013)			(0.018)	(0.018)
Public $investment_{it-1}$			0.095***	0.076**	0.072***			0.081**	0.0022
			(0.028)	(0.032)	(0.024)			(0.035)	(0.027)
Public spending interacted with past GDP per capita									
Spending to GDP $ratio_{it-1}$* $\ln(Y_{it-1}/POP_{it-1})$					0.028				
					(0.030)				
Public $investment_{it-1}$* $\ln(Y_{it-1}/POP_{it-1})$					-0.12***				
					(0.032)				
Population covered	Working -age	Working -age	Working -age	Working	Working -age	Working -age	Working -age	Working -age	Working
No. of observations	789	592	547	547	547	789	592	547	547
R^2	0.575	0.662	0.761	0.737	0.783	0.702	0.798	0.782	0.782
Country fixed effects	no	no	no	no	no	yes	yes	yes	Yes

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters. The long-run steady state coefficients can be calculated based on these short-run coefficients as ratios of the short-term coefficient to the negative of the convergence coefficient Φ.

4.2. Some forms of public investment can be more beneficial than others

26. Splitting public investment by function reveals a broad-based positive growth effect of public investment in defence, education, health, housing and community amenities and recreation, culture and religion (Table 2). The effect is particularly strong for health, possibly reflecting that health investment may improve workers' health and well-being and, in turn, productivity (e.g. Weil, 2007). The positive effect of defence investment on long-term growth may reflect research spill-overs from the high-technology defence industry to the business sector (e.g. internet in the United States). This finding should be interpreted with care as other forms of military spending are unlikely to increase potential GDP as they do not enter the production function.

Table 2. Growth regression: Detailed public investment results

All functions	General public services	Defence	Public order and safety	Economic affairs	Environment protection	Housing and community	Health	Recreation, culture and religion	Education
0.098***	0.042	0.25***	0.45	0.0064	0.026	0.20**	0.51***	0.31*	0.099*

Note: Public investment by function is added one by one in the growth regression presented in Table 1. Detailed regression results are reported in Table A1.2. Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters. This table presents the short-run coefficients of the variables in equation (1). The long-run steady state coefficients can be calculated based on these short-run coefficients as ratios of the short-term coefficient to the negative of the convergence coefficient Φ. The result in the first column differs slightly from the one reported in Table 1 because the sample is restricted to those observations for which the investment breakdown is available.

27. Public spending on research and development deserves particular attention as it can not only increase the level of GDP, but also potential growth (OECD, 2015b). The evidence in this paper shows that the effect of public spending on research and development on GDP is potentially large, particularly spending on basic research (Table 3). Basic research can drive fundamental advances in knowledge and, in turn, open up a window of opportunity for future research (e.g. Aghion and Howitt, 1996). Higher public spending on basic research can also enhance the ability of enterprises to learn from new innovations at the global frontier (Saia et al., 2015). Recent OECD work analyses the design of public spending on research and development and the mechanisms that underpin basic research (OECD, 2015b).

Table 3. Growth regression: Public spending on research and development

	Total R&D				Basic research	
R&D effect	0.31**	0.30	0.089	1.39***	0.32	2.99**
Source	GBAORD	GERD	GBAORD	GERD	GERD	GERD
Fixed effects	no	no	yes	yes	no	yes

Note: Public spending on total R&D and on basic research as a share of primary spending are added one by one in the growth regression presented in Table 1. Detailed regression results and alternative regressions with spending as a share of GDP are reported in Table A1.3. Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters. This table presents the short-run coefficients of the variables in equation (1). The long-run steady state coefficients can be calculated based on these short-run coefficients as ratios of the short-term coefficient to the negative of the convergence coefficient Φ. GBAORD is government budgetary appropriations or outlays for R&D. GERD is Gross Domestic Expenditure on R&D by the intramural government sector. GBAORD is based on reports by funders, whereas government-financed GERD are based on reports by R&D performers. The government sector covered by the GERD data does not include higher education.

