LATVIJAS BANKA
EIROSISTĒMA

ISBN 978-9934-578-48-9

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WORKING PAPER
4 / 2022

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Public investment crowds in private investment – with ifs and buts

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September 26, 2022

Abstract

This study explores the relationship between public and private investment using a sample of 33 industrialized economies of the OECD. The methodology relies on the fact that the relation between stocks of public and private capital can affect private investment also in the short term. We demonstrate that the immediate effect of public investment on private investment is either small or statistically insignificant, whereas in the medium to long term, extra public investment crowds in private investment as the latter adjusts in order to bring the stock of private capital closer to its long-term cointegrating relationship with public capital. The estimated median public investment multiplier over a horizon of seven years is around 2, which means that each additional dollar of public investment attracts approximately two dollars of private investment. Additionally, we examine whether the crowding-in effect depends on a country's institutional quality and the area of public spending. We show that it gets stronger with improvements in the quality of institutions related to the rule of law, government effectiveness and control of corruption. Public investment in economic affairs, education and health infrastructure is the most effective in attracting private investment.

Keywords: public investment, private investment, crowding in, crowding out, public investment multiplier, local projections, forecast errors, governance quality indicators.

JEL codes: C23, E22, E62, H54

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1 Introduction

Accumulation of public capital is an important engine of economic growth. Over the past several decades, and especially in the aftermath of the Great Recession period, there has been a significant decline in public investment. It left scars on economic growth, as GDP growth rates remained subdued throughout several years after the crisis. In addition to the direct negative impact on GDP, the reduction in public investment could have led to a decline in private investment, which may have further negatively affected output. At the moment, awareness of the need to boost public sector investment is rising, particularly in light of climate change, the ongoing digitization and the post-Covid recovery. Additional public investment in energy, telecommunications and infrastructure could encourage the private sector to accelerate private capital accumulation. But the direction and the magnitude of this effect is actually not straightforward. Our paper analyzes the relationship between public and private investment using a sample of advanced OECD economies.

A large body of literature has already explored the relationship between both types of investment. Standard macroeconomic theory makes the traditional argument that increasing any type of government spending promotes competition for the available resources, such as savings and labour, leading to higher interest rates. These, in turn, crowd out private activity such as consumption and investment. This channel certainly plays a role in the short term, but we cannot draw a definitive conclusion about the relationship between public and private investment based solely on it. The possibility of the crowding-in effect in the longer term was first explored by Aschauer (1989). Using the neoclassical production function approach, Aschauer (1989) confirms that in the short term higher public investment raises public capital and pushes the total capital stock of the economy above an optimal level chosen by rational economic agents, thus crowding out private investment. Conversely, in the longer term it increases the marginal productivity of private capital and crowds in private investment. In the empirical part of the study, Aschauer (1989) uses US data to estimate a set of simultaneous equations where private capital productivity is a function of public capital, but private investment reacts to both public investment (negatively) and private capital productivity (positively). The results indicate that public and private capital stocks can indeed be seen as complementary in the long-run. The direct crowding-out effect is offset over time by the indirect crowding-in effect.

The analytical framework laid out by Aschauer (1989) spurred considerable interest in the in-

teraction of private and public investment. Agrimon et al. (1997) employed an empirical approach similar to the one used by Aschauer (1989) and reported a significant crowding-in effect of public investment on private investment for OECD countries due to the positive impact of public infrastructure capital on the return to private capital. Both findings were criticized against the background of the possible endogeneity of public investment (see Pereira and Andraz (2016)). Additional evidence on the crowding-in effect was reported in Erenburg (1993) for the US, Toshiya (2010) for Japan, Eden and Kraay (2016) for 39 low-income countries.

Dreger and Reimers (2016) emphasize the importance of considering the stocks of private and public capital when studying the relationship between private and public investment. They employ a three-step stock-flow approach to capture the long-term nature of the relationship in a sample of the oldest members of the euro area. First, they estimate the long-run cointegrating relationship between private and public capital stocks. Second, they use the deviation of private capital from its stock equilibrium in the private investment cointegrating relationship. Finally, Dreger and Reimers (2016) provide estimates of the error-correction model for private investment. Private and public capital are cointegrated, while the deviation from the stock equilibrium improves the cointegrating relationship between private investment and other explanatory factors. The study shows that if the long-run interaction between the capital stocks is accounted for, there is a clear evidence of the crowding-in effect. It is the long-run perspective where both stocks should act as compliments.

In contrast to those results, the predominance of the crowding-out effect was confirmed in Bairam and Ward (1993) for OECD countries, Monadjemi (1993) for Australia and the USA, Voss (2002) for the USA and Canada, Cavallo and Daude (2011) for a large set of developing countries.

The inconsistency in the results obtained thus far may be explained as follows. First, the evidence provided in the literature depends on the empirical specification each study utilizes. Some papers employ methods which by construction focus on the short-term dynamics in private and public investment (such as the standard fixed effects regressions of private investment on public investment). In contrast, studies that account for the long-term relationship in stocks by means of cointegration analysis are more inclined to provide evidence of the crowding-in effect. Second, there are several factors which may affect the estimates. Abiad et al. (2016) find that the effect of public investment on private investment ratio to GDP is neutral, which implies the crowding-in effect for private investment expressed in absolute terms. At the same time, they also offer strong evidence of crowding out when there is less slack in the economy and when public investment is

inefficient. Erenburg and Wohar (1995) suggest the existence of feedback effects between both types of investment. Afonso and Aubyn (2009) point at cross-country differences as the crowding-in is confirmed for 8 countries out of 17. Atukeren (2005) using data for 25 developing countries shows that the probability of the crowding-out effect rises with the size of the government sector and capital controls, but declines with trade openness. Pereira (2001) using the US data confirms the crowding-in effect at the aggregate level. However, the aggregate effect mostly arises from public investment in core infrastructure in electric and gas facilities as well as in conservation and development structures. On the private investment side, aggregate public investment generates a particularly strong crowding-in effect for industrial and transportation equipment. Information equipment is the only type of private investment where aggregate public investment generates a marginal crowding-out effect. Cavallo and Daude (2011) develop an analytical framework that suggests that the quality of public institutions affects private investment both directly by raising economic efficiency and indirectly by increasing the efficiency of public investment. They provide empirical evidence suggesting that in the sample of developing countries the crowding-out effect is smaller in countries with better public institutions and higher openness to international trade, as well as in countries with a less restricted access to international capital markets.

All in all, it remains an empirical issue whether public investment crowds in or crowds out private investment. The results of the previous literature are mixed and depend on the method of analysis. The main objective of this study is to add to the existing literature:

- First, by exploring the possibility that institutions matter for the relationship between public and private investment and the effect persists beyond developing countries. We examine whether lower standards of governance reduce the effectiveness of public spending even in developed, industrialized economies with generally higher governance quality. If this is the case, improvements in public governance can increase the efficiency of public investment, raise private capital productivity and generate larger crowding-in effects;

- Second, by examining the possibility that public investment in specific *areas* is more successful in raising private capital productivity;

- Third, by providing the estimates of public investment multipliers, which have been mostly absent in the previous literature. To address these issues, we examine the relationship between private and public investment in OECD economies over the time period between 1995 and

2017.

Our main findings are as follows:

- First, there is a strong evidence of the crowding-in effect. Private investment appears to react to changes in the deviation of private capital from its equilibrium path determined by public capital. More specifically, public investment cuts that deplete public capital lead to a decline in private investment and vice versa;
- Second, private investment increases by more than one to one for each additional euro or dollar spent on public capital;
- Third, better accountability, government effectiveness and the rule of law magnify the crowding-in effect;
- Fourth, healthcare, economic affairs, culture and education are the areas with the largest potential for crowding-in.

The rest of the paper is structured as follows. Section 2 lays down the methodology of the study and the data used. Section 3 presents the estimation results of private investment regressions. Section 4 provides the robustness analysis of the results obtained. Section 5 transforms the obtained regression coefficients into impulse responses and the public investment multiplier. Finally, Section 6 concludes.

2 Methodology and data

2.1 Analytical framework

In our study, we employ a variant of the stock-flow approach suggested by Dreger and Reimers (2016) and Toshiya (2010) to account for both short-term and long-term interactions between public and private investment.

To provide the theoretical background of this approach, we refer to the variant of the Cobb-Douglas production function that splits the stock of capital into private capital (K^P) and public capital (K^G):

$$Y_t = A_t(L_t)^{\alpha}(K_t^P)^{\beta}(K_t^G)^{\theta} \tag{1}$$

where parameters α, β and θ denote output (Y) elasticities of labour (L), private and public capital respectively. From equation (1) it follows that the marginal products of private capital and public capital are equal to $\beta Y_t/K_t^P$ and $\theta Y_t/K_t^G$ respectively. Under the assumption of perfect capital markets, marginal products should be equal to their corresponding real rates of interest. As both interest rates are subject to arbitrage and should move in the same direction in tandem, maintaining a constant ratio (γ), one can obtain the following long-term cointegrating relationship between private and public capital:

$$K_t^P = K_t^G \frac{\beta}{\gamma\theta} \tag{2}$$

To incorporate this potential equilibrium into the relationship between the two types of investment, we proceed in two steps.

First, we estimate the coefficients of the long-term cointegrating relationship between private and public capital stocks.[1]

$$lnK_{it}^P = \alpha_0 + \vartheta_i + \alpha_1 lnK_{it}^G + u_{it} \tag{3}$$

where i and t index countries and time, ϑ_i denotes a country fixed effect, and u_{it} is a residual term. This residual has a clear and very useful interpretation: it can be thought of as the deviation from the linear cointegrating relationship between K^P and K^G, which can be thought of as a very long-term equilibrium: if there is 'too much' public capital, productivity of a marginal unit of private capital is high, which attracts private investment and pushes the ratio of private-to-public capital stocks up closer to its 'equilibrium' value.

Second, we incorporate u_{it} into the equation that describes the short-term relationship between private investment (I^P) and public investment (I^G). Thus, private investment does not merely react to short-term fluctuations in public investment, but also accounts for the disequilibrium in the relationship between the two types of capital.

$$\Delta lnI_{it+h}^P = \beta_{0h} + \mu_i + \beta_{1h}\Delta lnI_{it}^G + \beta_{2h}\Delta u_{it} + \sum_k \beta_{kh} X_{it}^k + \varepsilon_{ith} \tag{4}$$

where X is a vector of k control variables, μ_i is a country fixed effect and ε_{it} is an error term. The

[1] Two or more variables of order d are cointegrated if their linear combination is of a lower order (see Engle and Granger (1987) for the definition of cointegration, p. 253). Thus, $I(2)$ variables are cointegrated if their linear combination is either $I(0)$ or $I(1)$.

vector of controls includes real GDP, the long-term real interest rate and public debt-to-GDP ratio. Equation (4) is estimated in growth rates, as all the variables, including u_{it}, contain a unit root and need to be first differenced.[2]

Following economic theory and, in particular, considering diminishing returns of the production factors, we should expect a negative coefficient β_{2h}: an increasing deviation term to an excess of private capital relative to public capital, hence should be associated with lower private investment at least in some of the future periods. We do not have clear expectations about the coefficient of the direct effect of public investment: $\beta_{1h} > 0$ would point to the crowding-in effect, while $\beta_{1h} < 0$ would be an indication that crowding-out is the dominant effect h years after a public investment shock.

Although generally we follow the stock-flow approach applied by Dreger and Reimers (2016), we conduct the estimations in two steps rather than three steps (as in the original paper, see Introduction). When we try to replicate what Dreger and Reimers (2016) did using their time and country sample, we do not find a justification for three steps. In the second step, the use of the deviation of private capital from its stock equilibrium only marginally improves cointegrating properties of private investment with GDP and interest rate. The results of cointegration tests suggest the presence of cointegration even prior to the inclusion of the deviation term. Finally, both the value and statistical significance of the coefficient of the error correction term in the third step remain largely unaffected by the way this term is estimated, i.e. whether it is computed from the second-step regression which includes the deviation term from the first step or that does not include it. Therefore, the two-step stock-flow approach we follow in this paper is not only better justified by economic theory, but also simpler and allows to compute impulse responses and investment multipliers, and thus interpret results in a more straightforward and intuitive way.

To estimate private investment equation (4), we employ the Jorda local projection approach proposed by Jordà (2005), where short-term coefficients are estimated using local projections. The sequence of coefficients relating private investment and the deviation from the stock equilibrium is constructed using the values of $[\beta_{2h}]_{h=0}^{H}$ from individual private investment regressions where the horizon H is arbitrarily chosen to be seven years in this study. A similar approach has been widely used in the estimation of fiscal multipliers, among others by Auerbach and Gorodnichenko (2011), Auerbach and Gorodnichenko (2017) and Ramey and Zubairy (2018), as it has several advantages

[2]The results of the unit root test are available upon request.

over the STVAR or VECM approach:

- First, it uses a larger number of observations, thus improving the stability and precision of the estimates (less parameters to estimate);
- Second, it allows to estimate the coefficients and construct impulse responses for any macroeconomic variable of interest;
- Third, it allows to account for the possibility of cross-sectional dependence (whose presence is likely in the panel data setup) by using, e.g. Driscoll and Kraay (1998) standard errors (which are hard to handle in STVAR/VECM);
- Fourth, it conveniently accommodates non-linearities which is more challenging in STVAR/VECM.

