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journal homepage: www.elsevier.com/locate/ejpeInvest one – get two extra: Public investment crowds in private investment[☆]Olegs Matvejevs^{*}, Olegs Tkacevs

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ABSTRACT

This study uses panel econometric methods to explore the relationship between public and private investment in a sample of 34 industrialized economies of the OECD over the period between 1995 and 2019. It aims to establish whether public investment crowds in private investment, to what extent, and in which public policy areas the effect is stronger. The estimation results demonstrate that in the medium to long-term, extra public investment crowds in private investment as the latter adjusts to bring the stock of private capital closer to its long-term cointegrating relationship with public capital. The long-run public investment multiplier is around 2, which means that each additional dollar of public investment eventually attracts approximately two dollars of private investment. Public investment in economic affairs and infrastructure needed to improve human capital is the most effective in attracting private investment.

1. Introduction

Accumulation of public capital is an important engine of economic growth (Abiad et al. (2016); Berg et al. (2012); Mourougane et al. (2016)). Over the past several decades, and especially in the aftermath of the Great Recession, there has been a significant decline in public investment ratio.¹ It left scars on economic growth, as GDP growth rates remained subdued for several years after the crisis.² 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 digitalization and the post-Covid recovery. Additional public investment in energy, telecommunications and infrastructure could encourage the private sector to accelerate private capital accumulation. In this paper, we

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¹ In advanced economies, public investment has declined from the average of 2.4 percent of GDP in the 1990s to a historic low of less than 2 percent after 2010 (Miyamoto et al. (2020)).

² For the discussion of the post-crisis sluggish recovery see e.g. IMF (2018).

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study the relationship between public and private investment using a sample of advanced OECD economies and analyze the presence and the magnitude of the crowding-in effect, i.e. whether government investment attracts private investment and how strong this effect is.

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 is usually strong 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 empirically 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 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 recent review of fiscal policy studies published after the financial crisis, [Ramey \(2019\)](#) pointed out that there has been surprisingly little evidence on the macroeconomic effects of public investment. He emphasized that the literature needs to focus on both the short-run and the longrun effects of infrastructure investment. In this study, we aim to fill this gap. Our objective is to contribute to the existing literature by examining the relationship between public and private investment from several perspectives. First, we investigate the possibility that public investment in specific areas is more successful in raising private capital productivity. Thus, for consumption [Jalles and Karras \(2022\)](#) demonstrate that the degree of complementarity between private and public consumption differs substantially across different spending categories. Second, we provide estimates of the public investment multiplier, which has been absent in the previous literature. To achieve the outlined goals, we examine the relationship between private and public investment in OECD economies over the period between 1995 and 2019.

The results obtained in this paper provide 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 (hikes) lead to a decline (increase) in private investment. Furthermore, our findings suggest that in absolute terms private investment increases by more than one-to-one for each additional euro or dollar spent on public capital. The median value of the public investment multiplier reaches the value of 2 five-to-seven years after a public investment shock and exceeds 2 in an even longer term. Economic affairs and education are the areas where public investment is estimated to exhibit the strongest crowding-in effect, followed by recreation, culture and religion.

The findings of this paper suggest that insufficient government investment strongly depresses private investment and inhibits economic growth in the long-term. From the economic policy perspective it provides justification for fiscal rules to treat public investment in a different way as compared to other government spending items.

The rest of the paper is structured as follows. Section 2 discusses the previous literature. Section 3 lays down the methodology of the study and the data used. Section 4 presents the estimation results of private investment regressions. Section 5 provides robustness analysis of the obtained results, while Section 6 transforms the obtained regression coefficients into impulse responses of private investment to public investment and the public investment multiplier. Finally, Section 7 concludes.

2. Literature review

The analytical framework laid out by [Aschauer \(1989\)](#) spurred considerable interest in the interaction 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. Additional evidence on the crowding-in effect was reported in [Erenburg \(1993\)](#) for the US, [Hatano \(2010\)](#) for Japan, [Eden and Kraay \(2016\)](#) for 39 low-income countries. The crowding-in or complementarity was also recently shown by [Soete et al. \(2022\)](#) to exist between public and private R&D investment in several OECD countries. In countries where this complementarity was found to be strong, the TFP effect of extra public R&D investments also appeared stronger.

[Dreger and Reimers \(2016\)](#) emphasized the importance of considering the stocks of private and public capital when studying the relationship between private and public investment. They employed 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 used the deviation of private capital from its stock equilibrium in the private investment cointegrating relationship. Finally, [Dreger and Reimers \(2016\)](#) provided estimates of the error-correction model for private investment. Private and public capital appear 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. The importance of the long-term perspective is clearly seen in the theoretical analysis of the

macroeconomic effects of public investment by Ramey (2020). He utilizes both a neoclassical model and a mediumscale Non-Keynesian model to illustrate that in the long-run, a higher level of public capital raises the marginal products of labour and private capital, which attracts private investment. In addition, Ramey (2020) shows that private investment is not crowded out on impact once the adjustment costs on investment are taken into account. Second, there are several factors which may affect the estimates. Abiad et al. (2016) find that the effect of public investment on the ratio of private investment to GDP is neutral. Since the private investment ratio is significantly larger, this implies the crowding-in effect in absolute terms. At the same time, they also offer a strong evidence in favour of the crowding-out effect 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 effect is observed in 8 countries out of 17. Using the sample of 25 developing countries, Atukeren (2005) shows that the likelihood of the presence of the crowding-out rises with the size of the government sector and capital controls, but declines with trade openness. Using US data, Pereira (2001) confirms the crowding-in effect at the aggregate level and shows that the 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. Using a sample of developing countries, they show that 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.

As this review of literature demonstrates, 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 chosen method of analysis.

3. Methodology and data

3.1. Analytical framework

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

To provide the theoretical framework of this approach, we refer to a form of the Cobb-Douglas production function³ where the stock of capital is split into private capital (K^P) and public capital (K^G):

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

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,⁴ maintaining a constant ratio (γ), one can obtain the following long-term cointegrating relationship between private and public capital:

$$K_t^P = k_t^G \frac{\beta}{\gamma \theta} \quad (2)$$

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

First, we check whether the series of public and private capital are integrated of the same order (they both are $I(2)$, see Appendix B for details) and estimate the coefficients of the long-term cointegrating relationship between private and public capital stocks:⁵

$$\ln K_{it}^P = \alpha_0 + \varphi_i + \alpha_1 \ln K_{it}^G + u_{it} \quad (3)$$

where i and t index countries and time, φ_i denotes a country fixed effect, and u_{it} is a residual term. This residual has a clear and very useful interpretation: it reflects 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

³ The Cobb-Douglas production function has been criticised in the literature. For example, Labini (1995) claims that its success is the illusion as its two exponents are incompatible with the distributive shares that the function tries to explain. In contrast, Murthy (2004) defends the use of the Cobb-Douglas function by arguing that it is possible to address almost all of its criticism.

⁴ Although this assumption of perfect capital markets is often stated without further detail, we point out that the difference between real interest rates on public and private capital should hold only in the long-term. It is reasonable to assume that the wedge between the return on stocks and government bonds is stationary over long time spans, although it can fluctuate in the medium-term. Respectively, the ratio between public and private capital is constant in the long-run but varies in the short and medium-term, which is consistent with the methodology employed in this paper.