4.3. Marginal returns to public investment decrease, when the public capital stock increases

28. Growth benefits of public investment can be larger in countries with an initially low stock of public capital, as the needs for public investment are larger. By contrast, in countries with a high public capital stock, there may be no low-hanging fruits: the risk to invest in cost-inefficient projects is higher. Furthermore, if some public investment projects are complementary to business investment, these complementary projects may become scarce when the public capital stock is high. Instead, public investment may substitute and crowd out business investment, with little additional effect on growth. Thus, the long-term growth effect of public investment may decrease with the level of the public capital stock. As there is a financing cost for public capital, either through levying potentially distortionary taxes or through raising public debt, at some level of capital, the net marginal return of public investment may turn negative. Moreover, the distortionary effect of taxes tends to increase with the level of taxation.

29. Theory provides little information on the shape of the link between output and the level of the public capital stock. If one assumes a non-linear link between output and the level of the public capital stock, than the change in output is a non-linear function of the level of public capital and of the change in public capital. As gross public investment is measured better than changes in the public capital stock, one can combine the public capital stock level and public investment levels to capture the non-linear link between GDP and the capital stock. Therefore, a non-linear specification is used due to its flexibility to investigate the potential non-linear effect of public investment on growth:

$$\begin{aligned}\Delta \ln(y_{i,t} / POP_{i,t}) = \quad & a - \phi[\ln(y_{i,t-1} / POP_{i,t-1}) - a_1 \ln(schooling_{i,t-1} * PISA_{i,t-1}) - a_2 \ln(I_{i,t-1} / Y_{i,t-1}) - a_3 X_{i,t-1} - \\ & - a_4 G_{i,t-1} - a_5 PubInv_{i,t-1} - a_6 PubCap^d_{i,t-1} - a_7 PubInv_{i,t-1} PubCap^d_{i,t-1}] + \\ & + b_1 \Delta \ln(schooling_{i,t} * PISA_{i,t}) + b_2 \Delta \ln(I_{i,t} / Y_{i,t}) + v_t + \varepsilon_{i,t}\end{aligned} \quad (5)$$

where *PubInv* is the share of public investment to total public spending, *PubCap* is the stock of public capital to potential GDP ratio in 2010 PPPs as measured by the IMF.[12] The power *d* provides flexibility that allows a non-linear link between the level of public capital and the marginal return of investment. All other variables are defined as in equation (1). This model is estimated with a non-linear least square estimator without country fixed effects, or with country fixed effects and a constrained long-term convergence coefficient.

30. The results suggest that the marginal return of public investment is significantly positive at the capital stock level observed in most countries. This is consistent with the baseline estimate of constant returns to investment (Figure 2, panel A). Based on these results, and taking the level of public capital as given, the turning point at which the effect of additional public investment on growth turns negative is calculated (Table 4).[13] The marginal returns turn negative at the level of the public capital stock observed in Japan (Figure 2). The estimates of the optimal capital stock level is robust to specifications with country fixed effects (columns 4-6), without the crisis years (columns 2 and 4) and with public investment expressed as a share of GDP instead of as a share to primary spending (columns 3 and 6). Together these calculations provide evidence that the optimal stock of public capital is about 75 to 110% of GDP (Table 4).[14] While these results are somewhat above estimates of the optimal public capital stock in the recent literature, they are consistent with the whole literature on the effect of public investment that provides evidence of the positive effect on output, implicitly suggesting that the current level of public capital is below its optimal level.