It is important to highlight that β_{2h} coefficients are not impulse responses. However, β_{2h} together with β_{1h} and α_1 (from equation (3)) are ingredients in the estimation of impulse responses and public investment multiplier performed in Section 5.

2.2 Data on private and public investment and capital stock

Our study uses annual data for the period between 1995 and 2017. The panel is based on a sample of 33 countries that are OECD member states at the time of this writing.[3] The series are taken from two sources: the OECD.Stat database and the IMF dataset.

The only data source where total capital stock of countries is split between private and public capital for a sufficiently long period and a large number of countries is the IMF's Investment and Capital Stock dataset. This dataset provides annual country-level data on public and private investment and public and private capital stock. Investment data are expressed in constant 2011 international dollars, while capital stock data are provided both in nominal terms and in constant 2011 international dollars.

Another dataset where annual country-level data on both private and public investment are available is the OECD.Stat database. In the baseline estimation, we use the data on public and private investment from the OECD.Stat database, because it is the only source of data where public investment is also split into public policy areas or COFOG categories. For the sake of consistency,

[3]These countries are: Austria, Belgium, Canada, Chile, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. Due to lack of data, Australia is excluded from the sample.

we prefer the results on the policy area impact to be based on the same source of investment data as in the baseline.[4] As the investment and capital stock data are originally nominal, we need to transform them into real values. For that purpose we use Gross fixed capital formation deflator, also taken from the OECD.Stat database. In the Robustness section we also use both investment and capital stock data from the IMF dataset, where these are originally given in constant 2011 international dollars.

Table A.1 presents summary statistics of the data we use in the baseline estimation (including mean, median and the 10th and 90th percentiles of corresponding distributions across all countries (unweighted)).

In line with the previous literature that explored the link between private and public investment, we add a few controls, such as the long-term interest rate, GDP, and public debt-to-GDP ratio. We take the data for the former two variables from the OECD.Stat database and for the latter one from the IMF database.

2.3 Institutional quality measures

As mentioned above, examining the role of institutional factors for the possible crowding-in effect is one of our contributions. To account for differences in institutional quality, we use the Worldwide Governance Indicators database created by the Development Research Group of the World Bank. It publishes six aggregate measures of governance indicators which are based on over 30 data sources that report views and experiences of citizens, entrepreneurs and experts in the public, private and NGO sectors from around the world on the quality of various aspects of public governance. These data sources are rescaled and combined to create the aggregate indicators. We prefer using this database because, first, it provides the data for all countries and years in our sample without any missing observations and, second, the methodology underlying these data relies on a large amount of different questions about governance quality and responses to them by thousands of experts worldwide (Kaufmann et al. (2010)). In terms of scope and the number of respondents, this data source is superior to any comparable available dataset. One possible shortcoming of this dataset is its full reliance on the perception of institutional quality arising from opinions of respondents. The estimates of institutional quality cannot be supported by references to laws and cannot be

[4]We use the variable 'Gross fixed capital formation' in Table 14A 'Non-financial account by sector' for *Total economy* and *General government*. We calculate private investment as the difference between government investment and that of total economy.

objectively verified. However, since it is the perception of institutional quality that matters for attracting private investment, we find the Worldwide Governance Indicators database appropriate for this study.

Referring to Kaufmann et al. (2010), the above six aggregated governance indicators that capture different dimensions of institutional quality are the following:

Voice and Accountability (VAE). This indicator captures perceptions of the extent to which a country's citizens can select their government, as well as perceptions of the freedom of expression and the freedom of association. Among other estimates it incorporates the results of the Freedom House annual survey of political rights and civil liberties and the democracy index of the Economist Intelligence Unit.

Political Stability and Absence of Violence (PVE). It measures the perceptions of the likelihood of political instability and politically motivated violence. It uses inputs from the International country risk guide on government stability and the absence of internal and external conflicts.

Government Effectiveness (GEE). This indicator captures perceptions of the quality of public and civil services. It uses inputs from the Gallup World poll (on satisfaction with the public transportation system, roads and highways, the education system) and the Institutional profiles database among other indicators.

Regulatory Quality (RQE). It captures the ability of the government to formulate and implement sound policies and regulations. The indicators used to construct this aggregate range from the Economist Intelligence Unit Riskwire and Democracy Index to several measures provided by the Institutional profiles database.

Rule of Law (RLE). It aggregates several measures of perceptions of the extent to which agents have confidence in the rules. These individual measures come from the datasets, such as the above Institutional profiles database and the Economist Intelligence Unit Riskwire and Democracy Index.

Control of Corruption (CEE). This captures perceptions of the extent to which public power is used for a private purpose. A significant contribution to this aggregate comes from the World Economic Forum Global Competitiveness Report.

The aggregated indicators are provided on the annual basis and their values vary from 0 to 100. In Figure A.2, we show the value of each of the six governance indicators for the selected countries in our sample for 2019, as well as their change over the period from 2005 to 2019.

We want the transition across different levels of governance indicators to be smooth. For this

purpose, we use $F(z_{it})$ – a smooth transition function

$$F(z_{it}) = \frac{exp(-\gamma z_{it})}{1 + exp(-\gamma z_{it})} \tag{5}$$

where γ is set to be equal to 1, as in Abiad et al. (2016), that transforms the state of the economy and the degree of public investment efficiency. We check the robustness of the estimates by employing alternative γ values. For example, Auerbach and Gorodnichenko (2011) and Auerbach and Gorodnichenko (2017) in their study of fiscal multipliers use $\gamma = 1.5$. The transition function can be interpreted as the probability of the indicator reaching the lowest level. Thus, $F(z_{it}) = 1$ can be interpreted as institutions being of a poor quality, while $F(z_{it}) = 0$ corresponds to very strong institutions.

We allow the effect of the deviation term (i.e. the speed of adjustment to the long-term relation) to vary with the degree of institutional quality and therefore include its interactions with the smooth transition function in the estimation of equation (4).[5]

$$\Delta lnI^P_{it+h} = \beta_{0h} + \mu_i + \beta_{1h}\Delta lnI^G_{it} + \beta_{2h}F(z_{it})\Delta u_{it} + \beta^*_{2h}(1 - F(z_{it}))\Delta u_{it} + \sum_k \beta_{kh}X^k_{it} + \varepsilon_{it} \tag{6}$$

where z_{it} is a normalized governance indicator. Following the interpretation of the transition function, $[\beta_{2h}]^H_{h=0}$ and $[\beta^*_{2h}]^H_{h=0}$ provide the estimated deviation coefficients for very poor and very strong institutions respectively.

2.4 Public investment by policy area

Having estabilshed the relationship between public and private investment at the aggregate level, we now consider different areas of public investment (such as education, culture, defence, etc.). This part of our analysis aims to uncover the relative impact of allocating scarce resources to different areas of public spending.

For this purpose, we decompose public capital and government investment into 10 areas according to the Classification of the functions of government (COFOG).[6] As mentioned above, public investment data by COFOG is taken from the OECD.Stat database.[7] However, there is no official

[5] Although institutional improvements themselves can attract private investment, we are interested in their effect on the magnitude of the crowding-in effect.

[6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Classification_of_the_functions_of_government_(COFOG)

[7] Table 11 in the 'National Accounts' section of the OECD.Stat database provides annual figures for government

statistics on the split of public capital by COFOG. To construct our own estimates of public capital in each policy area, we start from the decomposition of total public capital in the year 2017. The share of public capital in each policy area is assumed to be equal to the share of public investment in this policy area relative to the total public investment over the period from 1995 to 2017. Using the end values for 2017 and applying a single depreciation rate of public capital, we iterate the calculation of public capital backwards.[8]

Figure A.1 illustrates the (unweighted) average shares of public investment by policy areas over the 1995–2017 period. Unsurprisingly, economic affairs (which stand for economic infrastructure, such as roads, bridges, the transport infrastructure, etc.) represent the biggest portion of total investment spending. The second largest part is general public services, followed by education. Other areas of spending constitute a lower share.

To proceed methodologically in line with the baseline estimation, we again refer to the production function (equation 1) which can be re-written as follows:

$$Y_t = A_t(L_t)^{\alpha}(K_t^P)^{\beta}\prod_{c=1}^{10}\left(K_t^{G_c}\right)^{\theta^c} \tag{7}$$

where c stands for a policy area and $K_t^{G_c}$ is the stock of public capital in the policy area c at the beginning of year t.

As argued above, marginal products of private capital and each type of public capital, i.e. $\beta Y_t/K_t^P$, $\theta^1 Y_t/K_t^{G_1}$, $\theta^2 Y_t/K_t^{G_2}$, ..., $\theta^1 0 Y_t/K_t^{G_{10}}$ should equal their corresponding real interest rates. It is reasonable to expect that real interest rates on different types of public capital are equal; however, even if not, they are expected to move in tandem. Therefore, we can assume a constant ratio γ^c between interest rates for private and each type of public capital (which may or may not differ between different policy areas of public capital – all γ^c must be equal in the latter case) and obtain the long-term cointegrating relationship between private capital and public capital of each individual policy area.

$$K_t^P = K_t^{G_c}\frac{\beta}{\gamma^c\theta^c} \tag{8}$$

Therefore, we apply two steps of the stock-flow approach to each of ten COFOG types of public

expenditure by OECD member country and COFOG category. For public investment in different policy areas, we use the item 'Gross fixed capital formation'.

[8] We recognize limitations related to the use of a single depreciation rate. We have experimented with alternative assumptions, e.g. deriving area-specific depreciation rates based on the available information by NACE sector. These alternative depreciation rates result in unreliable paths of public capital.

capital separately. First, we follow the same approach as in Section 2.1 and estimate a cointegrating relationship between private capital and public capital in each policy area.

$$lnK_{it}^{P} = \alpha_0^c + \vartheta_i^c + \alpha_1^c lnK_{it}^{G_c} + u_{it}^c \tag{9}$$

Next, we estimate equation (4) where aggregate public investment is replaced by public investment in a single policy area. The estimated coefficients represent *ceteris paribus* effects between private investment and public investment in each policy area. This implies that they should be interpreted assuming that everything else, including the deviation from the long-term cointegrating relationship between private capital and public capital in all other policy areas, remains unchanged.

2.5 Public investment forecast errors

Some part of what classifies as a shock to public investment can be anticipated in advance, i.e. ahead of actual spending, particularly if there is a delay between the decision to invest and the moment when a project is realized. Anticipated future public investment projects can affect private investment in the present period, leading to some immediate crowding-in or crowding-out. This may have serious implications for the econometric estimation of a public investment multiplier if econometric techniques and datasets do not allow to capture the anticipation effect.

The anticipation problem has been widely acknowledged in the literature on fiscal multipliers (see, e.g. Blanchard and Perotti (2002) and Ramey (2011)). it is always challenging to empirically isolate the unanticipated movements in public investment. Many authors simply ignore the anticipation issue (for example, the paper that we more closely follow methodologically, i.e. Dreger and Reimers (2016)). However, Abiad et al. (2016) make an attempt to address this problem by employing public investment forecast errors using forecasts from the OECD Economic Outlook. Unfortunately, at the time of writing this paper the forecast errors are mostly available for the period 2001–2008 and therefore could not be used in the baseline estimation.[9] Nevertheless, in the robustness section we follow the approach by Abiad et al. (2016) and estimate private investment regressions replacing the deviation variable with the forecast error, i.e. the difference between the actual public investment and the public investment projected by OECD forecasters. The approach is based on the following assumption, which looks sufficiently reasonable: the private sector cannot

[9] Prior to the year 2001, the data are available only for eight largest European countries.

anticipate the exact amount of public investment more precisely than the forecast in the OECD's Economic Outlook. The difference between the actual public investment and its expected value becomes known only after the year has ended and therefore serves as a truly exogenous shock, impossible to anticipate in advance. The figure for each year's public investment is taken from the following year's November vintage of the OECD Economic Outlook.[10] As to the forecasted values, two types of those are used: public investment projected by OECD forecasters as of November (in some years, December) of a) the same year and b) the previous year.

Following the outlined approach, we employ public investment forecast errors (as a ratio to GDP (FE_{it})) and estimate the following private investment regressions:

$$\frac{I^P_{it+h}}{Y_{it+h}} - \frac{I^P_{it}}{Y_{it}} = \beta_{0h} + \mu_i + \theta_t + \beta_{1h} FE_{it} + \varepsilon_{ith} \tag{10}$$

Y_{it} is GDP (hence the dependent variable is the change in private investment-to-GDP ratio) and θ_t is the time trend that controls for global shocks.

3 Results

In this section, we study the dynamic responses of private investment to the deviation in the identified relationship between private and public capital stocks. First, we present the baseline estimates of private investment regressions. Next, we proceed to the role of institutions. Finally, we examine the role of public spending area.