⁵ 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 $I(1)$.

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 depends on the disequilibrium in the relationship between the two types of capital:

$$\Delta \ln I_{it+h}^P = \beta_{0h} + \mu_i + \beta_{1h} \Delta \ln I_{it}^G + \beta_{2h} \Delta u_{it} + \sum_k \beta_{kh} X_{it}^k + \varepsilon_{it} \quad (4)$$

where X is a vector of k control variables, μ_i is a country fixed effect and ε_{it} is an error term. Subscript h in Equation (4) stands for the number of periods after a public investment shock. The 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 because u_{it} and other variables contain a unit root and need to be first differenced (see Appendix B).

Following economic theory and, in particular, considering diminishing returns of the production factors, we expect coefficient β_{2h} to be negative: a positive deviation term implies an excess of private capital relative to public capital, hence it 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. It is important to highlight that β_{2h} coefficients are not impulse responses, as the response is also affected by changing levels of public and private capital. However, β_{2h} together with β_{1h} and α_1 (from Equation (3)) are key ingredients in the estimation of impulse responses and public investment multiplier performed in Section 6.

To estimate Equation (4), we employ the Jorda local projection approach proposed by Jorda (2005). We estimate individual private investment regressions H times, where the horizon H is arbitrarily chosen to be seven years in this study, i.e. $h = 1..7$. The sequence of coefficients relating private investment and the deviation from the stock equilibrium is constructed using the values of $\beta_{2h} = \frac{h}{H} = 1$. A similar approach has been widely used in the estimation of fiscal multipliers, among others by Auerbach and Gorodnichenko (2013), Auerbach and Gorodnichenko (2017), Ramey and Zubairy (2018) and Romer and Romer (2019), as it has several advantages over the STVAR or VECM approach. First, it eliminates the need to estimate a larger number of equations (for other dependent variables), thus improving the stability and precision of the estimates (less parameters to estimate). Second, 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. Third, it does not constrain the shape of the IRF. Finally, it conveniently accommodates nonlinearities, as its application is much more straightforward as compared to non-linear structural VAR models.

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). When we try to replicate what Dreger and Reimers (2016) did using their time and country sample, we conclude that 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 in the second step. 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 is also simpler. Moreover, it allows to compute impulse responses and investment multipliers, and thus provide a more straightforward and intuitive interpretation.

3.2. Data description

Our study uses annual data for the period between 1995 and 2019.⁶ The panel is based on a sample of 34 countries that are OECD member states at the time of this writing.⁷ 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, we prefer the results on the policy area impact to be based on the same source of investment data as used for studying the impact of aggregate public

⁶ The choice of 1995 as the starting year is dictated by data availability. Several data series, such as investment and interest rate start in 1995 for most countries in the sample. Importantly, public investment by COFOG is available only from 1995 for all countries.

⁷ These countries are: Australia, Austria, Belgium, Canada, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, the United States. Due to lack of data, Chile, Columbia, Costa Rica, Romania and Turkey are excluded from the sample. The last observation for Ireland was also excluded, because the value of private investment in 2019 was extreme. More detailed explanation is provided here: <https://www.worldeconomicassociation.org/newsletterarticles/gfcf-ireland/>.

investment.⁸ As the investment and capital stock data are originally nominal, we need to transform them into real values. For that purpose we use the gross fixed capital formation deflator, also taken from the OECD.Stat database. In the Robustness section, we also employ both investment and capital stock data from the IMF dataset, where these are originally given in constant 2011 international dollars.

The list of variables used in this study alongside their sources is provided in Table A1. Table A2 presents summary statistics of the data we use in the baseline estimation (including unweighted mean, median and the 10th and 90th percentiles of corresponding distributions across all countries).

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,⁹ 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.

3.3. Public investment by policy area

In addition to establishing the relationship between public and private investment on the aggregate level, we further 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 policy areas of public investment.

For this purpose, we decompose public capital and investment into 10 categories according to the Classification of the functions of government (COFOG). As mentioned above, public investment data by COFOG are taken from the OECD.Stat database.¹⁰ However, there is no official 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 2019. 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 whole period from 1995 to 2019. Using the end values for 2019 and applying a single depreciation rate of public capital,¹¹ we iterate the calculation of public capital backwards.

Fig. A1 illustrates the (unweighted) average shares of public investment by policy areas over the 1995–2019 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 policy areas receive lower shares for financing public investment.

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:

$$Y_t = A_t(L_t)^\alpha (K_t^P)^\beta \prod_{c=1}^{10} (K_t^{Gc})^{\theta^c} \quad (5)$$

where c stands for a policy area and K_t^{Gc} 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. $\beta Y_t/K_t^P$, $\theta^1 Y_t/K_t^{G1}$, $\theta^2 Y_t/K_t^{G2}$, ..., $\theta^{10} Y_t/K_t^{G10}$ 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:

$$K_t^P = K_t^{Gc} \frac{\beta}{\gamma^c \theta^c} \quad (6)$$

Therefore, we apply the two steps of the stock-flow approach to each of ten COFOG types of public capital separately. First, we follow the same approach as in Section 3.1 and estimate a cointegrating relationship between private capital and public capital in each policy area:

$$\ln K_{it}^P = \alpha_0^c + \varphi_i^c + \alpha_1^c \ln K_{it}^{Gc} + u_{it}^c \quad (7)$$

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

⁸ We use variable ‘Gross fixed capital formation’ in ‘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.

⁹ For Estonia, due to the unavailability of the long-term interest rate we use the data on the short-term interest rate. The estimation results are robust to the exclusion of Estonia from the sample.

¹⁰ In the ‘National Accounts’ section of the OECD.Stat database provides annual figures for government expenditure by OECD member country and COFOG category. For public investment in different policy areas, we use the item ‘Gross fixed capital formation’.

¹¹ 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 implausible paths of public capital.

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.

3.4. Identification of a public investment shock

It has been widely acknowledged in the literature that fiscal aggregates are endogenous to output and it is important to correctly identify a discretionary fiscal policy shock when estimating fiscal multipliers. There have been several identification strategies suggested previously:

- to use news about military spending which are widely assumed to be exogenous (Ramey (2011); Ramey and Zubairy (2018));
- to construct an instrument for government spending, such as e.g. approved loans from official creditors to finance spending projects (Kraay (2014));
- to employ a narrative approach, which was first introduced by Romer and Romer (2010), who filtered out legislative tax changes for exogenous reasons, and was later extended to study the effect of fiscal consolidation measures by Alesina et al. (2018);
- to use forecast errors, computed as the difference between forecast series taken from a survey of professional forecasters, international organizations or government projections and the actual government spending growth rate (Auerbach and Gorodnichenko (2013));
- to conduct structural VAR identification by assuming that an unexpected expenditure shock affects output within the same quarter, but the opposite effect occurs with one period lag (Blanchard and Perotti (2002)).

We believe that the issue of endogeneity is not so obvious in the case of public and private investment interaction than in the traditional fiscal multiplier literature. In the latter, the relationship between output, taxes and spending is automatic. Better economic activity automatically translates into larger tax receipts, which are at least partially spent by the government. Likewise, lower economic growth implies larger spending on unemployment benefits. Therefore, when estimating fiscal multipliers, it is vital to identify discretionary changes in taxes and expenditure brought about by changes in legislation and isolate them from endogenous fluctuations.