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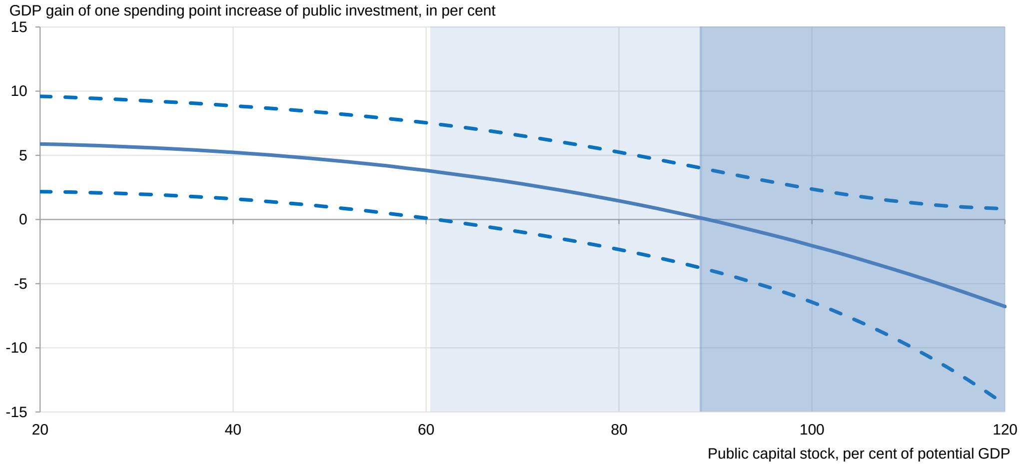
12. The measure of the capital stock depends on assumptions on the rate of depreciation of capital and on the level of disaggregation at which the calculation is made. The IMF database can thus differ from national sources. The data of the two sources are close for most countries. For a few countries, such as Austria, the difference is considerable. This database is used, because the capital stock is computed for all countries with the same methodology.

13. This level of public capital is calculated as the solution of the equation $a5+a7*PubCap^d=0$ where a_5 and a_7 are the estimated coefficients reported in Table 4. This is the level of capital at which the line crosses the horizontal axis in Panel A of Figure 2. For simplicity, this calculation ignores the long-term link between public capital, public investment, the growth rate and the depreciation of capital. In practice, given the small size of the direct effect of the capital stock on growth, this is a second-order issue.

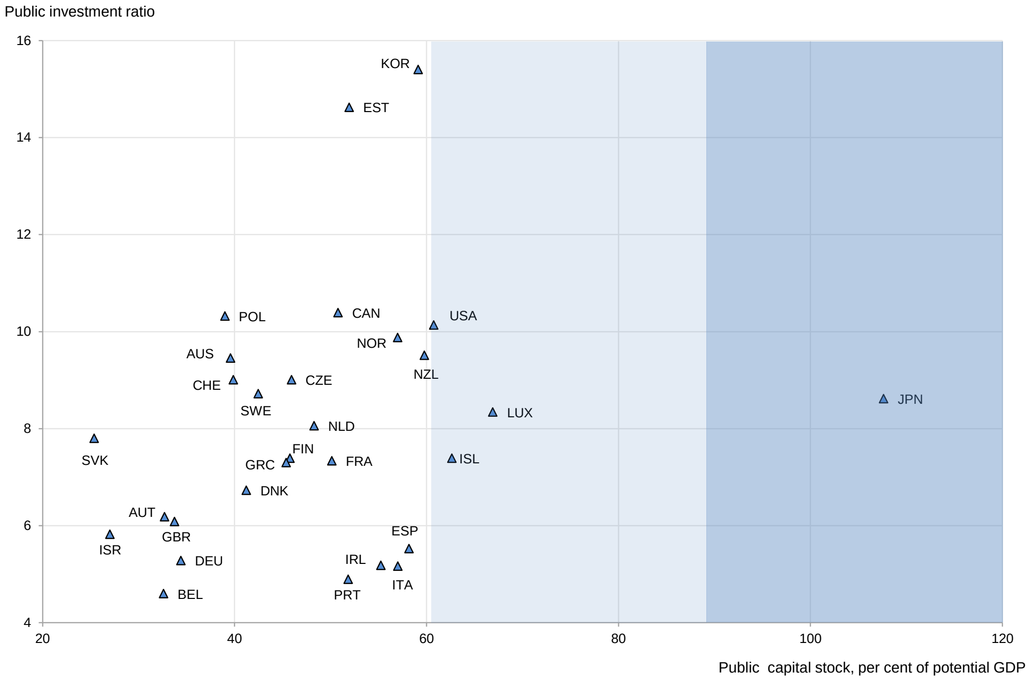
14. This threshold is to some extent driven by Japan. If Japan is excluded from the regression, little is known about the effect of public investment on growth at a level of the public capital stock beyond 60%.