3.1 Baseline estimation

We begin with the cointegration analysis to check whether the two types of capital stocks are linked with a linear cointegrating relationship. For this purpose, we employ three cointegration tests: Westerlund (2005), Kao (1999) and Pedroni (1999) tests of cointegration in a panel dataset. All tests have a null hypothesis of no cointegration. The alternative hypothesis of Kao, Pedroni and Westerlund II tests is the presence of cointegration in all cross-sections, while in Westerlund I test the alternative hypothesis is that the variables are cointegrated in some panels only. The results of

[10] The actual public investment figure in the following year's November vintage is the most accurate representation, because in June's vintage, some public investment carried out in the previous year can still be estimated imprecisely, whereas if we take the figure more than one year in the future, the difference between that figure of public investment and the one expected in the given year might include revaluations of public capital, rather than only the difference between the expected and the realized amounts of public investment.

these tests (see Table 1) indicate the presence of a long-term cointegrating relationship with a high level of statistical significance.

Table 1: Cointegration test results

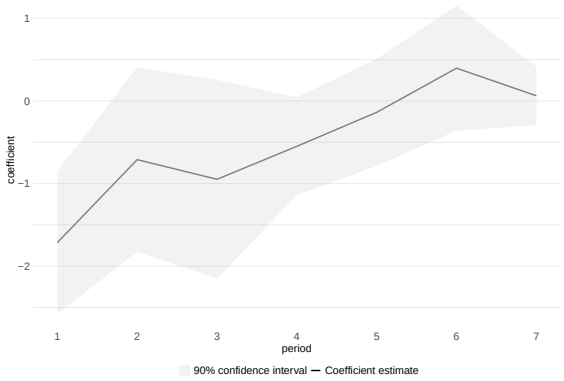
Test	Statistic	P-value
Westerlund I (some panels are cointegrated)	-2.665	0.004
Westerlund II (all panels are cointegrated)	-2.353	0.009
Kao	2.010	0.022
Pedroni	3.158	0.001

Next, we estimate the long-run parameters of this relationship using panel econometric technique with fixed effects and accounting for the possibility that residuals are cross-sectionally correlated.[11] The relationship takes the following form:

$$\begin{array}{lccccc} lnK_{it}^{P} = & 2.174 & + & 0.854 lnK_{it}^{G} & + & u_{it} \\ & (0.157) & & (0.025) & & \end{array}$$

Thus, a 1% increase in the stock of public capital is associated with a 0.85% increase in private capital stock. For comparison, the coefficient found in Dreger and Reimers (2016) for a smaller sub-sample of 12 euro area member states is lower, 0.604. The deviation from the identified linear relationship contains a unit root, i.e. it is a I(1) process. To incorporate it in the estimation of private investment regressions, it needs to be first differenced. The estimation results of equation (4) are reported in Table 2, but estimates of the deviation coefficient are drawn in Figure 1. These estimates are constructed from the sequence of h private investment regressions.

Figure 1: Private investment reaction to shocks in the deviation term



Source: Authors' estimation.

[11] xtscc command, that uses Driscoll–Kraay standard errors.

Table 2: Coefficient estimates of private investment regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.067*	0.002	-0.030	0.036	0.017	-0.088*	-0.085
	(2.09)	(0.07)	(-0.89)	(0.83)	(0.47)	(-2.37)	(-1.55)
D.Ln(GDP)	0.628*	-0.843*	-0.562	-0.002	-0.032	0.072	0.056
	(2.11)	(-2.27)	(-1.29)	(-0.00)	(-0.09)	(0.26)	(0.24)
D.Interest rate	-0.003*	-0.002	0.001	0.000	0.002	0.000	-0.002
	(-2.55)	(-2.02)	(1.05)	(0.37)	(1.50)	(0.01)	(-1.74)
D.Debt	-0.004*	-0.003**	-0.001	0.002	0.002	0.003*	0.003
	(-2.60)	(-3.06)	(-1.73)	(1.97)	(1.86)	(2.13)	(1.65)
D.Deviation	-1.714**	-0.710	-0.948	-0.549	-0.138	0.397	0.063
	(-3.42)	(-1.10)	(-1.36)	(-1.61)	(-0.37)	(0.92)	(0.31)
Constant	0.015	0.048***	0.040**	0.020	0.019	0.018	0.018
	(1.46)	(7.26)	(3.69)	(1.43)	(1.50)	(1.21)	(0.93)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll-Kraay standard errors
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We find that a deviation of private capital from the equilibrium path triggers private investment correction. To be more specific, as capital stocks are fixed at the beginning of a year, a positive deviation of private capital stock in period t induced by, say, smaller public investment in period t-1, brings about a downward correction in private investment in period t+1. The effect is not persistent, i.e, it is statistically significant for period t+1 only. But one should keep in mind that the adjustment that is followed in period t+1 does not fully bring private capital back on the equilibrium track and therefore further adjustments in the following years are anticipated. In Section 5, we calculate impulse responses of private investment by iterating these changes forward.

Other coefficient estimates are largely signed as expected. The short-term coefficient of public investment is positive and statistically significant, indicating that even in a relatively shorter period of time public investment might induce some crowding-in. This is probably because financing restrictions are less binding for a group of industrialized economies that have a broad access to international finances. However, as will be shown later, statistical significance of this coefficient is not robust to different specifications of the short-run relationship regression between private and public investment.

3.2 Role of institutional factors

The effect of institutional factors is explored using six different governance indicators. These are integrated in private investment regressions by means of the smooth transition function as explained in Section 2.3. As argued above, weak institutional quality may hinder private investment. The

impact of institutional factors has been uncovered for a group of developing countries by Cavallo and Daude (2011). However, it remains unclear whether this effect is idiosyncratic to that group of countries or there is a room for institutional improvements to magnify the crowding-in of private investment in industrialized economies as well. Moreover, owing to the stock-flow methodology employed in our study, we are able to investigate this complex issue from the long-term prospective (which is absent in Cavallo and Daude (2011)).

The estimates presented in Tables B.1– B.6 indicate that:

- The effect of the deviation term gets stronger as countries implement sound policies that improve their governance indicators. This reduces waste in the conduct of public investment, which magnifies the crowding-in effect;

- Better accountability, government effectiveness and the rule of law prolong the effect of dis-equilibrium term on private investment for the second period, which implies a larger multiplier already in the short-to-medium term and a faster adjustment to long-term equilibrium.

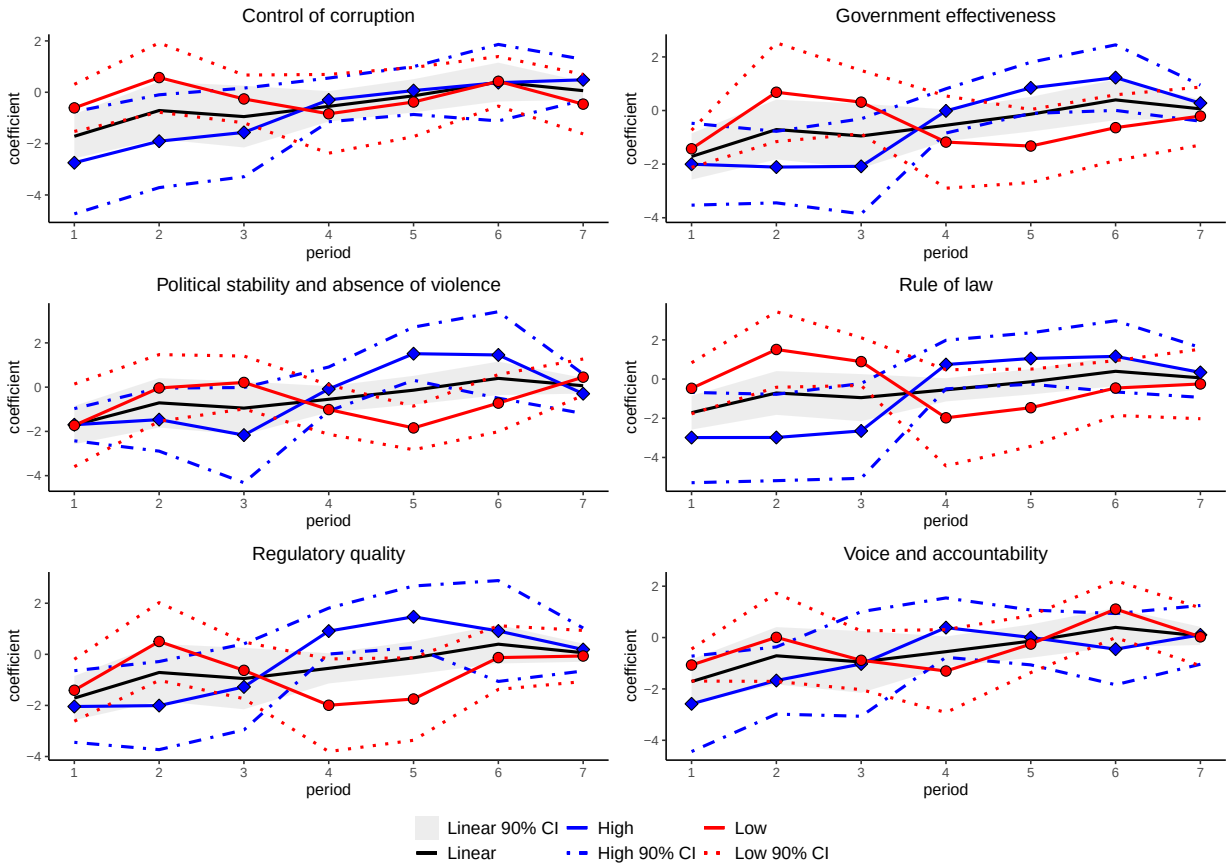
In Figure 2 we plot the sequence of deviation coefficients for both low and high values of governance indicators alongside their 90% confidence bands. The return to equilibrium is faster when standards of citizens' freedom and democracy are very high, government effectiveness is high, and when a country strongly sticks to the rule of law. Higher regulatory quality has only a marginally larger effect. The effect on private investment is not statistically different for different levels of political stability. All in all, the results obtained imply that not only developing but also industrialized countries can reap more benefits from larger public investment by raising institutional quality.

It should be noted that some caution is needed when interpreting these results. Confidence bands appear somewhat wide to allow conclusive evidence to be made about the size of the non-linear effect (magnitude of the response).

3.3 Role of public investment areas

We begin with the cointegration analysis and test whether the stock of public capital in each policy area is cointegrated with private capital. For eight out of ten areas, public capital stock is found to be cointegrated with private capital stock, whereas for two COFOG categories (Housing and community amenities and Social protection) the evidence on the presence of cointegrating

Figure 2: The role of institutions in private investment reaction to shocks in the disequilibrium term



Notes. The figures plot deviation coefficient estimates for linear vs for non-linear specification in the low vs high levels of indicators. 90% confidence bands are constructed using Driscoll–Kraay standard errors. The horizontal axis shows the response horizon measured in years.
Source: Authors' estimation.

relationship between stocks of these types of public capital and private capital is mixed.[12]

We proceed with the stock-flow approach for each of ten public policy areas, while bearing in mind that the estimation results of the private investment regression may be biased for the above two policy areas.

The first column of Table 3 presents the estimates of the coefficients of the cointegrating relationship between public capital in the respective policy areas and private capital. Other columns document the sequence of deviation coefficients β_2^c.

Except for the two areas, where cointegration with private capital is uncertain, public capital in all other areas in the long term is very closely related to the stock of private capital. The cointegrating coefficient varies between 0.57 and 0.80. Public order and safety, Economic affairs

[12]Results of cointegration tests are available per request.

Table 3: Coefficient estimates of private investment regressions

Policy area	L-t rel.	t+1	t+2	t+3	t+4	t+5	t+6	t+7
1. General public services	0.682***	-0.957***	-0.370	-0.706	-0.187	0.099	0.288	-0.018
	(11.060)	(-5.981)	(-0.892)	(-1.253)	(-0.633)	(0.285)	(1.020)	(-0.094)
2. Defense	0.697***	-0.295**	-0.003	0.009	-0.031	-0.137	-0.017	0.150
	(11.271)	(-2.099)	(-0.015)	(0.136)	(-0.147)	(-0.754)	(-0.160)	(1.467)
3. Public order and safety	0.797***	-0.951***	-0.464	-0.732	-0.614	-0.389	0.212	0.070
	(20.830)	(-3.723)	(-1.183)	(-1.288)	(-1.587)	(-1.055)	(0.636)	(0.391)
4. Economic affairs	0.789***	-1.489**	-0.711	-0.871	-0.339	-0.039	0.277	0.047
	(21.744)	(-2.749)	(-1.183)	(-1.517)	(-1.244)	(-0.128)	(0.812)	(0.224)
5. Environmental protection	0.570***	-0.827***	0.110	-0.023	-0.030	-0.050	-0.040	-0.385
	(11.628)	(-3.925)	(0.340)	(-0.086)	(-0.104)	(-0.122)	(-0.125)	(-1.043)
6. Housing and community amenities	0.504***	-0.134	-0.029	-0.473	-0.227	-0.117	0.180	0.131
	(5.497)	(-0.453)	(-0.167)	(-1.998)	(-1.219)	(-0.418)	(1.159)	(0.661)
7. Health	0.709***	-1.339***	-0.583	-0.923**	-0.824***	-0.613*	-0.211	-0.156
	(19.812)	(-3.692)	(-1.277)	(-2.208)	(-2.929)	(-2.089)	(-0.947)	(-0.738)
8. Recreation, culture and religion	0.762***	-1.189***	-0.321	-0.666	-0.485	-0.208	0.111	-0.166
	(19.245)	(-2.945)	(-0.700)	(-1.305)	(-1.342)	(-0.531)	(0.342)	(-0.572)
9. Education	0.785***	-1.478**	-0.785	-1.076	-0.771**	-0.453	0.068	0.027
	(19.560)	(-2.765)	(-1.194)	(-1.714)	(-2.443)	(-1.366)	(0.178)	(0.103)
10. Social protection	0.319**	-0.719***	-0.153	-0.441*	-0.354	-0.069	0.156	0.088
	(2.486)	(-2.904)	(-0.607)	(-2.014)	(-1.617)	(-0.285)	(1.098)	(0.591)

Notes. Standard deviation in parentheses.
Source: Authors' estimation.

and Education stand out as areas with the strongest cointegrating relationship, hence any public investment into these areas is likely to exhibit a stronger crowding-in effect.