We believe, there is no automatic link between private and public investment. Even though governments may react pro-actively to some private investment projects expected in the future by investing in infrastructure or other types of public capital in advance, we do not believe that such government behaviour is systematic and persistent. In the previous studies of public investment many authors simply ignore the endogeneity concerns. For instance, the paper that we more closely follow methodologically (Dreger and Reimers (2016)) merely states that public investment can be considered exogenous as it is determined by government budgetary decisions. Aschauer (1989), Afonso and Aubyn (2009) as well as Voss (2002) among others also treat public investment as exogenous at least with respect to private investment. Deleidi et al. (2020) provide the most comprehensive analysis of this issue – they develop a detailed narrative discussion of the reasons for public investment exogeneity and conduct a formal econometric test to prove that. Finally, employing the stock-flow approach implies that the long-run equilibrium relationship between stocks explains private investment. This leaves less room for endogeneity in our framework.

3.5. Anticipation of public investment

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 (see e.g. Forni and Gambetti (2010) for the discussion). 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 most 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 forecasts of public investment are mostly available only for the period 2001–2009 and therefore could not be used in the baseline estimation.¹² 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 anticipate the exact amount of public investment more precisely than the forecast in the OECD's Economic Outlook. Thus, the difference between the actual public investment and its expected value becomes known only after the year has ended and

¹² Prior to 2001, the data are available only for the eight largest European countries.

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.¹³ 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 (I_{it}^G) and b) the previous year (I_{it-1}^G)

Following the outlined approach, we employ public investment forecast errors (FE, as a ratio to GDP)¹⁴ and estimate the following private investment regressions:

$$\frac{I_{it+h}^P}{Y_{it+h}} - \frac{I_{it}^P}{Y_{it}} = \beta_{0h} + \mu_i + \psi_t + \beta_{1h} \frac{FE_{it}}{Y_{it}} + \varepsilon_{it} \quad (8)$$

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

4. Estimation results

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

4.1. Baseline estimation

We begin with the cointegration analysis to establish 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.

$${}^{14}FE_{it} = I_{it}^G - I_{it}^G \text{ or } FE_{it} - I_{it}^G - I_{it-1}^G$$

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, whereas Westerlund I test tests the absence of cointegration among the variables against the alternative hypothesis of the presence of cointegration in some panels.

The results of these tests are presented in Table 1 and indicate the presence of a long-term cointegrating relationship with a high level of statistical significance. Next, we estimate the long-run parameters of this relationship using panel econometric technique with fixed effects and accounting for the possibility that the residuals are cross-sectionally correlated.¹⁵ The relationship takes the following form:

$$\ln K_{it}^P = \begin{matrix} 2.625 \\ (0.208) \end{matrix} + \begin{matrix} 0.785 \\ (0.032) \end{matrix} \ln K_{it}^G + u_{it}$$

Note: Driscoll-Kraay standard errors are presented in parentheses.

Thus, a 1% increase in the stock of public capital is associated with a 0.79% 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 an $I(1)$ process (see Appendix B). To incorporate it in the estimation of private investment regressions, it needs to be first-differenced. The estimation results of the investment regressions (Equation (4)) are reported in Table 2, but estimates of the deviation coefficient are drawn in Fig. 1. These estimates are constructed from the sequence of h private investment regressions.

We find that a deviation of private capital from the equilibrium path triggers private investment adjustment. 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. its statistical significance drops markedly in $t+2$. 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 6, we calculate impulse responses of private investment by iterating these changes forward.

Other coefficient estimates mostly have the expected signs. 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

¹³ 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 during the year in question might include revaluations of public capital, rather than only the difference between the expected and the realized amounts of public investment.

¹⁴ ${}^{14}FE_{it} = I_{it}^G - I_{it}^G$ or $FE_{it} - I_{it}^G - I_{it-1}^G$.

¹⁵ `xtsc` command in Stata, which uses Driscoll-Kraay standard errors.

Table 1
Cointegration test results.

Test	Statistic	p-value
Westerlund I (some panels are cointegrated)	-2.742	0.003
Westerlund II (all panels are cointegrated)	-2.228	0.013
Kao	5.941	0.000
Pedroni	4.376	0.003

Table 2
Coefficient estimates of private investment regressions.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.082** (0.035)	0.023 (0.021)	-0.019 (0.035)	0.096 (0.059)	0.012 (0.034)	-0.063*** (0.020)	-0.077 (0.049)
D.Ln(GDP)	0.742** (0.284)	-0.856** (0.368)	-0.642 (0.426)	-0.178 (0.405)	-0.084 (0.380)	0.087 (0.241)	0.162 (0.259)
D.Interest rate	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	0.001* (0.000)	0.000** (0.000)	0.001*** (0.000)	0.000 (0.000)
D.Debt	-0.005** (0.002)	-0.004*** (0.001)	-0.001* (0.001)	0.002*** (0.001)	0.003** (0.001)	0.003* (0.001)	0.003 (0.002)
D.Deviation	-1.857*** (0.571)	-1.313* (0.756)	-1.290 (0.852)	-0.882 (0.534)	-0.044 (0.473)	-0.179 (0.549)	-0.392 (0.440)
Constant	0.017* (0.008)	0.053*** (0.006)	0.045*** (0.011)	0.023* (0.013)	0.016 (0.011)	0.014 (0.014)	0.015 (0.018)
Observations	706	672	638	604	570	536	502

Notes. Driscoll-Kraay standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation

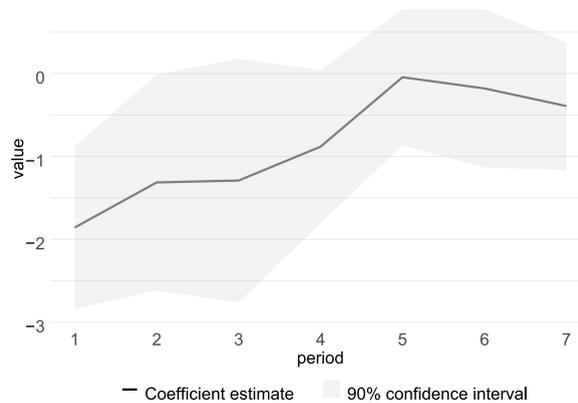


Fig. 1. Private investment reaction to the mismatch between private and public capital stocks.

Source: Authors' estimation, Note: The figure shows the point estimates of the deviation coefficient (Y-axis) for each period (X-axis) following a shock in the long-term cointegrating relationship between private and public capital. The shaded region is the 90% confidence interval constructed using Driscoll-Kraay standard errors.

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.

4.2. The 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 a cointegrating relationship between stocks of these types of public capital and private capital is mixed.¹⁶

¹⁶ Results of cointegration tests are available per request.

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_{2h}^* .

Except for the two areas, where cointegration with private capital is uncertain, public capital in all other areas is very closely related to the stock of private capital in the long-term. The cointegrating coefficient varies between 0.47 and 0.71. Economic affairs stand out as the area with the strongest cointegrating relationship, hence, any public investment in Economic affairs is likely to exhibit a stronger crowding-in effect.

