2106

Discussion Papers

Deutsches Institut für Wirtschaftsforschung 2025

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IMPRESSUM

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Fax +49 (30) 897 89-200
http://www.diw.de

ISSN electronic edition 1619-4535

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An Estimation and Decomposition of the Government Investment Multiplier*

Marius Clemens[a] Claus Michelsen[b] Malte Rieth[c]

January 31, 2025

Abstract

We construct a narrative instrument for government investment from official records in Germany. Using structural vector autoregressions, we document a significant crowding-in of private investment and an output multiplier of roughly 2. Then, we match a New Keynesian dynamic stochastic general equilibrium model to the empirical responses, and we decompose the multiplier into three channels. Public investment reduces private investment costs in the short run, it increases the production capacity in the medium run, and it generates demand effects along the production network. We find a similar multiplier in other euro area countries, using an indirect instrumental variable strategy.

JEL: E62, E65, H54

Keywords: Fiscal policy, public investment, structural vector autoregression, instrumental variable, general equilibrium model, Germany.

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*The authors are grateful for helpful comments and suggestions of Stylianos Asimakopoulos, Rüdiger Bachmann, Christiane Baumeister, Peter Bofinger, Jens Boysen-Hogreve, Christoph Große-Steffen, Maik Heinemann, Oliver Holtemöller, Robin Jessen, Mathias Klein, Tom Krebs, Alexander Kriwoluzky, Boreum Kwak, Xiang Li, Matthias Meier, Gernot Müller, Werner Röger, Gregor von Schweinitz, Jens Südekum, Nora Traum, Enzo Weber, Jakob von Weizsäcker, Francesco Zanetti, and the participants of presentations at DIW Berlin, Federal Ministry of Finance Germany, IWH Macro Reading Group, IAAE 2022 Conference London, EEA-ESEM 2022 Conference Milano, Verein für Socialpolitik 2022 Conference Basel. We particularly thank Erik Klär and Christoph Priesmeier for organizing the access to the archive of the Federal Ministry of Finance Germany and for helpful discussions and support to collect, interpret, and organize the records and data used to construct the instrument for government investment.

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1 Introduction

In response to the challenges posed by aging societies, climate change, energy insecurity, and the need to modernize the public infrastructure, economists have proposed massive public investment programs (Summers, 2015; Stiglitz, 2016; Blanchard et al., 2021). The programs also intend to stabilize the economy in the short run. In Europe, the report on the future of European competitiveness calls for additional public investment of up to 400 billion euro annually (Draghi, 2024). This is on top of national funds and the NextGenerationEU package, which provided 800 billion euro to address the consequences of the pandemic. What are the likely macroeconomic effects of such large-scale public investments? The academic literature provides no clear answer.[1]

In this paper, we build the first narrative instrument for public investment to answer the question. We use official records in Germany, such as government finance reports and legislative documents. The instrument measures the financial volume of concrete exogenous investment programs. We employ the instrument in structural vector autoregressions (SVAR) to trace out the dynamic effects of government investment shocks. We find a significant crowding-in of private investment and positive output effects. The estimated multiplier is roughly 2. We show that the estimate can approximately be generalized to other euro area countries by employing an indirect instrumental variable strategy. We also highlight the macroeconomic effects of alternative facets of the packages, such as physical investment in transport and education infrastructure or investment grants to the private sector. Then, we build a New Keynesian dynamic stochastic general equilibrium (DSGE) model to decompose the effects into three channels: public investment reduces private investment adjustment costs, it raises the production capacity, and it increases demand along the production network. We estimate the size of the effects by impulse response matching. We find that all three are relevant for understanding the empirical dynamics.