The coefficient of the deviation term is estimated highest in Economic affairs, Education and Health, indicating a faster adjustment of private capital stock through private investment to changes in public investment in these policy areas. For the following periods, the deviation coefficient stays negative in most cases but is close to zero, which points to the crowding-in effect that continues for several years and becomes weaker over time.

In the following section, we turn to additional robustness checks, while detailed interpretations of the obtained results and discussion of their policy implications are provided in Section 5, where we introduce public-to-private investment multipliers.

4 Robustness analysis

In this section, we conduct several robustness checks of the estimation results presented above. The robustness analysis is split into three parts according to the sample, specification and methodology used.

Robustness to the use of different data samples. First, we assess whether the crowding-in effect has changed over time. To this end, we split our sample into two sub-samples covering the

period before and after the start of the Great Recession: 1996–2007 and 2008–2017. In addition, we drop the crisis years of the Great Recession period 2008–2011 from the second sub-sample to avoid the crisis induced volatility in private investment to affect the estimation results.

Table 4: Estimation of the Jorda regression for t+1 using different period sub-samples

	1995–2007	2008–2017	2012–2017
D.Ln(Government investment)	0.095**	0.036	0.042
	(3.83)	(0.83)	(1.12)
D.Ln(GDP)	0.294	-0.060	0.933*
	(1.79)	(-0.15)	(2.59)
D.Interest rate	-0.002*	-0.007***	-0.002
	(-2.46)	(-5.61)	(-0.98)
D.Debt	-0.002	-0.007*	-0.003
	(-1.92)	(-3.03)	(-2.50)
D.Deviation	-1.752**	-2.394*	-1.697**
	(-4.37)	(-3.07)	(-4.92)
Constant	0.037**	0.017	0.015
	(4.01)	(1.21)	(1.48)
Observations	332	330	198

t statistics in parentheses, based on Driscoll–Kraay standard errors.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4 displays the estimation results of the private investment regression for the period t+1. The magnitude of the estimated deviation coefficient rises substantially in the second sub-sample vis-à-vis the pre-crisis period. However, the coefficient remains robust and very similar to the one obtained for the full sample if the crisis years are dropped. It should be noted that the direct effect of public investment is not statistically significant in the second period, both when four crisis years are included in the sample and when they are excluded from it.

Second, we examine whether changing the country sample affects the estimated coefficients. The estimation results are largely robust to dropping one OECD country at a time.[13] The magnitude of the deviation term effect gets lower when Iceland is excluded from the sample, but remains stable for the exclusion of other countries. To validate the stability of the deviation term, we also re-estimate private investment regressions for the sample of seventeen euro area countries. The deviation coefficient in period t+1 remains robust both in terms of its magnitude and the level of statistical significance (see Table 5).

Third, we check whether the results obtained can be biased due to the fact that the data source of both investment types (the OECD.stat database) differs from the one for capital (the IMF dataset). The IMF publishes both capital and investment data in billions of constant 2011 international

[13]Detailed results are available upon request.

Table 5: Estimation of private investment regressions using the sub-sample of the euroarea countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.034	-0.054	-0.048	0.042	0.047	-0.116*	-0.112
	(0.94)	(-0.76)	(-0.87)	(0.52)	(0.74)	(-2.33)	(-1.11)
D.Ln(GDP)	0.916*	-0.942	-0.586	0.079	0.126	0.097	-0.049
	(2.37)	(-1.96)	(-1.15)	(0.24)	(0.32)	(0.24)	(-0.16)
D.Interest rate	-0.004*	-0.002	0.002	0.003	0.002	-0.000	-0.003
	(-2.18)	(-1.19)	(0.88)	(1.07)	(1.19)	(-0.12)	(-1.89)
D.Debt	-0.003*	-0.006*	-0.003	-0.000	0.002	0.003	0.003
	(-2.62)	(-2.30)	(-1.65)	(-0.17)	(0.95)	(1.19)	(1.03)
D.Deviation	-1.650*	-0.267	-1.133	-1.730	-0.780	0.563	-0.249
	(-2.79)	(-0.29)	(-1.27)	(-1.68)	(-1.06)	(0.64)	(-0.42)
Constant	0.007	0.052***	0.040**	0.020	0.012	0.0126	0.018
	(0.46)	(5.37)	(3.35)	(1.31)	(0.63)	(0.61)	(0.76)
Observations	353	353	336	319	302	285	268

t statistics in parentheses, based on Driscoll–Kraay standard errors.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Estimation of private investment regressions using IMF investment data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.077*	0.027	0.011	0.060	0.055	-0.028	-0.053
	(2.61)	(1.08)	(0.37)	(1.34)	(1.41)	(-1.21)	(-0.75)
D.Ln(GDP)	0.709	-1.094**	-0.451	-0.137	0.046	0.133	0.118
	(2.05)	(-3.39)	(-1.08)	(-0.36)	(0.14)	(0.58)	(0.52)
D.Interest rate	-0.002	-0.001	0.001	0.002	0.003	0.001	-0.001
	(-1.61)	(-1.84)	(0.68)	(1.12)	(2.00)	(0.33)	(-1.44)
D.Debt	-0.005*	-0.004***	-0.000	0.002	0.003*	0.004**	0.003
	(-2.12)	(-4.79)	(-0.16)	(1.29)	(2.18)	(3.09)	(1.59)
D.Deviation	-2.479**	-1.756	-1.545	-1.053	-0.078	0.388	0.172
	(-3.17)	(-1.93)	(-1.71)	(-1.80)	(-0.18)	(0.61)	(0.52)
Constant	0.019	0.059***	0.038**	0.023	0.013	0.0113	0.014
	(1.78)	(6.66)	(2.99)	(1.33)	(0.82)	(0.54)	(0.53)
Observations	647	614	581	548	515	482	449

t statistics in parentheses, based on Driscoll-Kraay standard errors
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

dollars. As explained above, in the baseline, we prefer using the OECD data on investment, so that our results on the impact of public investment across different policy areas (where the OECD.stat database is the only source of COFOG investment) are based on the data from the same dataset. However, we believe that re-estimating baseline regressions using the IMF data (both the long-term relationship between both types of capital and private investment regressions) would provide an additional evidence on the robustness of the estimated effect. The long-term coefficient that links both types of capital is very close in magnitude (0.879 vs 0.854), but the estimation results of private investment regressions point to the possibility of a somewhat larger reaction of private investment

to the public sector capital buildup (see Table 6).

Robustness to different regression specifications and parameters. Additionally, we replicate the estimation of private investment regressions by dropping each control variable at a time. The value of the coefficient and its statistical significance remain close to the ones obtained in the baseline estimation. The magnitude of the deviation coefficient gets somewhat smaller when control variables enter equation (4) with one period lag aimed to minimize reverse causality concerns (see Table 7).

Table 7: Different specifications of private investment regressions for t+1 period

	$\Delta \ln I^P_{it+1}$	$\Delta \ln I^P_{it+2}$	$\Delta \ln I^P_{it+3}$	$\Delta \ln I^P_{it+4}$	$\Delta \ln I^P_{it+5}$
Baseline	-1.714***	-0.710	-0.948	-0.549	-0.138
Drop public investment	-1.557***	-0.703	-1.008	-0.405	-0.040
Drop GDP	-1.707***	-0.720	-0.945	-0.549	-0.137
Drop interest rate	-1.674***	-0.839	-0.828	-0.530	-0.104
Drop public debt	-1.659***	-0.683	-0.916	-0.507	-0.154
Controls enter with one period lag	-1.208***	-0.704	-1.249	-0.412	0.010
Use contemporaneous controls and controls with one period lag	-1.228***	-0.661	-1.246	-0.509	-0.050

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

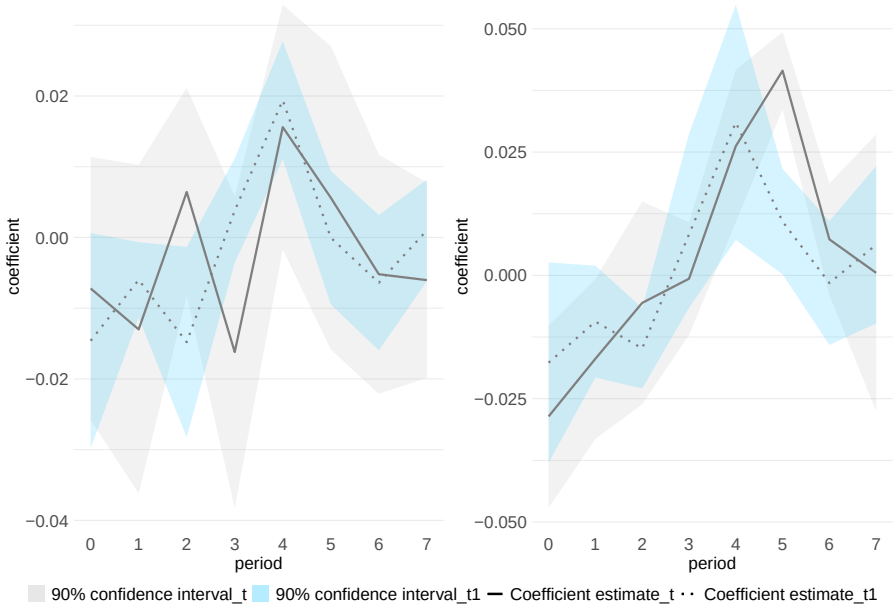
Second, concerning the role of institutional factors we also check the robustness of the obtained estimates by employing the alternative γ value of 1.5 (as used by Auerbach and Gorodnichenko (2011), for example) in the corresponding smooth transition function (see equation (5)). The findings do not change qualitatively when we use the alternative γ value.[14]

Robustness to the use of the alternative methodology. Finally, we assess whether our findings depend on the choice of the stock-flow approach followed in the paper. Some of the deviation from the stock equilibrium can be anticipated by the private sector. Anticipated future changes in public investment can affect private investment ahead of their implementation. To empirically isolate the unanticipated change in public investment, we follow the Abiad et al. (2016) approach by employing public investment forecast errors from the OECD Economic Outlook. Unfortunately, as mentioned in Section 2.2, at the time of writing this paper the forecast errors are available only until 2009 and therefore could not be used in the baseline estimation. Nevertheless, in the robustness

[14]Detailed results are available upon request.

exercise we follow the approach by Abiad et al. (2016) and estimate private investment regressions for a shorter time period using the forecast errors.

Figure 3: The impact of public investment on private investment using forecast errors in public investment (full sample of OECD countries on the left plot; a sample of euro area countries on the right plot)



Notes. The figures plot impulse responses of private investment growth to forecast errors, i.e. the difference between the actual public investment and the public investment projected by OECD forecasters as of October of a) the same year (t) and b) the previous year (t1). 90% confidence bands are constructed using Driscoll–Kraay standard errors. The horizontal axis shows response horizon measured in years.
Source: Authors' estimation.

The estimation results (see Figure 3) suggest that the immediate impact of public investment may be negative, but it gets positive in 4–5 years from the year of reference. This pattern is particularly visible when equation (10) is estimated using the sub-sample of the euro area countries.

Overall, the findings obtained so far reveal that the relation between public and private investment is robust to the number of different robustness exercises, including those that examine the effect of the sample selection and the choice of the methodology used in the paper. Yet, the magnitude of the speed of adjustment of private capital to any deviations from the stock equilibrium and therefore the value of the multiplier in the medium-term (calculated in the next section) can vary somewhat depending on the choice of the sample.

5 Response of private investment to a public investment shock

In Section 3.1, we established the long-run cointegrating relationship between the stocks of private and public capital and estimated private investment regressions. In this Section, we transform the obtained coefficients into impulse responses of private investment to a public investment shock and calculate the public investment multiplier, including by policy areas.

5.1 Private investment impulse response

As demonstrated previously, there are two possible channels how public investment affects private investment: a) the direct effect, captured by coefficient β_{1h} in equation (4), and b) the indirect effect through a change in the deviation term (Δu_{it}) from the long-term cointegration relationship (α_1 in equation (3)) between stocks of private and public capital. The strength of the indirect effect is determined by coefficient β_2. To estimate the impulse response of private investment to a 1% increase in public investment, we need to consider both channels together. Thus, we have to adopt an iterative approach, which we illustrate as follows.