The coefficient of the deviation term is estimated highest in Economic affairs and Education, indicating a faster adjustment of private capital stock to changes in public investment. For the following periods, the deviation coefficient stays negative in most cases but rarely statistically significant at the conventional level, which points to the crowding-in effect that continues for several years and becomes weaker over time.

5. 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 2008–2019. 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](#) 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, if the crisis years are dropped, the coefficient gets closer to the one obtained for the full sample. It should be noted that the direct effect of public investment is of lower statistical significance in the second period.

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.¹⁷ 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](#)). However, the direct effect of public investment becomes insignificant.

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 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 (0.788 vs 0.785), 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](#)).

Finally, we make use of the larger dataset we have at our disposal as the data for the years before 1995 are available for several countries in our sample. We re-estimate both the long-term cointegrating relationship,¹⁸ and private investment regressions.¹⁹ The cointegrating relationship between two types of capital gets closer to unity (0.942), as we would expect in a relatively long.

time span. The estimated coefficients of private investment regressions are largely in line with the results we obtained previously. The magnitude of the deviation coefficient gets somewhat lower, but the direct effect again loses its statistical significance (see [Table 7](#)).

Robustness to different regression specifications. Additionally, we replicate the estimation of private investment regressions by dropping each control variable at a time. The value of the deviation coefficient and its statistical significance remain close to the baseline estimates (see [Table 8](#)). Second, we examine whether the inclusion of lagged controls in private investment regressions.

affects the estimation results. In the baseline, we opted for a parsimonious specification which maximizes the number of observations. The magnitude of the deviation coefficient gets somewhat smaller when control variables enter Equation (4) with one period lag (with or without contemporaneous controls). Using up to four lags of controls does not affect the results markedly.²⁰

Third, we assess whether the results are robust to adding time fixed effects. The estimated deviation coefficient gets statistically significant for two more periods, which would imply a quicker return to the equilibrium.

Robustness to the alternative methodology. Finally, we assess whether our findings depend on the choice of the stock-flow

¹⁷ Detailed results are available upon request.

¹⁸ The earliest year for which we have capital data for some countries is 1960.

¹⁹ The earliest year for which we have public debt data for some countries is 1980.

²⁰ Results are available upon request.

Table 3
Coefficient estimates of private investment regressions.

Policy area	Coint. rel.	t+1	t+2	t+3	t+4	t+5	t+6	t+7
1. General public services	0.574*** (0.053)	-0.837*** (0.161)	-0.642 (0.429)	-0.810 (0.616)	-0.177 (0.324)	0.148 (0.372)	0.007 (0.299)	-0.346 (0.261)
2. Defense	0.519*** (0.035)	-0.410** (0.177)	-0.195 (0.226)	-0.154 (0.140)	0.081 (0.198)	0.023 (0.137)	0.004 (0.167)	-0.046 (0.163)
3. Public order and safety	0.632*** (0.036)	-0.959*** (0.269)	-0.891** (0.363)	-0.862 (0.587)	-0.820** (0.382)	-0.559 (0.460)	-0.308 (0.378)	-0.297 (0.411)
4. Economic affairs	0.706*** (0.040)	-1.499** (0.570)	-1.231* (0.690)	-1.084 (0.665)	-0.487 (0.367)	0.024 (0.384)	-0.218 (0.451)	-0.390 (0.415)
5. Environmental protection	0.562*** (0.052)	-0.567** (0.205)	-0.110 (0.301)	0.065 (0.299)	-0.155 (0.350)	-0.373 (0.403)	-0.703 (0.435)	-0.960* (0.531)
6. Housing and community amenities	0.548*** (0.075)	0.110 (0.258)	-0.042 (0.114)	-0.331** (0.149)	-0.141 (0.153)	-0.112 (0.227)	0.047 (0.137)	0.334 (0.213)
7. Health	0.633*** (0.041)	-1.109** (0.409)	-0.718 (0.459)	-0.529 (0.349)	-0.572* (0.304)	-0.703** (0.286)	-0.807*** (0.221)	-0.533 (0.411)
8. Recreation, culture and religion	0.642*** (0.044)	-1.116*** (0.360)	-0.753 (0.519)	-0.838 (0.583)	-0.668 (0.453)	-0.295 (0.440)	-0.383 (0.565)	-0.617 (0.579)
9. Education	0.604*** (0.033)	-1.707** (0.678)	-1.588* (0.854)	-1.480* (0.750)	-1.020** (0.375)	-0.447 (0.409)	-0.179 (0.508)	-0.246 (0.392)
10. Social protection	0.473*** (0.121)	-0.554** (0.218)	-0.336* (0.176)	-0.413 (0.254)	-0.262 (0.234)	-0.073 (0.276)	0.0026 (0.242)	-0.039 (0.219)

Notes. Driscoll-Kraay standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation.

Table 4
Estimation of the private investment regression for t+1 using different period sub-samples.

	1995–2007	2008–2019	2012–2019
D.Ln(Government investment)	0.087** (0.039)	0.091* (0.049)	0.067** (0.024)
D.Ln(GDP)	0.389 (0.337)	0.265 (0.377)	1.079*** (0.255)
D.Interest rate	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
D.Debt	-0.001 (0.002)	-0.007** (0.003)	-0.003 (0.001)
D.Deviation	-1.832*** (0.256)	-3.040*** (0.875)	-2.310*** (0.568)
Constant	0.043*** (0.013)	0.017 (0.010)	0.013 (0.009)
Observations	333	373	237

Notes. Driscoll-Kraay standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation.

approach followed in this 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 employing public investment forecast errors from the OECD Economic Outlook. Unfortunately, as mentioned in Section 3.2, 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, we estimate private investment regressions for a shorter time period using the forecast errors as explained in Section 3.5.

The estimation results (presented in [Fig. 2](#)) suggest that extra public investment exhibits a positive and significant effect on private investment in 4–5 years from the year of reference. In the sample of OECD countries, the immediate impact of public investment is negative albeit insignificant. In the sample of the euro area countries, the negative effect gets more visible with a higher level of statistical significance. This implies that in the short-term some crowding out may indeed take place due to a higher demand for investment goods.

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 methodology. Yet, the magnitude of the private investment response and therefore the value of the multiplier can vary. We explore this in detail in the following section.

Table 5

Estimation of private investment regressions using the sub-sample of the euro area countries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.047 (0.045)	-0.024 (0.070)	-0.028 (0.052)	0.101 (0.087)	0.071 (0.081)	-0.054 (0.037)	-0.081 (0.111)
D.Ln(GDP)	1.070*** (0.307)	-0.979** (0.466)	-0.655 (0.470)	-0.189 (0.413)	0.128 (0.393)	0.141 (0.294)	0.146 (0.331)
D.Interest rate	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.001* (0.000)	0.000 (0.000)	0.001*** (0.000)	0.001 (0.001)
D.Debt	-0.003* (0.001)	-0.005** (0.002)	-0.002 (0.002)	0.002 (0.001)	0.004** (0.002)	0.003 (0.002)	0.003 (0.003)
D.Deviation	-1.367** (0.562)	-0.624 (0.757)	-1.134 (0.953)	-1.171 (0.828)	-0.744 (0.668)	-0.997 (0.771)	-1.192* (0.459)
Constant	0.004 (0.46)	0.052*** (5.37)	0.040*** (3.35)	0.018 (1.31)	0.004 (0.63)	0.009 (0.61)	0.014 (0.76)
Observations	360	343	326	309	292	275	258

Notes. Driscoll-Kraay standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation.