Figure 2. Estimates of decreasing returns to public investment

Panel A. The effect of public investment on potential GDP decreases with the level of capital stock[1]



Panel B. Most countries have room to increase the stock of public capital (2013 data)



1. Public investment is scaled by underlying primary public spending. The dashed line indicates the 95% confidence interval. The effect is computed with the estimates of column 4 in Table 4. The measure of the capital stock depends on assumptions on the rate of depreciation of capital and on the level of disaggregation at which the calculation is made. The IMF data can thus differ from national sources. The data of two sources are close for most countries. In a few cases, such as Austria, the difference can be considerable. The IMF database is used here because the capital stock is computed in all countries with the same methodology. Light shading indicates a positive not significant investment effect and darker shading indicates a negative not significant investment effect.

Table 4. Decreasing returns to public capital

	(1)	(2)	(3)	(4)	(5)	(6)
Selected estimated coefficients						
Public investment	0.11***	0.27***	0.13***	0.12***	0.32**	0.12***
Capital stock	0.0039	0.0051	0.0027	-0.0066	-0.0080	-0.0042
Public investment * Capital stock[d]	-0.040	-0.15	-0.032	-0.17***	-0.48**	-0.22***
Optimal public capital level derived from the estimates						
Capital stock at which returns to investment turn negative (GDP ratio)[1]	109.6***	106.1***	113.5***	89.2***	84.2***	75.6***
Public investment as a share of	Primary spending	GDP	Primary spending	Primary spending	GDP	Primary spending
End of sample	2012	2012	2007	2012	2012	2007
Country fixed effects	No	No	No	Yes	Yes	Yes

Note*:* Detailed regression results are reported in Table A1.4. Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters.

5. Conclusion

31. This paper provides evidence that the average effect of public investment on growth is sizeable, in line with economic theory and past empirical evidence. There is also evidence that in most countries the public capital stock level is below its optimal level. However, public investment has decreased recently, suggesting that policy makers have preferred the present (with current spending) against the future (with public investment).

32. This paper also illustrates that the effect of public investment depends on circumstances. It is the highest in fields that are associated with large externalities, such as research and development or health. And it is the lowest in countries where the public capital stock is already high such as Japan. In practice, the magnitudes presented in this paper are illustrative, and the effect also depends on public investment effectiveness. Should governments implement sound public investment policies (provide the right incentives, carry out cost/benefit analysis underpinned with good data) and focus on fields with high externalities, public investment is a lever to boost growth in the long run.

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ANNEX 1

Table A1.1. Data definitions

Variable	Definition	Source
Potential GDP	Potential output in 2010 PPPs	OECD Economic Outlook, Nov. 2015
Population	Working-age population age 15-74	OECD Economic Outlook, Nov. 2015
Old-age dependency ratio	Share of population age 65 and above relative to the population 15 to 64	OECD Long-term scenario database, Nov. 2014
Schooling	Average years of schooling of the working-age population	OECD Long-term database
PISA score	Average of mean PISA score in reading, science and math PISA, 2006	OECD Education at a Glance
Investment	Gross fixed capital formation, total economy, volume	OECD Economic Outlook, Nov. 2015
Private investment	Private gross fixed capital formation, volume	Calculations based on OECD Economic Outlook, Nov. 2015
Size of government	Underlying primary spending to potential GDP, cyclically adjusted	OECD Economic Outlook, Nov. 2015
General government capital stock	Constructed using a perpetual inventory model based on general government investment flows and then reported as a share of potential GDP.	IMF Investment and Capital Stock Dataset
Openness	Absolute sum of exports and imports as a share of GDP	OECD Economic Outlook, Nov. 2015
Inflation	Consumer price inflation	OECD Economic Outlook, Nov. 2015
Credit ratio	Private credit to GDP	World Bank Global Financial Development database with adjustments as in Cournède and Denk, 2015
Employment protection legislation	Employment protection legislation for regular contracts based on the second edition of the OECD indicator.	OECD Employment database
Rule of law	Perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.	Worldwide Governance Indicator, World Bank
Public expenditure on research and development (GBAORD)	Government budget appropriations or outlays for R&D.	OECD Research and Development Statistics
Public expenditure on research and development (GERD)	Total intramural research and development spending of the government, excluding higher education and public enterprises, but including the non-profit institutions (NPIs) controlled and mainly financed by government but not administered by the higher education sector.	OECD Research and Development Statistics