We contribute to a literature that uses government documents, for example, laws or budgetary reports, to construct time series of narratively identified exogenous changes in fiscal policy. Such series can be used as instrumental variable to estimate the macroeconomic effects of fiscal policy

[1] One metric that summarizes the macroeconomic effects of additional public spending is the output multiplier. It measures by how many euros GDP increases if the government spends 1 euro more. In theoretical models, the output multiplier of public investment ranges from slightly negative to above 10, depending on the type of model, the calibration, and the horizon considered (Baxter and King, 1993; Leeper et al., 2010; Ramey, 2021). In empirical studies, the range of estimated multipliers is a bit tighter, between 0 and 4, and typically depends on the assumption that government investment is exogenous to the current state of the economy (Bachmann and Sims, 2012; Auerbach and Gorodnichenko, 2012; Ilzetzki et al., 2013; Boehm, 2020). Caldara and Kamps (2017) show that empirical multipliers are sensitive to the identification strategy.

measures. Some studies concentrate on the revenue side of the government. In a seminal contribution Romer and Romer (2010) construct a narrative account of legislated tax changes in the U.S. Mertens and Ravn (2013) decompose these further into corporate and personal income tax changes and document that the former have larger output effects than the latter. Cloyne (2013) constructs a narrative instrument for tax changes in the U.K. and documents similar output effects as Romer and Romer (2010). Nguyen et al. (2021) decompose these tax changes into income and consumption tax changes and find stronger effects of the former.

Other articles focus on the expenditure side of the government. Ramey (2011), Ramey and Zubairy (2018), and Barro and Redlick (2011) use (news about) military build ups as instrument for government spending. These articles identify exogenous variation in total government spending, which comprises consumption and investment expenditures. What is missing so far in the literature are instruments for these components. Government consumption and government investment can have different effects on the economy, just as different tax instruments have different effects (Mertens and Ravn, 2013; Nguyen et al., 2021). We fill this gap by constructing the first narrative instrument for government investment.

We contribute to the debate along two dimensions. First, based on our narrative instrument, we reassess the empirical question about the size of the public investment multiplier and whether there is crowding-in or out of private demand.[2] The instrument incorporates key public investment programs in Germany since 1970Q1. The primary sources for the series are the annual finance reports and historical budgetary plans in the library archive of the German Federal Ministry of Finance. These include chronological notes about the size and duration of investment programs. While the documents are in principle available to the general public, access to the archive required the approval of the Ministry, a signed project contract to enter the Ministry, and the supervision by staff within the Ministry. We add information on the purpose of the spending, specifically, whether it was designed to stabilize aggregate output in the short run or to increase potential output in the medium run, from legislative documents of the German Bundestag and forecasts.

[2] Since Aschauer (1989), researchers have aimed at measuring the effects of government investment, whether it is productive, and whether private activity is crowded-in or out. Crowding-in can occur if public investment increases the returns for the private sector and stimulates investment activity there. An expansion of the public road network, for example, can accelerate the transport and trade of goods. This would lead to gains in the efficiency of the production process and raise the profit expectations of private companies. Firms are then potentially more willing to invest as the marginal product of private capital increases. On the contrary, crowding-out of private activity might occur if additional public investment raises the user costs of capital and private investment becomes less profitable. Although this channel may be weakened in a low interest rate environment, financing public investment can still be harmful to the private sector as it leads to higher tax burdens that might depress demand.

We use the narrative series as an external instrument in SVAR models to identify the causal effects of public investment, using the methodology of Stock and Watson (2012) and Mertens and Ravn (2013). We find that an expansionary government investment shock raises private consumption and investment significantly. The shock mainly consists of additional public construction expenditures that raise private construction investment across the board (residential, nonresidential, civil and building construction). The unemployment rate falls and the real wage rises, while prices increase little. A variance decomposition shows the importance of public investment shocks for output fluctuations.The shocks explain between 10-20% of the variability in GDP.

We estimate a government investment to output multiplier of 1.9 upon impact and of 2.5 after three years. We compare our results to estimates for other euro area countries, using an indirect instrumental variable strategy (Caldara and Kamps, 2017; Angelini et al., 2024) applied to a panel SVAR. We find that the multiplier in the other countries is a bit lower in the first year than in Germany but thereafter statistically indistinguishable, suggesting that our results hold more broadly. Furthermore, we compare our multiplier for government investment to the multiplier for government consumption and find that the latter is significantly smaller upon impact and decreases more rapidly, indicating that the two components of government spending indeed have different effects on the economy. Finally, within investment programs, we categorize the packages underlying our instrument into physical investment into infrastructure or education, and investment grants to the private sector. Infrastructure spending yields an output multiplier of about 2 over five years. The effects of education spending are smaller than this at the beginning but larger after 6 quarters. Grants to the private sector have similar output effects as infrastructure spending in the short run but the effects dissipate quickly.