Table 6

Estimation of private investment regressions using IMF investment data.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.074* (0.033)	0.026 (0.022)	-0.004 (0.036)	0.082 (0.070)	0.010 (0.035)	-0.057*** (0.018)	-0.024 (0.040)
D.Ln(GDP)	0.710** (0.279)	-0.802* (0.392)	-0.589 (0.406)	-0.256 (0.399)	-0.122 (0.363)	0.0524 (0.220)	0.185 (0.281)
D.Interest rate	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.001** (0.000)	0.000 (0.000)	0.001*** (0.000)	0.000 (0.000)
D.Debt	-0.005** (0.002)	-0.003*** (0.001)	-0.001 (0.001)	0.002** (0.001)	0.003*** (0.001)	0.003** (0.001)	0.003 (0.002)
D.Deviation	-1.986*** (0.632)	-1.371 (0.862)	-1.125 (0.853)	-0.847 (0.682)	-0.114 (0.507)	-0.191 (0.437)	-0.714 (0.550)
Constant	0.020** (0.009)	0.052*** (0.006)	0.042*** (0.010)	0.026* (0.013)	0.017 (0.011)	0.015 (0.013)	0.016 (0.017)
Observations	710	676	642	608	574	540	506

Notes. Driscoll-Kraay standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation.

Table 7

Estimation of private investment regressions (unbalanced panel for 1980–2019).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D.Ln(Government investment)	0.042 (0.031)	-0.003 (0.029)	-0.013 (0.030)	0.070 (0.053)	0.005 (0.031)	-0.040* (0.022)	-0.029 (0.032)
D.Ln(GDP)	0.796*** (0.2364)	-0.561 (0.426)	-0.566* (0.331)	-0.269 (0.371)	-0.155 (0.306)	-0.081 (0.186)	0.024 (0.231)
D.Interest rate	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.001*** (0.000)	0.000 (0.000)	0.001*** (0.000)	0.000 (0.000)
D.Debt	-0.004** (0.002)	-0.002 (0.001)	0.000 (0.001)	0.002*** (0.001)	0.003*** (0.001)	0.002* (0.001)	0.002 (0.001)
D.Deviation	-1.447*** (0.401)	-1.013* (0.516)	-0.935 (0.576)	-0.518 (0.390)	0.022 (0.280)	-0.129 (0.269)	-0.422 (0.421)
Constant	0.012* (0.007)	0.043*** (0.006)	0.040*** (0.009)	0.027** (0.011)	0.023** (0.009)	0.022** (0.010)	0.020 (0.014)
Observations	846	813	780	747	714	681	648

Notes. Driscoll-Kraay standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation.

Table 8
Different specifications of private investment regressions for t+1 period.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Baseline	-1.857***	-1.313*	-1.290	-0.882	-0.044	-0.179	-0.392
Drop public investment	-1.603**	-1.241	-1.326	-0.619	0.025	-0.393	-0.781
Drop GDP	-1.851***	-1.317	-1.308	-0.886	-0.043	-0.182	-0.403
Drop interest rate	-1.619***	-1.107*	-0.777	-0.359	0.337	0.254	-0.136
Drop public debt	-1.677***	-1.170	-1.231	-0.943*	-0.157	-0.301	-0.543
Controls enter with one period lag	-1.014**	-1.485	-1.726	-0.670	-0.094	-0.463	0.024
Use contemporaneous controls and controls with one period lag	-1.325***	-1.555*	-1.716*	-0.998**	-0.079	-0.121	0.464
Add time effect	-1.362***	-1.272**	-1.293**	-0.721*	0.012	-0.107	-0.114

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Authors' estimation.

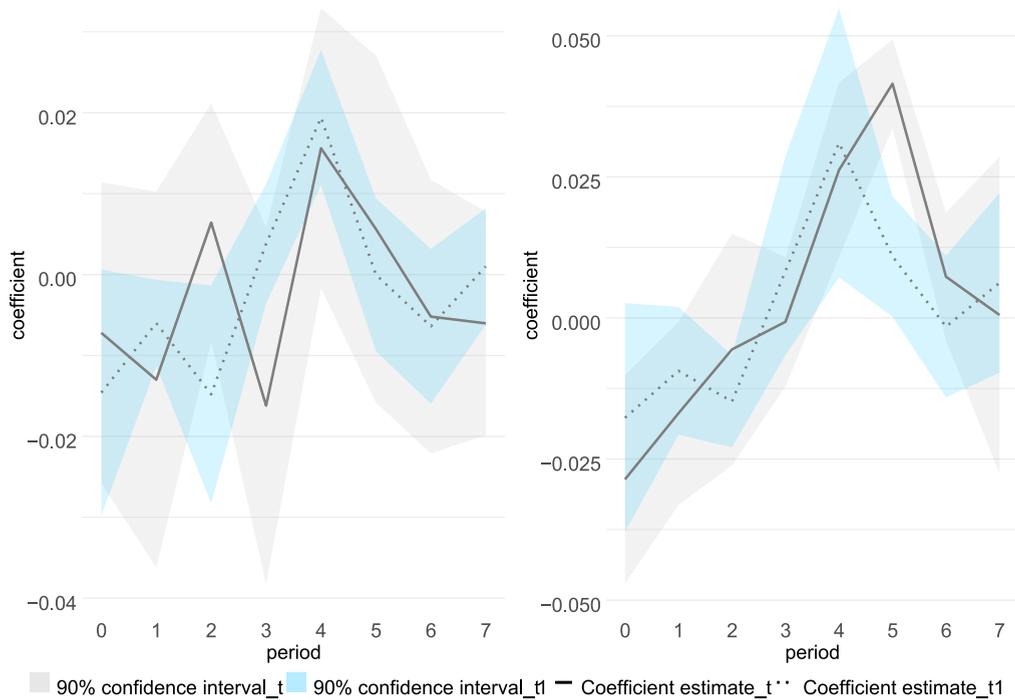


Fig. 2. Impact of public investment on private investment using forecast errors in public investment (full sample of OECD countries on the left plot; sample of the euro area countries on the right plot).

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.

6. Response of private investment to a public investment shock

In Section 4, 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 of public investment.

6.1. 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 changes in the deviation term (Δu_{it}) from the long-term cointegration relationship between private and public capital stocks (captured by coefficient β_{2h} in Equation (4)). To estimate the impulse response of private investment to a 1% increase in public investment, we need to consider both channels together.

Therefore, we estimate impulse responses using an iterative approach, such that we update values of private and public capital and the deviation term between public and private capital before each following iteration of the private investment regression.²¹ We construct impulse responses to a public investment shock for each country separately (using data for 1995–2010).²²

Fig. 3 presents the median and the interdecile range of cross-country impulse response functions. Fig. 3 also contrasts the impulse responses with and without the direct effect, whose significance is not robust across different samples. The responses indicate that the crowding-in effect reaches its maximum two years after the additional public investment takes place, in line with a high and statistically significant value of coefficient β_{2h} for $h = 1$. 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, i.e. private investment stays elevated but the relative difference with respect to the scenario without the shock is smaller.