Consider a shock in government investment in year t-1 is of the magnitude c_{it-1}, such that $\hat{I}^G_{it-1} = I^G_{it-1} \cdot c_{it-1}$.[15] Suppose we were to calculate the impulse response of private investment in period t+1 accounting only for the direct effect of public investment for h=1. It would imply a small positive effect (whose magnitude is $exp(\beta_{1,h=1} \cdot c_{it-1})$) and would not account for the fact that a positive c_{it-1} leads to an increase in K^G_{it}, which implies that u_{it} is lower. This, in turn, would have a large and significant effect on I^P_{it+1}, since, as demonstrated in Sections 3.1 and 4, β_{2h} is always negative and significant for h=1.

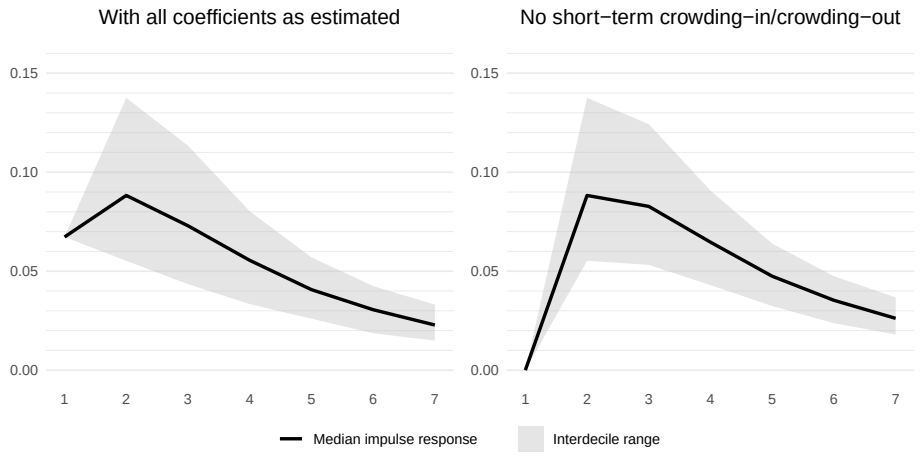
Therefore, we estimate impulse responses using an iterative approach, such that we update values of private capital and the deviation term between public and private capital before each following iteration. The detailed derivation of impulse responses is provided in Appendix C.1.

We construct impulse responses to a public investment shock for each country separately (using data for 1995–2010). Below, in Figure 4 we present the median and the interdecile range of cross-country impulse response functions. Figure 4 also contrasts the impulse responses with and without the direct effect, whose significance is not robust in the estimation. The responses are similar and indicate that the crowding-in effect reaches its maximum two years after the additional public

[15] Henceforth, for any variable X (in this equation– public investment), we denote its value in the alternative scenario (after a shock) by $\hat{X}$ and in the baseline scenario (no shocks occurred, i.e. all variables are equal to their historical values) by X.

investment took place – this is consistent with high and statistically significant values of coefficient β_{2h} for h=t+1. Starting from the third year after the shock occurs, the gap between stocks of public and private capital diminishes and private capital adjustment continues at a slower pace.

Figure 4: Private investment impulse response (elasticity) to a public investment shock



Notes. The impulse response shows by how much (in percent) private investment increases every year after an increase in public investment by 1%.
Source: Authors' estimation.

The effect one year after the public investment shock reflects a positive value of β_{1h} which we interpret as the *immediate* crowding in, i.e. that happens regardless of the deviation between stocks of public and private capital. At the beginning of this paper, we have highlighted that there is no consensus in the literature about the direction of this effect. Some authors document evidence for crowding out. As we have demonstrated in Section 4, the statistical significance of this coefficient is not robust. We therefore repeat estimation of impulse responses by assuming that in a year's time, public capital neither crowds in nor crowds out private investment by constraining β_{1h} to zero. As the right-hand side of (Figure 4) shows, impulse responses under the assumption of no immediate crowding in are very similar.

5.2 Public investment multiplier

A useful way to summarize the extent to which public investment crowds in private investment is by computing a public investment multiplier. It provides an assessment of additional private investment generated by one unit increase in public investment. There are few ways to define a multiplier: *the impact multiplier* shows the immediate effect of public investment on private investment; *the multiplier at horizon* T measures the effect on private investment at year T after

the shock; finally, *the cumulative multiplier at horizon* T provides the measure of private investment accumulated over the horizon of T years.

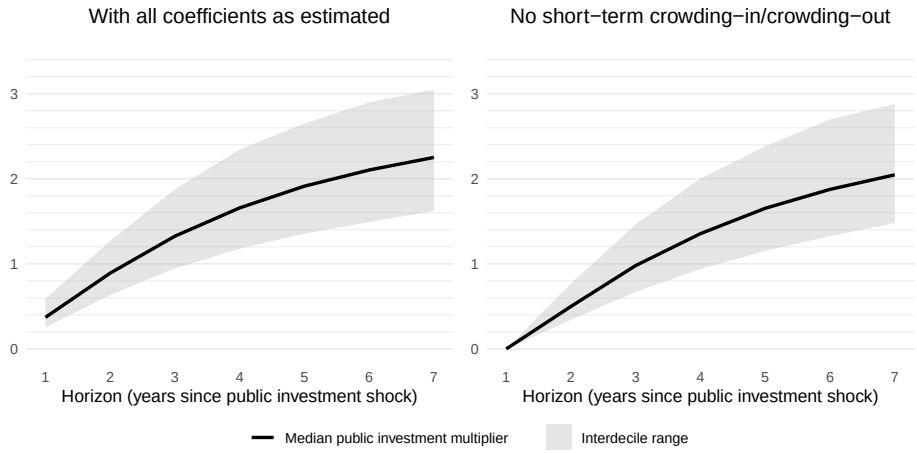
In this study, we use the cumulative multiplier at time horizon up to seven years to measure how strongly public investment crowds in private investment.

$$Public\ \ Investment\ \ Multiplier\ (T) = \frac{\sum_{v=0}^{T} \hat{I}^{P}_{it+v} - I^{P}_{it+v}}{\sum_{v=0}^{T} \hat{I}^{G}_{it+v} - I^{G}_{it+v}} \tag{11}$$

This cumulative public investment multiplier, as defined by formula 11, has a very intuitive explanation: it shows how many additional dollars are invested by the private sector over a period of T years in response to each dollar invested by the public sector.

Similarly to impulse responses, the public investment multiplier can be calculated for each country in the sample. In Figure 5 we plot the median and the interdecile range of the resulting multiplier both with (on the right) and without (on the left) the direct effect.

Figure 5: Public investment multiplier



Notes. The public investment multiplier shows how many additional dollars are invested by the private sector in total over a certain horizon (the number of years since a shock to public investment) in response to each dollar invested by the public sector.
Source: Authors' estimation.

There is some variation in the magnitude of the multiplier because countries differ in terms of stocks of public and private capital and volumes of public and private investment. As impulse responses remain positive over the 7-year horizon, the public investment multiplier keeps increasing over time, which implies that every dollar invested by the government has a meaningful lasting effect on attracting private investment over many years into the future. In particular, over the period of three years, additional public investment crowds in extra private investment of approximately the

same magnitude (the public investment multiplier on average reaches unity). Moreover, each dollar invested by the government increases private investment on average by two dollars over a horizon of seven years since the additional public investment. This is the key finding of our study: in the long run, the crowding-in effect of public investment is significant and large, and for the 33 developed countries in our sample, the public investment multiplier for a 7-year horizon lays around 2.

Appendix C.2 presents the public investment multipliers for each country in the sample.

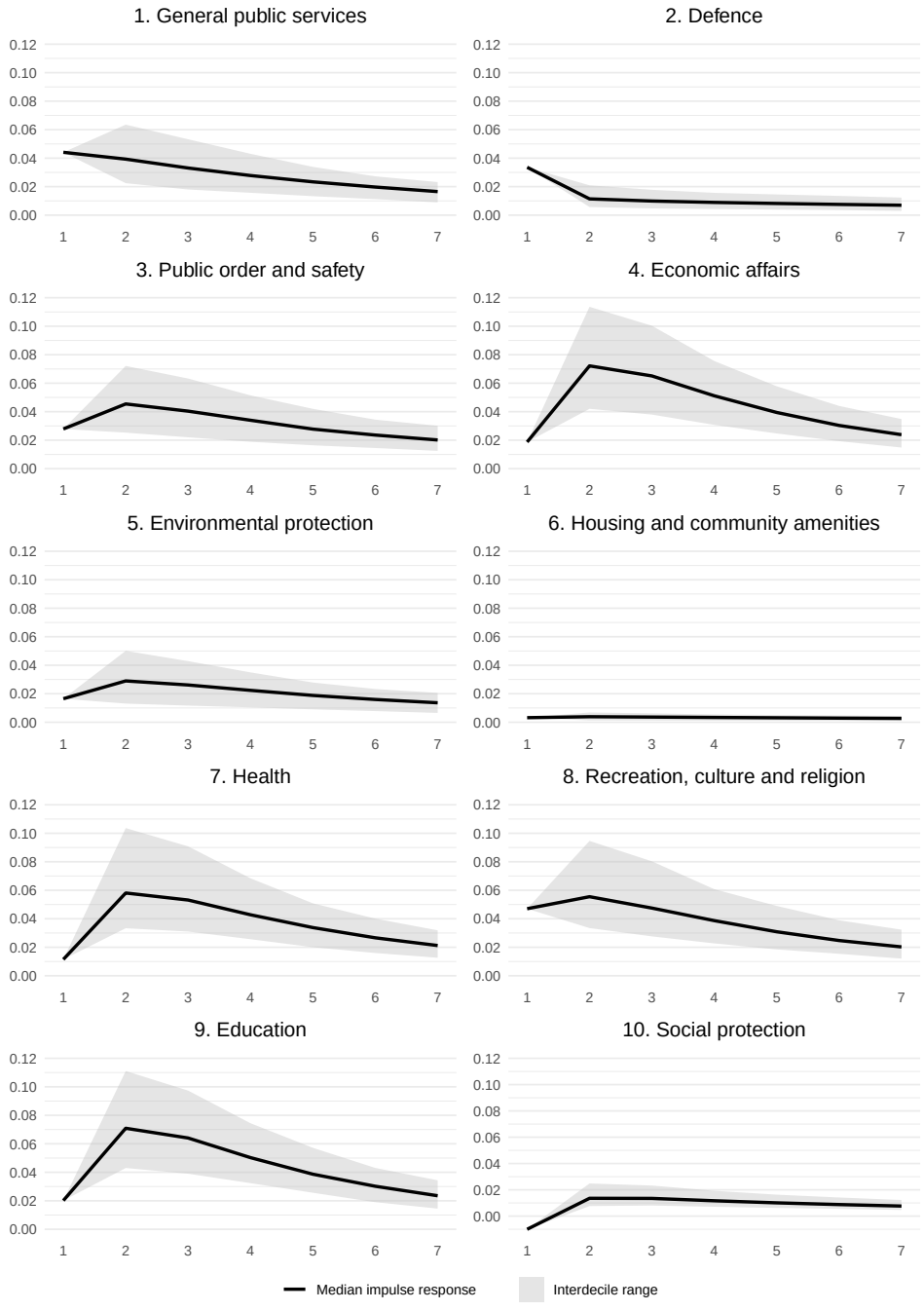
5.3 Impulse responses and public investment multipliers by areas of public policy

We conclude our study by presenting private investment impulse responses to a shock in public investment in each policy area. Their median values and the interdecile ranges are plotted in Figure 6. The evolution of impulse responses in most policy areas is similar to that for total public investment. There is much lower or no crowding-in effect in areas where cointegration between capital stocks is uncertain, i.e. Housing and Social protection. Crowding-in is also smaller in Defense, where the deviation coefficient (coefficient β_{2h} in Equation 4) is low. Increasing public investment in Education, Economic affairs, Health and Recreation, culture and religion by 1% has the largest impact on private investment. These areas exhibit rapid adjustment of private investment to a mismatch in capital stocks.

Finally, we calculate public investment multipliers in each policy area. Their interpretation is difficult because raising public investment and accumulating more capital in one COFOG category crowds in private investment, but only on the assumption that no disequilibrium appears between private capital and public capital of other COFOG categories. Thus, the multiplier of public investment of a certain type can be reliably estimated only provided that public investment in other policy areas goes up as well. Therefore, we present the median values (alongside the interdecile ranges) of the multipliers weighted by shares of public investment (relative to total public investment) in the respective policy areas.