Table A1.2. Growth regression: Detailed public investment results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Long-term macro										
$\ln(Y_{it-1}/POP_{it-1})$	-0.020***	-0.024***	-0.022***	-0.023***	-0.023***	-0.023***	-0.025***	-0.025***	-0.022***	-0.022***
	(0.0031)	(0.0040)	(0.0032)	(0.0036)	(0.0038)	(0.0040)	(0.0037)	(0.0030)	(0.0035)	(0.0037)
$\ln(PISA_i h * schooling_{it-1})$	0.0044	-0.00063	0.0051	-0.0016	-0.0013	-0.0013	0.0039	0.0063	0.000068	-0.0011
	(0.0064)	(0.0065)	(0.0068)	(0.0059)	(0.0066)	(0.0068)	(0.0072)	(0.0063)	(0.0067)	(0.0065)
$\ln(\text{Private Invt}_{it-1}/Y_{it-1})$	0.0014	0.0065	0.0072	0.0062	0.0063	0.0066	0.0045	0.0053	0.0060	0.0068
	(0.0044)	(0.0049)	(0.0043)	(0.0046)	(0.0049)	(0.0049)	(0.0046)	(0.0047)	(0.0047)	(0.0049)
Short-term dynamic										
$\Delta\ln(PISA_i * schooling_{it})$	-0.27*	-0.28*	-0.12	-0.28*	-0.29*	-0.30*	-0.32**	-0.18	-0.29*	-0.27*
	(0.14)	(0.16)	(0.15)	(0.16)	(0.16)	(0.17)	(0.14)	(0.18)	(0.17)	(0.16)
$\Delta\ln(\text{Private Invt}_{it}/Y_{it})$	0.0031	0.0095*	0.0076	0.0079	0.0097*	0.0094	0.0063	0.0088	0.0083	0.0088
	(0.0059)	(0.0055)	(0.0064)	(0.0053)	(0.0057)	(0.0057)	(0.0057)	(0.0056)	(0.0061)	(0.0057)
Control variables										
Openness_{it-1}	0.0052*	0.0055	0.0053*	0.0052	0.0057*	0.0056*	0.0047	0.0073***	0.0058*	0.0062*
	(0.0025)	(0.0034)	(0.0030)	(0.0031)	(0.0032)	(0.0032)	(0.0029)	(0.0023)	(0.0031)	(0.0031)
$\ln(\text{population size})_{it-1}$	-0.00045	-0.00034	-0.00081	-0.00032	-0.00044	-0.00043	-0.00051	0.00016	-0.000078	-0.00017
	(0.00071)	(0.0011)	(0.00076)	(0.00097)	(0.0011)	(0.0011)	(0.0010)	(0.00067)	(0.00090)	(0.00096)
$\text{Average rule of law}_i$	0.0077***	0.0089***	0.0073***	0.0091***	0.0085***	0.0086***	0.0092***	0.0080***	0.0087***	0.0081**
	(0.0025)	(0.0029)	(0.0023)	(0.0029)	(0.0030)	(0.0030)	(0.0029)	(0.0020)	(0.0030)	(0.0029)
Average employment protection_i	-0.0014	-0.0026	-0.00053	-0.0025	-0.0030*	-0.0029*	-0.0016	-0.00052	-0.0027	-0.0027
	(0.0016)	(0.0016)	(0.0020)	(0.0015)	(0.0016)	(0.0017)	(0.0020)	(0.0016)	(0.0016)	(0.0016)
Inflation_{it-1}	-0.044***	-0.057**	-0.059***	-0.057***	-0.054**	-0.055**	-0.052**	-0.065***	-0.050***	-0.053***
	(0.015)	(0.021)	(0.016)	(0.018)	(0.020)	(0.020)	(0.019)	(0.016)	(0.017)	(0.018)
$\text{Credit ratio}_{it-1}$	-0.0080***	-0.0066***	-0.0065***	-0.0073***	-0.0069***	-0.0068***	-0.0072***	-0.0067***	-0.0070***	-0.0071***
	(0.0019)	(0.0017)	(0.0017)	(0.0015)	(0.0017)	(0.0017)	(0.0016)	(0.0016)	(0.0015)	(0.0017)
Old age dependency ratio_i	-0.0087	-0.0091	-0.023	-0.011	-0.0077	-0.0079	-0.012	-0.023	-0.015	-0.0097
	(0.019)	(0.027)	(0.022)	(0.024)	(0.027)	(0.028)	(0.026)	(0.021)	(0.024)	(0.025)
Public spending										
$\text{Spending to GDP ratio}_{it-1}$	-0.047***	-0.062***	-0.053***	-0.055***	-0.059***	-0.059***	-0.060***	-0.061***	-0.056***	-0.053***
	(0.013)	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.015)	(0.015)	(0.013)	(0.014)
Public investment in										
All functions	0.098***									
	(0.018)									
General public services		0.042								
		(0.049)								
Defence			0.25***							
			(0.073)							
Public order and safety				0.45						
				(0.28)						
Economic affairs					0.0064					
					(0.013)					
Environment protection						0.026				
						(0.047)				
Housing and community amenities							0.20**			
							(0.097)			
Health								0.51***		
								(0.12)		
Recreation, culture and religion									0.31*	
									(0.18)	
Education										0.099*
										(0.055)
No. of observations	331	331	331	331	331	331	331	331	331	331
R^2	0.864	0.833	0.851	0.842	0.833	0.833	0.840	0.853	0.842	0.838