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. We have previously 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 5, 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 (Fig. 3) shows, impulse responses under the assumption of no immediate crowding in are very similar.

6.2. 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 in absolute terms generated by one unit increase in public investment. There are several 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* tell how much additional private investment gets accumulated over the horizon of T years since the public investment shock.

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

$$\text{Public Investment Multiplier } (T) = \frac{\sum_{v=0}^T \hat{I}_{it+v}^P - I_{it+v}^P}{\sum_{v=0}^T \hat{I}_{it+v}^G - I_{it+v}^G} \quad (9)$$

This cumulative public investment multiplier, as defined by Equation (9), 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. Since we are interested in the impact of a one-time public investment shock $\hat{I}^G > I^G$ only in period t , whereas all other terms in the denominator for $v \leq 1$ are zero.²³

Similarly to impulse responses, the public investment multiplier can be calculated for each country in the sample. 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. In Fig. 4 we plot the median and the interdecile range of the resulting multiplier both with (on the left) and without (on the right) the direct effect.

As impulse responses remain positive over a number of years, the public investment multiplier keeps accumulating 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 around two or 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 five to 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 34 developed countries in our sample, the long-term public investment multiplier lays around 2 and eventually exceeds it.

²¹ To capture the indirect effect following a public investment shock, stocks of private and public capital need to be updated. First, public capital changes as a result of the shock in public investment. Second, beginning with the second period after the shock, private capital is affected because of the change in private investment. Both of these changes to capital stocks affect the deviation term, which enters the private investment regression. Hence, we adopt an iterative approach, which we illustrate as follows.

²² The detailed derivation of impulse responses is provided in the Online Appendix.

²³ For any variable X (in this equation — public investment), we denote its value in the alternative scenario (after a shock) by X^* and in the baseline scenario (no shocks occurred, i.e. all variables are equal to their historical values) by X .

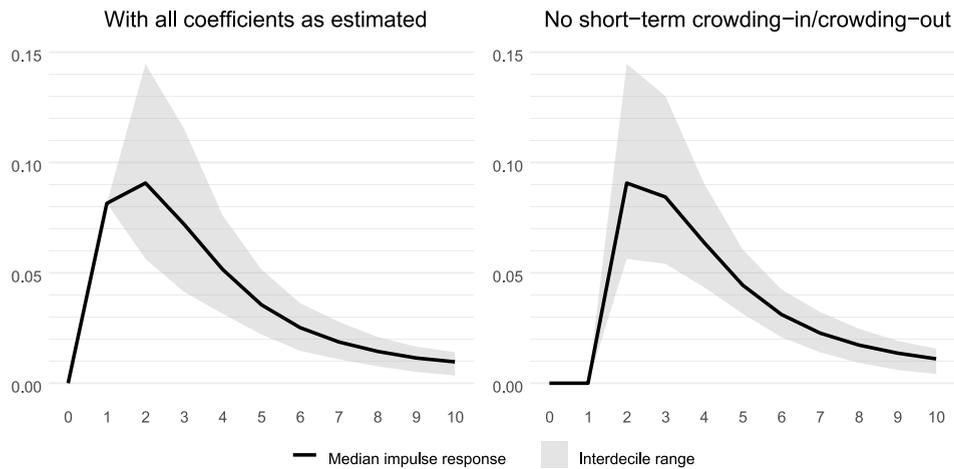


Fig. 3. Private investment impulse response to a public investment shock

Notes. The impulse response shows how many percent (vertical axis) private investment increases in each year (horizontal axis) following an increase in public investment by 1% in year 0. Source: Authors' estimation.

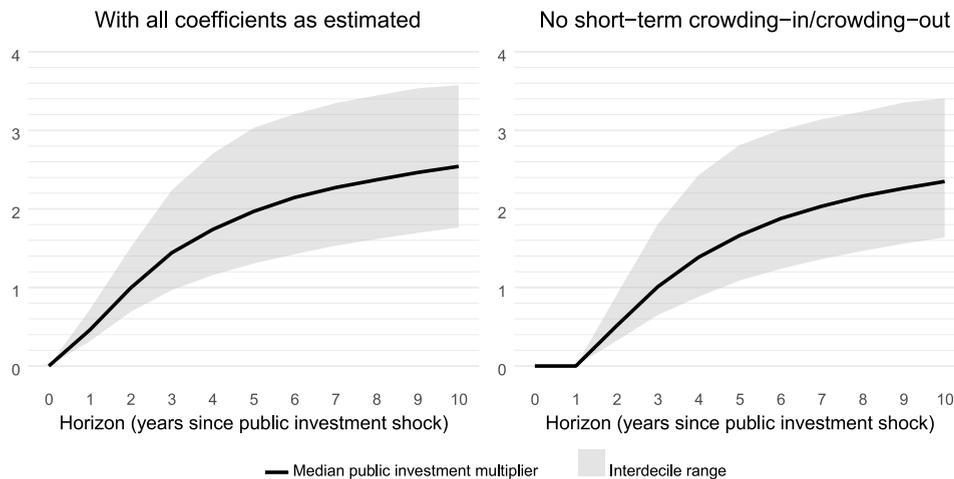


Fig. 4. Public investment multiplier

Notes. The public investment multiplier shows the cumulative amount of additional dollars invested by the private sector (vertical axis) over a certain number of years (horizontal axis) after a one-dollar shock to public investment. Source: Authors' estimation.

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

6.3. Impulse responses and public investment multipliers by public policy areas

We conclude our study by presenting private investment impulse responses to a shock in public investment by each policy area. Their median values and the interdecile ranges are plotted in Fig. 5. 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 Housing, where cointegration between the stocks of public and private capital is uncertain. Crowding in is also smaller in Defense, Environmental protection and Social protection, where the deviation coefficient (coefficient β_{2h} in Equation (4)) is low. Increasing public investment in Education, Economic affairs, Health as well as in 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 under 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 multiplied by shares of public investment in the respective policy areas relative to the total public investment.