The second contribution is that we decompose the estimated output effects of government investment shocks. We set-up a New Keynesian DSGE model that builds on Leeper et al. (2017). We add public investment to the model and focus on three transmission channels. First, government investment enters an otherwise standard private investment adjustment cost function. The second channel is the traditional augmentation of the production function of private firms with public capital (Baxter and King, 1993). The third channel is a production network structure, as in Bouakez et al. (2023), that creates demand effects at each stage of the network through input-output linkages. To determine the importance of these channels, we match the impulse response functions of the DSGE model to those of the SVAR.

We find that all three channels are relevant for understanding the size and shape of the output multiplier. The first is relevant for the short run. Public investment reduce private investment adjustment costs by 15%. One interpretation is that a tighter transportation network allows firms to produce more quickly. Similarly, an expansion of public digital infrastructure may imply that private-sector projects will be approved with less bureaucracy and more rapidly. The second channel is relevant for the medium run. Government investment raises the public capital stock. The estimated output elasticity of public capital is 0.04. Hence, public investment programs raise private demand because they increase the marginal product of private inputs and generate a positive wealth effect. The third channel is relevant for both the short and medium run. Government investment is complementary to private investment at each stage of the production network according to the data. The estimated elasticities of substitution in CES production functions are 0.2-0.3. The complementarity generates sectoral demand effects in the network.

2 Construction of instrument for government investment

To estimate the macroeconomic effects of public investment we construct a novel and unique account of government investment programs in Germany. We record significant policy events, from which we construct an instrumental variable for government investment. The development of the account and the instrument follows Fieldhouse et al. (2018). A detailed description of both is given in our companion paper (Clemens et al., 2024).

2.1 Data Sources

The narrative covers public investment programs since 1970Q1. We collect the information from several sources. First, we use historical budget plans of the federal government to collect information on the planned volume and duration of public investment programs. The plans also include information on the instruments used, that is, whether they are direct investments, grants to other authorities, or grants to private entities. The second and most important source are the finance report ('Finanzbericht') and the annual economic report ('Jahreswirtschaftsbericht') of the federal government. The reports include detailed information on actual spending since 1970. In principle, the reports are available to the public. However, the printed documents are exclusively available in the library of the federal ministry of finance. Access to the library is possible only in consent with the ministry, based on a project agreement, and under supervision of ministry staff.[3]

The budget and actual spending data are cross-checked and supplemented with information from additional sources. The third source is the archive of the German Parliament (Bundestag). It contains 167.000 legislative documents and reports, including more than 8.700 enacted laws. These documents include rich information on the purpose, character, and the exact dates of the announcement and resolution of the programs. The fourth source are the semi-annual reports of the 'Joint Economic Forecast Group' and the annual report of the 'Council of Economic Experts'.[4] These reports include macroeconomic forecasts and projections of the fiscal budget as well as detailed analyses of public investment and grants.

2.2 Program Selection

We use the information from the four sources to identify significant policy events. First, we restrict the sample to have consistent and overlapping data coverage from all primary sources. Second, we identify binding and significant changes in federal public investment policy that are expected to change federal government investment directly or indirectly through investment by states or municipalities. Third, we quantify the size of the stimulus. Fourth, we document when each change was announced and implemented. Finally, we classify each investment program as either cyclical (endogenous) or non-cyclical (exogenous).

The sample covers the period 1970Q1-2018Q4. This is for institutional and data availability reasons. We focus on programs financed by the federal government as consistent data for local and federal states' budgets are not available. We consider only significant policy events that are expected to have a notable impact on public investment activity. We include investment programs with a duration of more than one year and a total volume of more than 500 million euros.