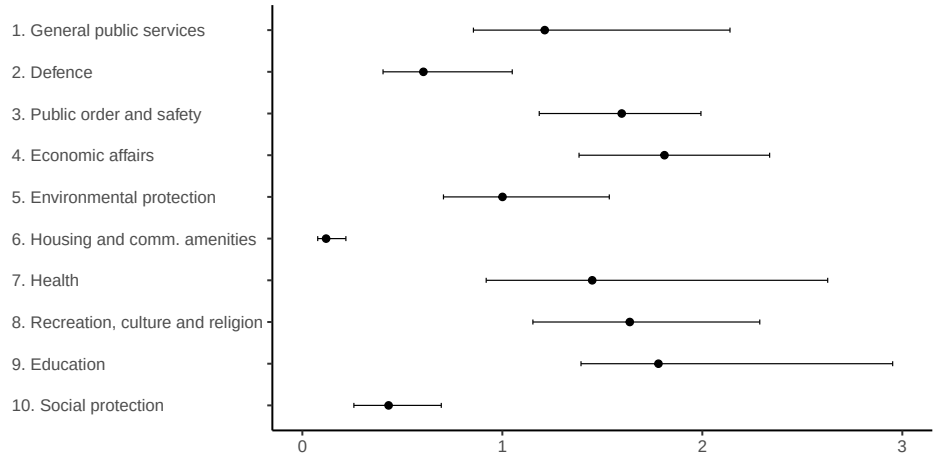
The estimates, presented in Figures 6 and 7 indicate that the strongest crowding in effect is observed after additional investment spending in the areas of Economic affairs, Education, Recreation, culture and religion and Health. The reason for such a strong response in these areas is probably the fact, that investing in human capital (health, education) and economic infrastructure (economic affairs) makes a country particularly more attractive to private investors. Investing in

Figure 6: Private investment response (elasticity) to a public investment shock by policy areas



Notes. Y axis–multiplier value; X axis–horizon.
Source: Authors' estimation.

Figure 7: Public investment multiplier by policy area



Notes'. The dots stand for the median (of all years and OECD countries in the sample) public investment multiplier cumulated over seven years after a one-off 1% increase in public investment in each of the policy areas. The error bars represent the interquartile range. The multiplier for each policy area should be interpreted carefully, assuming that everything else, including the deviation from the long-term cointegrating relationship between private capital and public capital in all other policy areas, remains unaltered.
Source: Authors' estimation'.

recreation, culture and religion is probably mostly associated with stimulating tourism and building new hotels, restaurants and other private amenities.

6 Conclusion

This study aims to establish whether public investment crowds in private investment, to what extent and under which conditions. We find that public and private capital are cointegrated: one percent increase in the stock of public capital is associated with 0.85 percent increase in the stock of private capital. A shock in public investment raises public capital and lowers its deviation from the long-term cointegration relationship. A 1% decline in this deviation term raises private investment by 1.7% in the following year.

We transform the obtained regression coefficients into impulse responses of private investment and public investment multipliers. Overall, the 7-year cumulative median multiplier value reaches 2, indicating that an extra dollar of public investment eventually leads to 2 additional dollars of private investment.

The crowding-in effect of public investment varies depending on the quality of institutions in a given country captured by different governance indicators. In general, improvements in institutional quality magnify the crowding-in effect, whereby improving the rule of law, general effectiveness of

the government or eliminating corruption have the largest positive effect on attracting private investment in response to a hike in public investment. Hence we confirm that the positive effect of institutional quality is not idiosyncratic to the group of developing countries, but there is a room for institutional improvements to magnify the crowding-in of private investment in industrialized economies as well.

A look at the effects of different areas of public policy suggests that investment in economic infrastructure and human capital exhibits the largest crowding-in effect.

This paper corroborates some of the results of the previous literature by providing evidence of a strong crowding-in effect, which appears significant and large in the medium and long term. It further contributes to the literature by illustrating the role of institutional factors and public policy areas. Moreover, it calculates public multiplier values for each OECD country in the sample.

There are two possible directions for continuing the research on the interaction between public and private capital. First, different types of private capital can respond to a shock to public investment in a different manner. Obtaining data on private investment and the stock of capital by categories and examining the differences in their responses would facilitate practical importance of the findings. Second, public and private capital should be analyzed together with other factors including GDP, interest rates, indebtedness, etc. to understand potential second-round effects of the crowding-in effect and the impact of public and private investment on the economy.

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Appendices

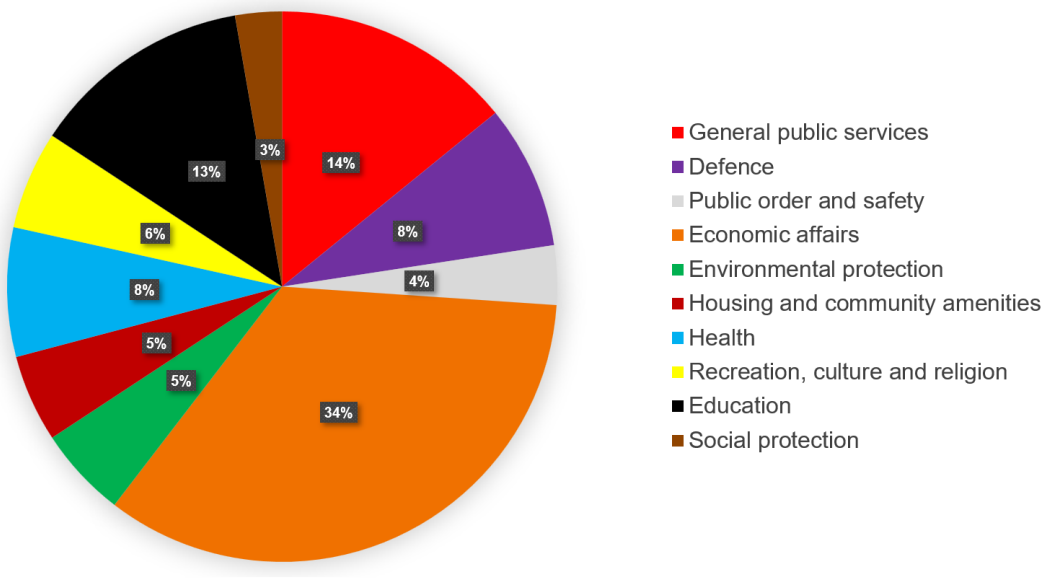
A Descriptive statistics

Table A.1: Summary statistics of key variables and their ratios

	Year	p10	Median	Mean	p90
Public investment to GDP	2000	0.0220	0.0324	0.0319	0.0409
	2010	0.0289	0.0400	0.0391	0.0498
	2017	0.0198	0.0335	0.0342	0.0462
Private investment to GDP	2000	0.1573	0.1899	0.1891	0.2273
	2010	0.1287	0.1629	0.1636	0.1946
	2017	0.1501	0.1809	0.1848	0.2167
Public investment to private investment	2000	0.1157	0.1730	0.1699	0.2241
	2010	0.1372	0.2452	0.2477	0.3450
	2017	0.1190	0.1884	0.1979	0.2828
Public capital to GDP	2000	0.3949	0.5085	0.5533	0.7363
	2010	0.4329	0.5639	0.5956	0.7406
	2017	0.4221	0.5896	0.5860	0.7055
Private capital to GDP	2000	1.5148	1.8894	1.9248	2.4409
	2010	1.7114	2.1346	2.0799	2.3574
	2017	1.6200	2.0161	1.9722	2.2865
Public capital to private capital	2000	0.2110	0.2696	0.2933	0.4566
	2010	0.2162	0.2723	0.2893	0.3711
	2017	0.2139	0.2940	0.2997	0.4125
Long-term real interest rate (%)	2000	-7.25	2.18	0.40	4.52
	2010	-0.30	2.36	2.83	5.31
	2017	-2.14	-0.30	-0.16	1.56
Debt to GDP (%)	2000	16.68	50.39	51.88	105.83
	2010	29.69	59.40	68.36	119.20
	2017	34.24	61.17	72.36	126.14

Sources: OECD (OECD.Stat database), IMF (Investment and Capital Stock dataset.)

Figure A.1: Public investment by COFOG categories, historical averages



Note. Policy areas on the chart are in the same order as on the legend.

Figure A.2: Governance indicators by countries in 2019 (blue bars) and their change since 2005 (gray numbers with arrows)

2019	Voice and accountability		Political stability		Government effectiveness		Regulatory quality		Rule of law		Control of corruption	
Austria	93.6	▲ 3.2	82.9	▼ -3.6	91.8	▬ -0.8	91.3	▼ -3.8	97.1	▬ -0.5	90.9	▼ -4.3
Belgium	95.6	▲ 4.2	61.9	▼ -8.5	80.8	▼ -12.4	87.5	▬ 0.2	88.5	▬ 0.4	91.3	▬ 1.1
Czechia	77.8	▬ 1.9	80.5	▲ 2.8	78.4	▬ 1.4	86.5	▲ 6.1	81.7	▲ 2.3	68.8	▬ 0.5
Denmark	98.5	▬ -1.5	83.8	▬ -1.6	99.0	▬ -0.5	92.3	▼ -5.7	98.1	▬ -1.0	97.6	▬ -1.4
Estonia	88.7	▲ 7.9	68.1	▲ 2.6	85.6	▲ 6.2	92.8	▲ 4.6	87.0	▲ 6.2	90.4	▲ 8.4
Finland	99.0	▬ -0.5	79.0	▼ -21.0	98.6	▬ -1.4	97.6	▬ -1.4	100.0	▬ 0.0	99.0	▬ -1.0
France	87.7	▼ -5.1	58.6	▬ 0.8	89.4	▼ -2.7	90.9	▲ 4.6	89.4	▬ -1.0	88.9	▬ -0.8
Germany	95.1	▬ 1.8	66.7	▼ -9.1	93.3	▲ 4.1	96.2	▲ 4.0	92.3	▬ -2.0	95.2	▬ 1.0
Greece	77.3	▼ -6.3	57.1	▼ -6.4	66.8	▼ -6.2	70.7	▼ -6.8	60.6	▼ -14.5	56.3	▼ -9.1
Hungary	54.7	▼ -31.9	71.4	▼ -8.7	70.2	▼ -4.3	72.6	▼ -6.8	68.3	▼ -10.7	57.7	▼ -14.5
Ireland	94.6	▼ -3.0	82.4	▼ -11.8	86.5	▼ -7.1	93.3	▬ 1.6	88.9	▼ -3.4	89.4	▼ -2.8
Italy	79.8	▬ -1.9	61.0	▼ -2.2	69.2	▬ -0.4	76.9	▬ -1.0	61.5	▼ -2.6	62.0	▼ -5.3
Korea, Rep.	72.9	▬ 1.3	61.4	▬ -1.2	88.5	▲ 8.1	82.2	▲ 10.2	86.1	▲ 3.8	76.9	▲ 5.2
Latvia	74.4	▲ 2.3	60.0	▼ -11.4	83.7	▲ 13.6	83.7	▲ 7.2	80.8	▲ 12.8	68.3	▲ 2.4
Lithuania	81.8	▲ 7.3	75.2	▲ 5.8	81.3	▲ 6.3	83.2	▲ 4.7	81.3	▲ 12.4	74.5	▲ 9.6
Luxembourg	96.6	▬ 0.4	95.7	▬ 0.6	95.7	▬ 0.1	95.2	▼ -2.4	95.7	▬ -1.0	98.1	▲ 5.4
Netherlands	97.5	▬ -1.5	75.7	▼ -3.4	96.6	▬ -1.4	98.1	▬ -0.5	96.2	▬ 0.5	96.6	▬ 0.5
Poland	70.9	▼ -7.4	64.3	▲ 7.5	73.1	▲ 4.9	81.3	▲ 8.7	66.3	▲ 3.7	71.2	▲ 7.7
Portugal	89.2	▼ -2.7	91.0	▲ 10.4	84.1	▬ 0.8	77.9	▼ -9.9	84.6	▼ -2.5	77.4	▼ -5.0
Slovakia	75.4	▬ 1.3	72.4	▼ -4.3	74.0	▼ -3.4	79.8	▼ -4.0	71.2	▲ 5.6	64.4	▼ -4.4
Slovenia	80.8	▼ -2.4	73.8	▼ -12.1	82.2	▲ 6.2	80.3	▲ 4.8	84.1	▲ 3.8	80.3	▬ 0.3
United Kingdom	90.6	▬ -1.7	63.8	▲ 12.8	90.4	▼ -4.7	93.8	▼ -2.8	91.3	▬ -0.5	93.8	▬ -0.9

Source: Worldwide Governance Indicators database.