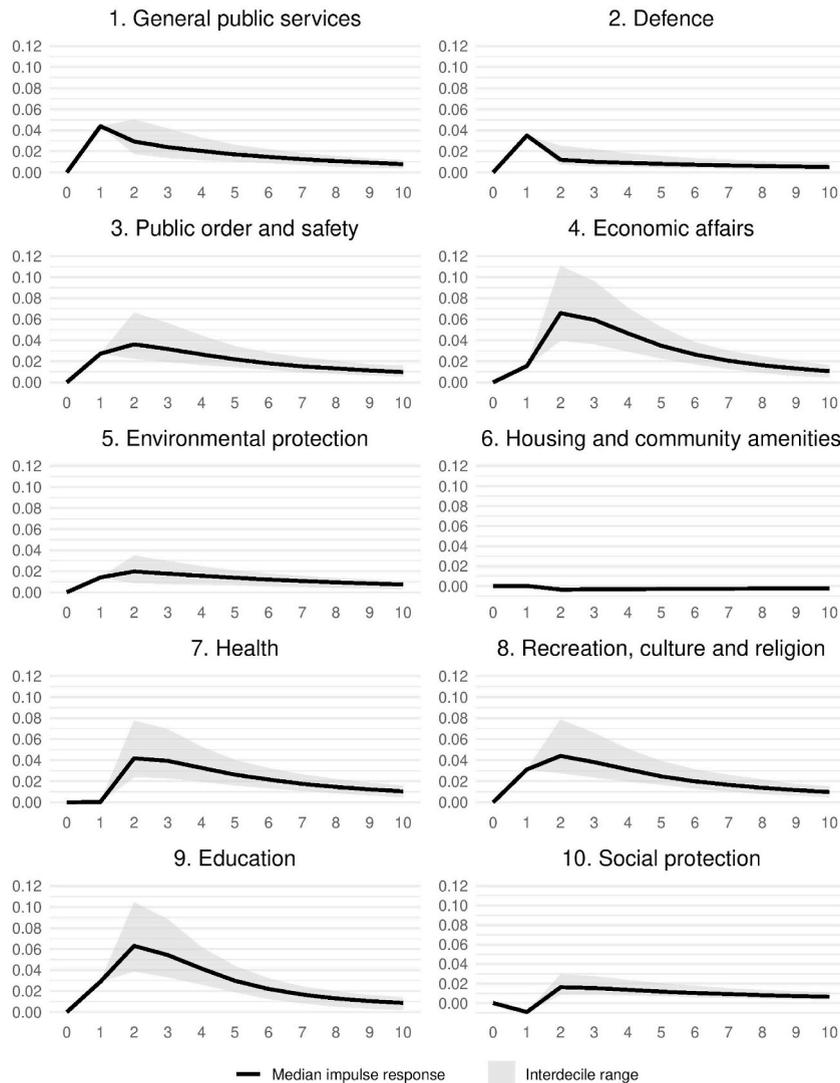


Fig. 5. Private investment impulse response to a public investment shock by policy areas.

Notes. The impulse responses show by how many percent (vertical axis) private investment increases in each year (horizontal axis) following an increase in public investment in a concrete policy area by 1% in year 0. Source: authors' estimation.

The estimates presented in Figs. 5 and 6 indicate that the strongest crowding-in effect is observed after additional public investment spending in Economic affairs and the areas closely related to human capital development. The reason for such a strong response in these areas is probably the fact that investing in human capital and economic infrastructure makes a country particularly more attractive to private investors. Investing in recreation, culture and religion is probably mostly associated with stimulating tourism and building new hotels, restaurants and other private amenities.

7. Conclusion

This study aims to establish whether public investment crowds in private investment, to what extent, and in which policy areas the effect might be stronger. We find that public and private capital are cointegrated: one percent increase in the stock of public capital is associated with 0.8 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 1.9% in the following year. We transform the estimated regression coefficients into impulse responses of private investment and then obtain public investment multipliers. Overall, the public investment multiplier value reaches the value of 2 five to seven years after a shock and exceeds 2 over a longer period of time, indicating that an extra dollar of public investment eventually leads to at least two additional dollars of private investment.

This study demonstrates that it is important to consider government investment projects also from the perspective of their ability to

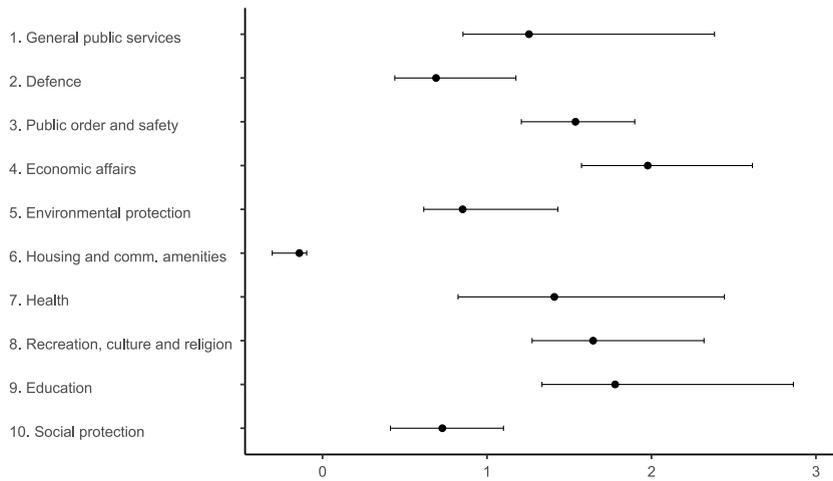


Fig. 6. Public investment multiplier by policy area Notes'. The dots stand for the median (of all years and OECD countries in the sample) public investment multiplier accumulated over seven years after a one-off 1% increase in public investment in each of the policy areas. The error bars represent the 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'.

attract private investment, which varies across different public policy areas. In particular, investment in economic infrastructure and human capital exhibits the largest crowding-in effect. Public investment has a long-lasting multiplier effect and attracts private capital for many years into the future, hence is a powerful policy tool to increase productive capacity of the economy. Therefore, fiscal policy frameworks should encourage public investment spending and treat it differently to other types of government expenditure in cases when it does not jeopardize fiscal sustainability.

There are few possible directions for continuing the research on the interaction of public and private capital formation. For example, private sector can respond to a shock in different types of public investment in a different manner. Obtaining data on types of public investment and examining the differences in their responses would facilitate practical importance of the findings. Also, examining the role of a country's institutional quality and the quality of public investment would contribute to the existing literature on the effects of public investment in industrialized economies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendices.

A Descriptive statistics

Table A1
List of variables used in the study, their definition and source

Variable	Data source	Definition
Government investment in real terms (used in the baseline estimation)	OECD	Gross fixed capital formation, General government sector, deflated by total investment deflator
Government investment in real terms	IMF	Gross fixed capital formation, General government sector, billions of constant 2017 international dollars

(continued on next page)

Table A1 (continued)

Variable	Data source	Definition
Government investment by COFOG in real terms	OECD	Gross fixed capital formation in COFOG, General government sector, deflated by total investment deflator
Private investment in real terms (used in the baseline estimation)	OECD	Gross fixed capital formation, private sector, deflated by total investment deflator
Private investment in real terms	IMF	Gross fixed capital formation, private sector, billions of constant 2017 international dollars
Government capital in real terms (used in the baseline estimation)	IMF	General government capital stock, deflated by total investment deflator
Government capital in real terms	IMF	General government capital stock, billions of constant 2017 international dollars
Private capital in real terms (used in the baseline estimation)	IMF	Private capital stock, deflated by total investment deflator
Private capital in real terms	IMF	Private capital stock, billions of constant 2017 international dollars
GDP in real terms (used in the baseline estimation)	OECD	Gross domestic product, OECD base year
GDP in real terms	IMF	Gross domestic product, billions of constant 2017 international dollars
Public debt	IMF WEO	Government debt ratio to GDP
Interest rate	OECD	Long-term interest rate percent per annum
Inflation rate	OECD	CPI inflation, all goods

Table A2

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 29.69	50.39 59.40	51.88 68.36	105.83
	2010				119.20
	2017	34.24	61.17	72.36	126.14

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

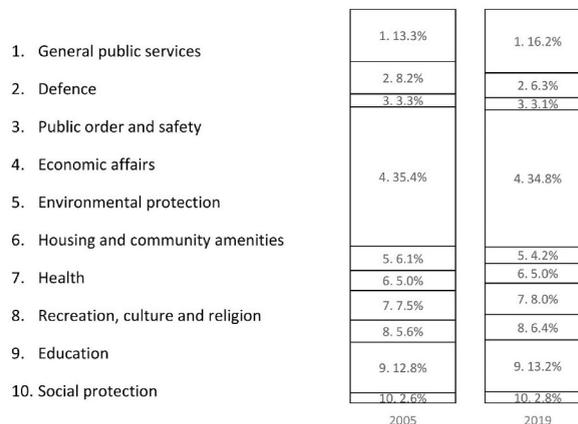


Fig. A1. Public investment by COFOG categories, averages for 2005 and 2019.