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters. This table presents the short-run coefficients of the variables in equation (1). The long-run steady state coefficients can be calculated based on these short-run coefficients as ratios of the short-term coefficient to the negative of the convergence coefficient Φ. The results in column 1 differ slightly from the one reported in Table 6 because the sample is restricted to those observations for which the investment breakdown is available.

Table A1.3. Public spending on research and development: Detailed regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Long-term macro										
$\ln(Y_{it-1}/POP_{it-1})$	-0.019***	-0.017***	-0.019***	-0.017***	-0.021	-0.021	-0.021	-0.021	-0.015**	-0.021
	(0.0053)	(0.0054)	(0.0053)	(0.0054)	(c)	(c)	(c)	(c)	(0.0056)	(c)
$\ln(PISA_i * schooling_{it-1})$	-0.0015	0.0019	-0.0013	0.0028	-0.0047	-0.011	-0.0041	-0.012	0.0014	-0.0085
	(0.0057)	(0.0075)	(0.0059)	(0.0074)	(0.028)	(0.033)	(0.027)	(0.033)	(0.0085)	(0.033)
$\ln(I_{it-1}/Y_{it-1})$	0.014**	0.0091	0.014***	0.0090	0.014	0.015	0.014	0.016*	0.014*	0.015*
	(0.0052)	(0.0072)	(0.0052)	(0.0073)	(0.0097)	(0.0094)	(0.0097)	(0.0094)	(0.0069)	(0.0087)
Short-term dynamic										
$\Delta\ln(PISA_i * schooling_{it})$	-0.17	-0.11	-0.16	-0.089	0.10	0.16	0.10	0.15	0.033	0.12
	(0.18)	(0.18)	(0.18)	(0.17)	(0.19)	(0.24)	(0.19)	(0.25)	(0.21)	(0.23)
$\Delta\ln(I_{it}/Y_{it})$	0.0064	0.0021	0.0067	0.0021	0.0058	0.0022	0.0058	0.0025	0.0053	0.0050
	(0.0055)	(0.0064)	(0.0055)	(0.0064)	(0.0057)	(0.0054)	(0.0057)	(0.0055)	(0.0069)	(0.0073)
Additional variables										
$Openness_{it-1}$	0.0090***	0.0080***	0.0090***	0.0079***	0.014**	0.00062	0.014**	0.00043	0.0079**	-0.0023
	(0.0029)	(0.0028)	(0.0029)	(0.0027)	(0.0066)	(0.0077)	(0.0066)	(0.0080)	(0.0029)	(0.0076)
$\ln(\text{population size})_{it-1}$	0.00029	0.00074	0.00033	0.00075	0.074***	0.086***	0.074***	0.074***	0.00063	0.066***
	(0.00059)	(0.00080)	(0.00060)	(0.00080)	(0.022)	(0.024)	(0.022)	(0.025)	(0.00083)	(0.023)
Average rule of law_i	0.0031	0.0041*	0.0029	0.0042*					0.0039	
	(0.0023)	(0.0024)	(0.0024)	(0.0024)					(0.0026)	
Average employment $protection_i$	-0.0019	0.00083	-0.0020	0.0010					-0.00070	