B The role of institutions

Table B.1: Coefficient estimates of private investment regressions interacted with Control of corruption index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.067	0.002	-0.029	0.035	0.016	-0.089*	-0.084
	(2.00)	(0.05)	(-0.83)	(0.82)	(0.47)	(-2.39)	(-1.52)
D.Ln(GDP)	0.635*	-0.835*	-0.560	-0.002	-0.033	0.073	0.050
	(2.16)	(-2.33)	(-1.29)	(-0.01)	(-0.09)	(0.26)	(0.21)
D.Interest rate	-0.003*	-0.002	0.001	0.001	0.002	0.000	-0.002
	(-2.63)	(-1.94)	(1.00)	(0.40)	(1.50)	(0.01)	(-1.79)
D.Debt	-0.004*	-0.003*	-0.001	0.002	0.002	0.003	0.003
	(-2.70)	(-2.81)	(-1.59)	(1.94)	(1.79)	(2.10)	(1.65)
D.Deviation × CCE low	-0.608	0.573	-0.260	-0.839	-0.379	0.426	-0.462
	(-1.14)	(0.73)	(-0.48)	(-0.95)	(-0.49)	(0.77)	(-0.70)
D.Deviation × CCE high	-2.746*	-1.906	-1.563	-0.297	0.066	0.374	0.485
	(-2.38)	(-1.82)	(-1.57)	(-0.61)	(0.12)	(0.44)	(1.07)
Constant	0.015	0.049***	0.040**	0.020	0.019	0.018	0.018
	(1.48)	(7.00)	(3.61)	(1.44)	(1.51)	(1.21)	(0.93)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll–Kraay standard errors.
CCE stands for Control of corruption index.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.2: Coefficient estimates of private investment regressions interacted with Government effectiveness index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.068*	0.006	-0.027	0.036	0.018	-0.086*	-0.084
	(2.12)	(0.18)	(-0.76)	(0.83)	(0.52)	(-2.29)	(-1.54)
D.Ln(GDP)	0.627*	-0.852*	-0.567	0.0023	-0.030	0.069	0.054
	(2.10)	(-2.31)	(-1.29)	(0.01)	(-0.08)	(0.25)	(0.23)
D.Interest rate	-0.003*	-0.002	0.001	0.000	0.002	-0.000	-0.002
	(-2.54)	(-1.94)	(0.98)	(0.39)	(1.51)	(-0.01)	(-1.75)
D.Debt	-0.004*	-0.003**	-0.001	0.002	0.002	0.003*	0.003
	(-2.60)	(-3.07)	(-1.85)	(1.98)	(1.94)	(2.13)	(1.64)
D.Deviation × GEE low	-1.427**	0.682	0.313	-1.177	-1.325	-0.639	-0.207
	(-3.55)	(0.64)	(0.46)	(-1.19)	(-1.69)	(-0.91)	(-0.34)
D.Deviation × GEE high	-2.003*	-2.110*	-2.082	-0.014	0.846	1.228	0.276
	(-2.26)	(-2.73)	(-2.03)	(-0.03)	(1.54)	(1.75)	(0.72)
Constant	0.015	0.049***	0.040**	0.020	0.019	0.018	0.018
	(1.48)	(7.36)	(3.71)	(1.39)	(1.48)	(1.19)	(0.92)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll–Kraay standard errors.
GEE stands for Government effectiveness index.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.3: Coefficient estimates of private investment regressions interacted with political Stability and absence of violence index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.067*	0.001	-0.032	0.036	0.020	-0.085*	-0.087
	(2.09)	(0.03)	(-0.91)	(0.81)	(0.56)	(-2.37)	(-1.54)
D.Ln(GDP)	0.629*	-0.857*	-0.586	0.010	0.001	0.092	0.049
	(2.13)	(-2.33)	(-1.34)	(0.03)	(0.00)	(0.33)	(0.21)
D.Interest rate	-0.003*	-0.002	0.001	0.001	0.003	0.000	-0.002
	(-2.48)	(-1.94)	(0.87)	(0.41)	(1.56)	(0.08)	(-1.79)
D.Debt	-0.004*	-0.003**	-0.001	0.002	0.003*	0.003	0.003
	(-2.68)	(-3.14)	(-1.91)	(1.99)	(2.18)	(2.04)	(1.67)
D.Deviation ×PVE low	-1.727	-0.037	0.211	-1.013	-1.843**	-0.722	0.451
	(-1.60)	(-0.04)	(0.31)	(-1.58)	(-3.25)	(-0.98)	(0.96)
D.Deviation × PVE high	-1.699***	-1.468	-2.168	-0.085	1.511*	1.455	-0.298
	(-4.03)	(-1.78)	(-1.74)	(-0.15)	(2.19)	(1.30)	(-0.59)
Constant	0.015	0.049***	0.042***	0.019	0.017	0.017	0.019
	(1.37)	(7.55)	(4.00)	(1.41)	(1.35)	(1.05)	(0.97)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll–Kraay standard errors
PVE stands for Political Stability and Absence of Violence index
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.4: Coefficient estimates of private investment regressions interacted with Rule of law index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.070*	0.008	-0.023	0.034	0.015	-0.089*	-0.085
	(2.12)	(0.26)	(-0.71)	(0.79)	(0.42)	(-2.38)	(-1.54)
D.Ln(GDP)	0.627*	-0.845*	-0.562	-0.003	-0.034	0.069	0.053
	(2.11)	(-2.36)	(-1.30)	(-0.01)	(-0.09)	(0.25)	(0.23)
D.Interest rate	-0.003*	-0.002	0.001	0.000	0.002	-0.000	-0.002
	(-2.59)	(-1.79)	(1.01)	(0.37)	(1.50)	(-0.04)	(-1.83)
D.Debt	-0.004*	-0.003*	-0.001	0.002	0.002	0.003	0.003
	(-2.69)	(-2.84)	(-1.53)	(2.07)	(1.74)	(2.04)	(1.66)
D.Deviation × RLE low	-0.471	1.510	0.891	-1.976	-1.461	-0.457	-0.249
	(-0.62)	(1.35)	(1.27)	(-1.40)	(-1.29)	(-0.57)	(-0.25)
D.Deviation × RLE high	-2.984*	-2.980*	-2.645	0.742	1.050	1.159	0.340
	(-2.23)	(-2.33)	(-1.89)	(1.04)	(1.40)	(1.11)	(0.47)
Constant	0.014	0.047***	0.0386**	0.021	0.020	0.019	0.012
	(1.37)	(6.37)	(3.43)	(1.60)	(1.71)	(1.31)	(0.99)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll–Kraay standard errors.
RLE stands for Rule of law index.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.5: Coefficient estimates of private investment regressions interacted with Regulatory quality index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.lngovinvreal	0.068	0.007	-0.028	0.026	0.006	-0.092*	-0.086
	(2.05)	(0.20)	(-0.83)	(0.65)	(0.17)	(-2.22)	(-1.52)
D.lngdpreal	0.623*	-0.862*	-0.567	0.020	-0.008	0.079	0.057
	(2.12)	(-2.36)	(-1.29)	(0.06)	(-0.02)	(0.29)	(0.24)
D.ilongreal	-0.003*	-0.002	0.001	0.000	0.002	-0.000	-0.002
	(-2.54)	(-1.93)	(1.05)	(0.37)	(1.45)	(-0.02)	(-1.77)
D.debt	-0.004*	-0.003**	-0.001	0.002	0.002	0.003	0.003
	(-2.58)	(-3.06)	(-1.76)	(1.99)	(1.95)	(2.09)	(1.64)
D.Residuals × RQE low	-1.406	0.503	-0.627	-1.993	-1.749	-0.128	-0.0656
	(-2.00)	(0.57)	(-0.98)	(-1.91)	(-1.88)	(-0.18)	(-0.11)
D.Residuals × RQE high	-2.043*	-2.006	-1.275	0.910	1.469*	0.913	0.189
	(-2.51)	(-2.01)	(-1.31)	(1.76)	(2.12)	(0.81)	(0.39)
Constant	0.015	0.049***	0.040**	0.019	0.019	0.018	0.018
	(1.50)	(7.69)	(3.69)	(1.39)	(1.50)	(1.21)	(0.93)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll–Kraay standard errors.
RQE stands for Regulatory Quality index.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.6: Coefficient estimates of private investment regressions interacted with Voice and accountability index

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.069*	0.004	-0.030	0.035	0.017	-0.089*	-0.085
	(2.15)	(0.13)	(-0.89)	(0.80)	(0.46)	(-2.32)	(-1.56)
D.Ln(GDP)	0.628*	-0.843*	-0.562	-0.001	-0.032	0.077	0.055
	(2.10)	(-2.29)	(-1.29)	(-0.00)	(-0.09)	(0.27)	(0.24)
D.Interest rate	-0.003*	-0.002	0.001	0.001	0.002	0.000	-0.002
	(-2.59)	(-1.97)	(1.05)	(0.40)	(1.51)	(0.01)	(-1.73)
D.Debt	-0.004*	-0.003**	-0.001	0.002	0.002	0.003*	0.003
	(-2.57)	(-3.06)	(-1.73)	(1.97)	(1.87)	(2.15)	(1.65)
D.Deviation × VAE low	-1.069**	0.008	-0.885	-1.303	-0.254	1.108	0.029
	(-2.96)	(0.01)	(-1.34)	(-1.40)	(-0.40)	(1.74)	(0.04)
D.Deviation × VAE high	-2.581*	-1.673*	-1.028	0.387	0.005	-0.451	0.105
	(-2.40)	(-2.21)	(-0.87)	(0.58)	(0.01)	(-0.57)	(0.16)
Constant	0.015	0.048***	0.040**	0.020	0.019	0.018	0.018
	(1.46)	(7.11)	(3.68)	(1.41)	(1.50)	(1.21)	(0.93)
Observations	662	658	625	592	559	526	493

t statistics in parentheses, based on Driscoll–Kraay standard errors.
VAE stands for Voice and accountability index.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C Investment multiplier

C.1 Deriving the impulse response

Here we demonstrate the derivation of the impulse response functions of public capital, private investment and private capital to a public investment shock.

As in the example in Section 5.1, X denotes a variable without a shock and $\hat{X}$ the same variable after a shock. c_{it} denotes a shock to public investment for country i in year t, so that $\hat{I}^G_{it} = I^G_{it} \cdot c_{it}$. ψ, φ and ξ denote the response of respectively public capital, private investment and private capital to a public investment shock.

$$\begin{aligned} \hat{K}^G_{it} &= K^G_{it} \cdot \psi_{it} \quad & ln\hat{K}^G_{it} &= lnK^G_{it} + \psi_{it} \\ \hat{I}^P_{it} &= I^P_{it} \cdot \varphi_{it} & ln\hat{I}^P_{it} &= lnI^P_{it} + \varphi_{it} \\ \hat{K}^P_{it} &= K^G_{it} \cdot \xi_{it} & ln\hat{K}^P_{it} &= lnK^P_{it} + \xi_{it} \end{aligned} \tag{12}$$

Capital stock in year $t+1$ can be expressed as a function of capital stock in year t, investment in year t and the average depreciation rate over the same year n year t:

$$K_{t+1} = (1 - \delta_t) \cdot K_t + \left(1 - \frac{\delta_t}{2}\right) \cdot I_t$$

ψ_{it+1} can be calculated using such a relationship for public capital, public investment and c_{it}:

$$\psi_{it+1} = \frac{\hat{K}^G_{it+1}}{K^G_{it+1}} = \frac{(1 - \delta^G_{it}) \cdot \hat{K}^G_{it} + \left(1 - \frac{\delta^G_{it}}{2}\right) \cdot \hat{I}^G_{it}}{(1 - \delta^G_{it}) \cdot K^G_{it} + \left(1 - \frac{\delta^G_{it}}{2}\right) \cdot I^G_{it}} = \frac{(1 - \delta^G_{it}) \cdot K^G_{it} \cdot c_{it} + \left(1 - \frac{\delta^G_{it}}{2}\right) \cdot \hat{I}^G_{it} \cdot c_{it}}{(1 - \delta^G_{it}) \cdot K^G_{it} + \left(1 - \frac{\delta^G_{it}}{2}\right) \cdot I^G_{it}} \tag{13}$$

Similarly for private capital, a change in stocks can be calculated as follows:

$$\xi_{it+1} = \frac{\hat{K}^P_{it+1}}{K^P_{it+1}} = \frac{(1 - \delta^P_{it}) \cdot \hat{K}^P_{it} + \left(1 - \frac{\delta^P_{it}}{2}\right) \cdot \hat{I}^P_{it}}{(1 - \delta^P_{it}) \cdot K^P_{it} + \left(1 - \frac{\delta^P_{it}}{2}\right) \cdot I^P_{it}} = \frac{(1 - \delta^P_{it}) \cdot K^P_{it} \cdot \xi_{it} + \left(1 - \frac{\delta^P_{it}}{2}\right) \cdot \hat{I}^P_{it} \cdot \varphi_{it}}{(1 - \delta^P_{it}) \cdot K^P_{it} + \left(1 - \frac{\delta^P_{it}}{2}\right) \cdot I^P_{it}} \tag{14}$$

As mentioned in Section 5.1, we assume that private investment evolves according to equation 4 with an input from equation 3, which updates the deviation from the long-run relationship between public and private capital. For periods longer than one year after the initial shock, the recursive method is used, meaning that estimates of private investment for each following year are obtained using point estimates of private investment and capital for previous periods. Respectively, stocks of public and private capital for next year are updated accordingly.

Period t. There are no changes in private investment, since we estimate equation 4 for time periods starting with $h = 1$, *i.e.* $t + 1$.