B Stationarity tests

We perform unit root tests designed for panel data. We employ both the first and the second-generation panel unit root tests. The former rely on the assumption of no cross-series correlation, while the latter produce a test statistic which is robust to a possible cross-series correlation. [Table B1](#) presents the results of Harris & Tzavalis test, which is the first-generation panel stationarity test, while the results of the second-generation Pesaran's test are reported in [Table B2](#). We report the z statistic and its p-value for each variable, with the null hypothesis that all panels contain a unit root. The order of integration of the private capital stock seems uncertain: while both the first- and the second-generation tests suggest there is no unit root in the differenced series of private capital for the whole sample of countries, the null of non-stationarity cannot be rejected for a subsample of euro area countries.

To resolve the issue, we run a test with a reverse null hypothesis – rather than testing against a presence of a unit root in all panels as in the first two tests, the null hypothesis of the Hardi test is that all panels are stationary. The results are presented in [Table B2](#). The test rejects stationarity of private capital both in levels and in differences, both for the whole sample and the euro area subsample. All in all, these results suggest that the most reasonable way to treat private capital is as $I(2)$, same as public capital.

Table B1
Stationarity test results: [Harris and Tzavalis \(1999\)](#) (1st generation)

Variable	Whole sample		Euro Area	
	z statistic	p-value	z statistic	p-value
Public capital	4.747	1.000	2.432	0.993
Private capital	5.623	1.000	2.808	0.998
Public capital (difference)	-1.459	0.072	1.103	0.865
Private capital (difference)	-13.366	0.000	-1.090	0.138
Public investment	2.319	0.990	0.424	0.664
Private investment	4.357	1.000	1.247	0.894
Residual of cointegration (u_{it} in Eq. 3)	4.460	1.000	3.8381	1.000
Log of GDP	3.352	0.999	1.999	0.977
Long-term interest rate	-2.665	0.004	-2.665	0.004
Debt-to-GDP	2.788	0.997	2.400	0.992

Note 1. All variables are expressed in real terms.

Note 2. Harris & Tzavalis test's H0: each series in the panel follows a random walk with drift.

Table B2
Stationarity test results: [Pesaran \(2007\)](#) (2nd generation)

Variable	Whole sample		Euro Area	
	z statistic	p-value	z statistic	p-value
Public capital	2.563	0.995	2.861	0.998
Private capital	1.171	0.957	0.138	0.555
Public capital (difference)	-0.934	0.175	-0.754	0.225
Private capital (difference)	-3.008	0.001	-1.111	0.133
Public investment	1.199	0.885	2.724	0.997
Private investment	-1.323	0.093	1.310	0.905
Residual of cointegration (u_{it} in Eq. 3)	2.744	0.997	2.380	0.991
Log of GDP	-1.264	0.103	-1.447	0.074
Long-term interest rate	0.151	0.560	-0.767	0.222
Debt-to-GDP	0.151	0.560	-0.767	0.222

Note 1. All variables are expressed in real terms.

Note 2. Pesaran test's H0: all series are non-stationary.

Table B3
Stationarity test results: [Hardi \(2000\)](#)

Variable	Whole sample		Euro Area	
	z statistic	p-value	z statistic	p-value
Public capital	85.264	0.000	60.150	0.000
Private capital	85.680	0.000	59.149	0.000
Public capital (difference)	57.857	0.000	28.174	0.000
Private capital (difference)	12.409	0.000	29.604	0.000
Public investment	68.411	0.000	23.273	0.000
Private investment	74.983	0.000	35.594	0.000
Residual of cointegration (u_{it} in Eq. 3)	70.198	0.000	43.846	0.000
Log of GDP	78.498	0.000	53.922	0.000
Long-term interest rate	0.151	0.000	-0.767	0.000
Debt-to-GDP	58.255	0.000	40.265	0.000

Note 1. All variables are expressed in real terms. Note 2. Hardi test's H0: all series are stationary.

C Country-specific public investment multipliers

Table C.1
Long-term (10-year) public investment multiplier by country

Country	All coefficients			With $\beta_1 = 0$		
	10-th perc.	Mean	90-th perc.	10-th perc.	Mean	90-th perc.
Australia	3.756	3.922	4.060	3.605	3.764	3.902
Austria	2.522	2.564	2.610	2.311	2.342	2.375
Belgium	3.470	3.672	3.796	3.216	3.407	3.512
Canada	2.432	2.530	2.588	2.318	2.399	2.455
Czechia	2.422	2.674	2.904	2.313	2.535	2.743
Denmark	1.546	1.679	1.757	1.403	1.511	1.572
Estonia	2.353	2.786	3.017	2.280	2.698	2.955
Finland	2.082	2.173	2.218	1.926	2.025	2.076
France	1.878	1.899	1.915	1.741	1.772	1.790
Germany	2.663	2.759	2.870	2.398	2.497	2.635
Greece	1.176	1.803	2.111	1.041	1.689	2.017
Hungary	2.525	3.197	3.918	2.353	3.046	3.749
Iceland	1.672	1.924	2.079	1.541	1.799	1.998
Ireland	3.137	3.387	3.518	2.980	3.268	3.397
Israel	2.988	3.154	3.252	2.853	3.007	3.113
Italy	2.132	2.376	2.534	1.944	2.183	2.356
Japan	1.252	1.286	1.314	1.117	1.146	1.189
Korea	2.543	2.678	2.844	2.436	2.581	2.775
Latvia	2.798	4.662	5.803	2.718	4.519	5.643
Lithuania	2.464	3.403	4.109	2.378	3.282	3.918
Luxembourg	1.988	2.052	2.167	1.906	1.961	2.066
Mexico	2.733	2.946	3.185	2.565	2.709	2.894
Netherlands	1.763	1.870	1.958	1.637	1.739	1.814
New Zealand	1.711	1.768	1.824	1.616	1.654	1.707
Norway	2.145	2.241	2.288	2.031	2.119	2.177
Poland	2.218	2.740	3.168	2.135	2.616	3.024
Portugal	1.842	2.134	2.411	1.676	1.986	2.313
Slovakia	2.683	2.961	3.069	2.553	2.797	2.902
Slovenia	2.022	2.685	3.016	1.882	2.538	2.885
Spain	2.126	2.520	2.739	2.009	2.380	2.619
Sweden	1.672	1.777	1.841	1.565	1.660	1.733
Switzerland	2.931	3.056	3.151	2.727	2.829	2.914
United Kingdom	2.353	2.595	2.747	2.211	2.359	2.474
United States	1.786	1.862	1.926	1.659	1.744	1.807

Notes. For each country, the public investment multiplier varies depending on the year when the initial public investment shock occurs because of different ratios between private investment, public investment, private capital, and public capital.

For the precise definition of the public investment multiplier, see Section 6.2.

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