	(0.0021)	(0.0026)	(0.0021)	(0.0026)					(0.0025)	
$Inflation_{it-1}$	0.0076	0.017	0.0078	0.016	-0.038**	-0.019	-0.038**	-0.019	0.014	-0.0076
	(0.024)	(0.027)	(0.024)	(0.026)	(0.018)	(0.028)	(0.018)	(0.027)	(0.028)	(0.027)
Credit $ratio_{it-1}$	-0.0051**	-0.0044*	-0.0051**	-0.0043*	-0.0062	-0.0047	-0.0062	-0.0048	-0.0050*	-0.0036
	(0.0022)	(0.0024)	(0.0022)	(0.0024)	(0.0058)	(0.0057)	(0.0057)	(0.0056)	(0.0027)	(0.0063)
Old-age dependency $ratio_{it-1}$	-0.0061	-0.045**	-0.0072	-0.047**	0.053	0.067	0.053	0.053	-0.045*	0.053
	(0.024)	(0.021)	(0.024)	(0.022)	(0.045)	(0.052)	(0.045)	(0.053)	(0.025)	(0.050)
Public spending										
Spending to GDP $ratio_{it-1}$	-0.014	-0.032*	-0.027*	-0.036**	-0.035*	-0.046*	-0.038*	-0.065**	-0.022	-0.045*
	(0.014)	(0.017)	(0.015)	(0.016)	(0.018)	(0.025)	(0.019)	(0.029)	(0.018)	(0.026)
Research and development spending										
$GBAORD_{it-1}$	0.31**				0.089					
(share of primary spending)	(0.13)				(0.17)					
$GERD_{it-1}$		0.30				1.39***				
(share of primary spending)		(0.21)				(0.47)				
$GBAORD_{it-1}$			0.79**				0.20			
(share of GDP)			(0.35)				(0.37)			
$GERD_{it-1}$				0.80				3.07**		
(share of GDP)				(0.51)				(1.32)		
Basic research $(GERD)_{it-1}$									0.32	2.99**
(share of primary spending)									(0.88)	(1.38)
No. of observations	505	293	505	293	505	293	505	293	252	252
R^2	0.719	0.786	0.719	0.786	0.774	0.823	0.774	0.821	0.797	0.838

Note: Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters. The long-run steady state coefficients can be calculated based on these short-run coefficients as ratios of the short-term coefficient to the negative of the convergence coefficient Φ. The indicators interacted with the size of government are perception indicators, which are strongly correlated within each other. The interacted variables are mean centered, which implies that the coefficients can be interpreted as average effects. GBAORD is government budgetary appropriations or outlays for R&D. GERD is Gross Domestic Expenditure on R&D by the intramural government sector. GBAORD is based on reports by funders, whereas government-financed GERD are based on reports by R&D performers. The government sector in GERD data does not include higher education.