Period $t+1$. As private investment was not affected in year t, the stock of private capital at the beginning of year $t+1$ stays the same. Public capital following the shock to public investment in year t changes by ψ_{it+1}, as shown in equation 13.
The changed stock of public capital affects the relationship between public and private capital.

$$ln\hat{K}^P_{it+1} = \alpha_0 + \vartheta_i + \alpha_1 \cdot ln\hat{K}^G_{it+1} + \hat{u}_{it+1}$$

By expressing public capital after the shock through its value a year ago and the impulse response we obtain:

$$lnK^P_{it+1} = \alpha_0 + \vartheta_i + \alpha_1 \cdot lnK^G_{it+1} + \alpha_1 \cdot \psi_{it+1} + \hat{u}_{it+1} \tag{15}$$

The deviation term following the shock is then as follows:

$$\hat{u}_{it+1} = u_{it+1} - \alpha_1 \psi_{it+1} \tag{16}$$

The response of private investment is:

$$\Delta ln\hat{I}^P_{it+1} = \beta_0 + \mu_i + \beta_1 \Delta ln\hat{I}^G_{it} + \beta_2 \Delta\hat{u}_{it} + \sum_k \beta_k X^k_{it}$$

To find the difference in private investment after the shock vs the baseline scenario (without a shock), we note that:

$$\Delta ln\hat{I}^P_{it+1} - \Delta lnI^P_{it+1} = (ln\hat{I}^P_{it+1} - ln\hat{I}^P_{it}) - (lnI^P_{it+1} - lnI^P_{it}) \tag{17}$$

which yields:

$$\Delta ln\hat{I}^P_{it+1} - \Delta lnI^P_{it+1} = ln\hat{I}^P_{it+1} - lnI^P_{it+1} \tag{18}$$

and results in the impulse response of private investment:

$$ln\hat{I}^P_{it+1} - lnI^P_{it+1} = \beta_1 \left(\hat{I}^G_{it} - I^G_{it}\right) + \beta_2 \left(\hat{u}_{it} - u_{it}\right) = \beta_1 c_{it} \tag{19}$$

Period $t+2$. A change of private investment in $t+1$ affects the stock of private capital at the beginning of year $t+2$. The relative difference between private capital before and after the shock is represented by ξ_{it+2}, which is calculated using equation 14.

Public capital in $t+2$ after the shock to public investment evolves according to equation 13 for $t+2$. As discussed previously, there could have been another shock c_{it+1} that affects it, or the shock was temporary and $c_{it+1} = 0$.

The long-run relationship between public and private capital is now affected due to changes in stocks of both public and private capital.

$$ln\hat{K}^P_{it+2} = \alpha_0 + \vartheta_i + \alpha_1 \cdot ln\hat{K}^G_{it+2} + \hat{u}_{it+2}$$

$$lnK^P_{it+2} + \xi_{it+2} = \alpha_0 + \vartheta_i + \alpha_1 \cdot lnK^G_{it+2} + \alpha_1 \cdot \psi_{it+2} + \hat{u}_{it+2} \tag{20}$$

$$\hat{u}_{it+2} = u_{it+2} - \alpha_1 \psi_{it+2} + \xi_{it+2} \tag{21}$$

For the direct relationship between private and public investment (equation 4) for $t+2$, we must be able to express $\Delta\hat{u}_{it+2}$ from its value in the baseline scenario and impulse responses. We use equations 16 and 21 to obtain the result.

$$\Delta\hat{u}_{it+2} = \hat{u}_{it+2} - \hat{u}_{it+1} = (u_{it+2} - \alpha_1\psi_{it+2} + \xi_{it+2}) - (u_{it+1} - \alpha_1\psi_{it+1}) \tag{22}$$

which finally yields

$$\Delta\hat{u}_{it+2} = (u_{it+2} - u_{it+1}) - \alpha_1(\psi_{it+2} - \psi_{it+1}) + \xi_{it+2}$$

or, since $\xi_{it+1} = 0$:

$$\Delta\hat{u}_{it+2} = \Delta u_{it+2} - \alpha_1 \Delta\psi_{it+2} + \Delta\xi_{it+2} \tag{23}$$

Periods $t+v$. ψ_{it+v} and ξ_{it+v} are calculated using the values of respectively public capital, public investment, private capital and in the previous year using equations 13 and 14.

By subtracting equation 3 evaluated after the shock from itself in a baseline scenario, $\hat{u}_{it+v}$ is expressed, from which we obtain the term representing the difference in the deviation from the long-run relationship between private and public capital

$$\Delta\hat{u}_{it+v} = \Delta u_{it+v} + \Delta\xi_{it+v} - \alpha_1\Delta\psi_{it+v} \tag{24}$$

and use it in equation 4 to get the direct response of private investment from public investment.

Summary. Therefore, after any shock to public investment that starts at t, the impulse response of private investment, private capital and public capital at any point in time $t+v$ can be expressed in a recursive manner as follows:

$$\begin{aligned}
\psi_{it+v} &= \frac{\hat{K}^G_{it+v}}{K^G_{it+v}} = \frac{(1-\delta^G_{it+v-1})\cdot K^G_{it+v-1}\cdot\psi_{it+v-1} + \left(1-\frac{\delta^G_{it+v-1}}{2}\right)\cdot I^G_{it+v-1}\cdot c_{it+v-1}}{(1-\delta^G_{it+v-1})\cdot K^G_{it+v-1} + \left(1-\frac{\delta^G_{it+v-1}}{2}\right)\cdot I^G_{it+v-1}} \\
\xi_{it+v} &= \frac{\hat{K}^P_{it+v}}{K^P_{it+v}} = \frac{(1-\delta^P_{it+v-1})\cdot K^P_{it+v-1}\cdot\xi_{it+v-1} + \left(1-\frac{\delta^P_{it+v-1}}{2}\right)\cdot I^P_{it+v-1}\cdot\varphi_{it+v-1}}{(1-\delta^P_{it+v-1})\cdot K^P_{it+v-1} + \left(1-\frac{\delta^P_{it+v-1}}{2}\right)\cdot I^P_{it+v-1}} \\
\varphi_{it+v} &= \beta_1 c_{it+v-1} - \beta_2\alpha_1\psi_{it+v-1} + \beta_2\xi_{it+v-1}
\end{aligned} \tag{25}$$

These formulas allow us to perform counterfactual analysis of any scenario of shocks to public investment: for any country i, given the historical data on private and public investment and capital I^P_{it}, K^P_{it}, I^G_{it}, K^G_{it} for $\forall t$ and a vector of shocks to public investment c_{it}, c_{it+1}, c_{it+2}, ... starting at any t, we can, by using the three formulas (25), reconstruct the relative differences of public capital, private capital and private investment to the counterfactual values and in this way obtain their values in the alternative scenario.

Note on limitations. Another crucial assumption we are implicitly making in these calculations is that none of the control variables are affected by the shock to private investment. This is clearly a stricter assumption because:

1. An increase in public investment implies higher demand for capital, which likely leads to an increase in interest rates provided there has not been slack in the economy before the shock;

2. Public investment counts towards GDP, so GDP is likely to go up, especially considering our results that show that even if the crowding-out effect exists in the same period, its magnitude is likely insignificant;

3. The increase in public investment can be financed either by higher tax revenue due to more economic activity, or by higher tax revenue due to higher taxes, or by increasing government debt, or by a combination of these. Therefore, the debt-to-GDP ratio is likely to increase as a result of a positive shock to public investment, and other changes to the economy are likely.

However, we cannot reliably show how considering these changes would affect the results, because to demonstrate it, we would have to engage in estimation of the impact of extra public and private investment on the whole economy, which is beyond the scope of this paper.

C.2 Public investment multipliers for different countries and model specifications

Table C.1: Impulse response to a 1% public investment shock in 2010

Country	2011	2012	2013	2014	2015	2016	2017
Austria	0.0673	0.0754	0.0630	0.0504	0.0402	0.0324	0.0264
Belgium	0.0673	0.0756	0.0622	0.0485	0.0381	0.0298	0.0234
Canada	0.0673	0.1254	0.1050	0.0769	0.0553	0.0409	0.0315
Czechia	0.0673	0.1114	0.0937	0.0721	0.0556	0.0428	0.0317
Denmark	0.0673	0.0636	0.0526	0.0423	0.0340	0.0273	0.0220
Estonia	0.0673	0.1067	0.0872	0.0604	0.0406	0.0282	0.0202
Finland	0.0673	0.0771	0.0636	0.0499	0.0393	0.0312	0.0253
France	0.0673	0.0805	0.0672	0.0530	0.0419	0.0335	0.0274
Germany	0.0673	0.0647	0.0530	0.0426	0.0345	0.0282	0.0233
Greece	0.0673	0.0772	0.0689	0.0617	0.0552	0.0493	0.0438
Hungary	0.0673	0.1109	0.0947	0.0745	0.0560	0.0394	0.0256
Iceland	0.0673	0.0646	0.0555	0.0472	0.0398	0.0328	0.0265
Ireland	0.0673	0.1070	0.0927	0.0733	0.0579	0.0445	0.0321
Israel	0.0673	0.0799	0.0633	0.0455	0.0320	0.0233	0.0177
Italy	0.0673	0.0808	0.0689	0.0574	0.0484	0.0411	0.0350
Japan	0.0673	0.0396	0.0305	0.0252	0.0211	0.0178	0.0153
Korea	0.0673	0.1157	0.0953	0.0690	0.0486	0.0350	0.0259
Latvia	0.0673	0.1511	0.1252	0.0885	0.0619	0.0430	0.0294
Lithuania	0.0673	0.1529	0.1280	0.0958	0.0690	0.0493	0.0353
Luxembourg	0.0673	0.1382	0.1152	0.0817	0.0567	0.0390	0.0276
Mexico	0.0673	0.0638	0.0513	0.0402	0.0324	0.0267	0.0227
Netherlands	0.0673	0.0862	0.0725	0.0583	0.0470	0.0383	0.0303
New Zealand	0.0673	0.0753	0.0607	0.0457	0.0336	0.0251	0.0197
Norway	0.0673	0.1051	0.0879	0.0657	0.0474	0.0344	0.0256
Poland	0.0673	0.1377	0.1120	0.0786	0.0545	0.0373	0.0262
Portugal	0.0673	0.1142	0.1012	0.0871	0.0754	0.0654	0.0563
Slovakia	0.0673	0.1058	0.0882	0.0690	0.0533	0.0401	0.0264
Slovenia	0.0673	0.1231	0.1072	0.0876	0.0702	0.0554	0.0438
Spain	0.0673	0.1116	0.0975	0.0816	0.0689	0.0582	0.0487
Sweden	0.0673	0.0857	0.0708	0.0546	0.0419	0.0322	0.0249
Switzerland	0.0673	0.0787	0.0643	0.0489	0.0370	0.0284	0.0222
United Kingdom	0.0673	0.1057	0.0909	0.0727	0.0574	0.0446	0.0346
United States	0.0673	0.0848	0.0710	0.0552	0.0426	0.0332	0.0263

Interpretation. The figures show the percentage by which private investment would have increased in each country and year relative to their historical values if public investment in the respective country had been by 1% higher than its historical value in 2010.

Table C.2: Public investment multiplier for a 7-year horizon by countries and model specifications

	All coefficients			With $\beta_1 = 0$		
Country	2000-2007	2010-2017	2010-2017*	2000-2007	2010-2017	2010-2017*
Austria	2.287	2.247	2.148	2.015	2.041	2.087
Belgium	3.037	3.276	3.072	2.776	2.981	2.992
Canada	2.412	2.217	2.053	2.263	2.100	2.028
Czechia	2.591	2.144	2.008	2.413	2.006	1.972
Denmark	1.664	1.507	1.423	1.488	1.359	1.380
Estonia	2.922	2.155	1.920	2.850	2.018	1.890
Finland	2.080	1.816	1.730	1.907	1.630	1.670
France	1.743	1.674	1.592	1.604	1.526	1.549
Germany	2.335	2.513	2.387	2.031	2.249	2.308
Greece	2.040	0.779	0.829	1.942	0.639	0.755
Hungary	3.467	2.196	2.087	3.308	2.046	2.044
Iceland	2.071	1.638	1.588	2.003	1.529	1.559
Ireland	3.479	3.353	2.782	3.389	3.292	2.782
Israel	2.569	3.331	2.874	2.371	3.100	2.830
Italy	2.536	1.923	1.940	2.330	1.703	1.853
Japan	.	1.116	1.036	.	0.950	0.985
Korea	2.921	2.410	2.095	2.816	2.288	2.070
Latvia	4.247	2.375	2.267	4.032	2.253	2.233
Lithuania	3.209	2.101	1.921	3.041	2.019	1.903
Luxembourg	1.833	1.847	1.638	1.705	1.768	1.625
Mexico	.	2.192	2.022	.	1.992	1.976
Netherlands	1.802	1.580	1.516	1.647	1.449	1.478
New Zealand	1.721	1.529	1.318	1.595	1.436	1.299
Norway	2.084	2.067	1.916	1.943	1.938	1.884
Poland	1.556	1.550	1.347	1.415	1.486	1.337
Portugal	2.094	1.428	1.481	1.939	1.316	1.437
Slovakia	2.602	2.347	2.226	2.379	2.164	2.173
Slovenia	2.839	1.642	1.667	2.688	1.514	1.619
Spain	2.726	1.860	1.890	2.591	1.731	1.846
Sweden	1.674	1.701	1.563	1.531	1.576	1.534
Switzerland	2.816	2.811	2.564	2.576	2.588	2.507
United Kingdom	2.546	2.179	2.106	2.236	2.046	2.067
United States	1.985	1.651	1.529	1.852	1.543	1.504

Notes. The third and six column present the public investment multiplier evaluated with coefficients estimated on a sample from 2008 to 2017.