Table A1.4. Decreasing returns to public capital

	(1)	(2)	(3)	(4)	(5)	(6)
Long-term macro						
$\ln(Y_{it-1}/POP_{it-1})$	-0.020***	-0.021***	-0.019***	-0.021	-0.021	-0.021
	(0.0048)	(0.0051)	(0.0056)	(c)	(c)	(c)
$\ln(PISA_i h * schooling_{it-1})$	0.0011	0.0067	0.0073	-0.0086	-0.012	0.0063
	(0.0067)	(0.0071)	(0.0072)	(0.029)	(0.029)	(0.037)
$\ln(Private\ Invt_{it-1}/Y_{it-1})$	0.0066	0.0076	0.0078	0.013	0.014	0.019**
	(0.0054)	(0.0054)	(0.0057)	(0.0086)	(0.0084)	(0.0086)
Short-term dynamic						
$\Delta\ln(PISA_i * schooling_{it})$	-0.14	0.015	0.094	0.24	0.31	0.27
	(0.21)	(0.22)	(0.22)	(0.27)	(0.30)	(0.33)
$\Delta\ln(Private\ Invt_{it}/Y_{it})$	0.0019	0.0025	0.0066	0.0066	0.0061	0.015**
	(0.0045)	(0.0046)	(0.0065)	(0.0054)	(0.0053)	(0.0067)
Additional variables						
$Openness_{it-1}$	0.0098***	0.0092***	0.010***	0.015**	0.012*	0.022**
	(0.0026)	(0.0025)	(0.0031)	(0.0071)	(0.0072)	(0.0085)
$\ln(\text{population size})_{it-1}$	0.00097	0.0011	0.00078	0.060***	0.054**	0.028
	(0.00075)	(0.00079)	(0.00084)	(0.021)	(0.023)	(0.030)
Average rule of law_i	0.0042	0.0041	0.0035			
	(0.0026)	(0.0026)	(0.0026)			
Average employment $protection_i$	-0.0017	-0.00085	-0.0027			
	(0.0021)	(0.0024)	(0.0024)			
$Inflation_{it-1}$	0.0050	0.0025	0.020	-0.051***	-0.052***	-0.034
	(0.021)	(0.021)	(0.024)	(0.015)	(0.015)	(0.021)
Credit $ratio_{it-1}$	-0.0050	-0.0045	-0.0056	-0.0043	-0.0041	-0.0037
	(0.0031)	(0.0030)	(0.0042)	(0.0049)	(0.0049)	(0.0052)
Old-age dependency $ratio_{it-1}$	-0.0089	-0.021	0.021	0.062	0.066	-0.0018
	(0.020)	(0.022)	(0.026)	(0.056)	(0.050)	(0.063)
Public spending						
Spending to GDP $ratio_{it-1}$	0.0082	-0.017	0.022	-0.030	-0.055**	-0.0090
	(0.014)	(0.015)	(0.016)	(0.020)	(0.022)	(0.021)
Public invest. (share of primary spending)	0.11***		0.13***	0.12***		0.12***
	(0.023)		(0.026)	(0.038)		(0.034)
Public invest. (GDP ratio)		0.27***			0.32**	
		(0.067)			(0.12)	
Capital stock	0.0039	0.0051	0.0027	-0.0066	-0.0080	-0.0042
	(0.0024)	(0.0034)	(0.0021)	(0.012)	(0.012)	(0.016)
Public invest. (share of primary spending)* Capital $stock^d$	-0.040		-0.032	-0.17***		-.22***
	(0.027)		(0.029)	(0.052)		(0.064)
Public invest. (GDP ratio) * Capital $stock^d$		-0.15			-0.48**	
		(0.11)			(0.18)	
d	11.31***	10.20**	11.13**	2.54**	2.40**	2.22**
	(3.84)	(4.21)	(4.63)	(0.92)	(0.90)	(0.88)
Optimal public capital level derived from the estimates						
Capital stock at which returns to investment turns negative (GDP ratio)	109.6*** (4.01%)	106.1*** (5.62%)	113.5*** (4.30%)	89.2*** (11.1%)	84.2*** (10.7%)	75.6*** (12.5%)
No. of observations	521	521	396	521	521	396
R^2	0.786	0.772	0.778	0.810	0.805	0.834
End of sample	2012	2012	2007	2012	2012	2007
Country fixed effects	no	no	no	yes	yes	yes

Note*:* Non-linear least square estimation of equation (5). Asterisks (*, **, ***) indicate the significance level (10%, 5%, 1%) of the coefficients. Year fixed effects are included in all regressions. The standard errors are adjusted for country clusters. The power *d* allows a non-linear link between the level of public capital and the marginal return of investment.