We include only programs that focus on public investment. The political measures that have an impact on the public capital stock include direct federal investment in buildings, equipment, and research and development, as well as indirect investment through funds allocated to states and municipalities. The local level is frequently targeted as catalyst for public investment programs

[3]We are grateful to Erik Klär and Christoph Priesmeier for their time and support to access, collect, and organize the documents and for fruitful discussions about the data.

[4]The group is an institutionalized project of Germany's leading economic research institutes. The reports for 1970-2007 are physically available in the library archive of DIW Berlin. For 2007 onward, they can be downloaded via `https://gemeinschaftsdiagnose.de/` All the annual reports of the German Council of Economic Experts are available online via `https://www.sachverstaendigenrat-wirtschaft.de/publikationen/jahresgutachten.html`

by the federal government. Municipalities bear the largest burden, approximately 60%, of public infrastructure investment in Germany. They construct roads, schools, and sports facilities and provide public transport, among others. At the same time, the municipalities are chronically underfunded and they are legally borrowing-constrained. They mostly rely on unexpected revenues or grants from the federal government to finance infrastructure investment. Because of the consistent underfunding, they have the tradition of having ready-made, often granular 'drawer projects' that can be started at short notice once financial resources are available. In addition, some federal grants are allocated at a first-come, first-serve basis, which speeds up outlays. Overall, the indirect investment by states and municipalities is often quicker than the direct federal investment, which frequently involves larger, more complex, and more bureaucratic projects.[5]

Direct federal public investment in fixed assets is referred to as gross fixed capital formation (GFCF) in the national accounts and is included in the use of gross domestic product. It accounts for 57% of federal investment outlay in the sample. The indirect allocations of federal funds to the local authorities initially appear as domestic investment grants in the government finance statistics and are recorded in the national accounts as GFCF as soon as the funds are spent by the states and municipalities. They account for 21% of federal investment. Finally, investment funds to private companies and organizations are recorded in the government finance statistics as investment grants to the private sector and appear in the national accounts under private investment. They account for 22% of federal investment. However, large shares of these investments are through private-public partnerships and to state-owned but private companies. The national railroad company Deutsche Bahn alone accounts for 4% points of the 22%.

In total, we collect information on 24 investment programs for the period 1970Q1-2018Q4. Table 1 lists them. For example, in 1977Q1 the German government started a 6.7bn euro five-year Program for Future Investments (No. 4), in which states and municipalities were involved. The regulation statements emphasize the long term growth and structural motivation for the program. Consequently, it contained mainly infrastructure investments. Business cycle stabilization or employment goals are not mentioned. The federal government has earmarked 4.1bn euro for itself. The states and municipalities had planned to spend 1.6bn and 1bn, respectively.

[5]We also include programs that formally benefit the private sector. Since the early 1970s, the public sector more and more outsourced public infrastructure investments to state-owned private companies. While these companies are accounted as private investment entities in the national accounts, they maintain important public infrastructure and are therefore state-owned. The most prominent example is the German railway company Deutsche Bahn. The companies have traditionally also been active in the energy and water sector and became more important in road infrastructure and as service contractors for energy efficiency investments in public buildings. Today, their investments are equal in size to the core investment budgets of municipalities.

Nr.	Official title	Start	End	Volume (bn euro)	Exclude
1	Second Stability Program	1973Q2	1974Q4	-4.2	Yes
2	Program to Promote Employment & Growth	1974Q1	1974Q4	4.0	Yes
3	Program for Housing and other Investment	1975Q3	1976Q3	2.9	Yes
4	Program for Future Investments	1977Q1	1981Q4	6.7	
5	Program to Promote of Growth & Employment	1977Q3	1978Q4	2.7	Yes
6	Program to Promote Energy-Saving Investments	1978Q2	1982Q4, repeatedly ext.	2.2	
7	Federal Aid Program for Investments in Saarland	1984Q4	1985Q4	0.3	Yes
8	Balancing Economic Disparities Act	1989Q1	1998Q4	12.3	
9	Economic Resilience Plan	1990Q1	1990Q2	0.7	
10	German Reunification Fund	1990Q1	1995Q1	10.5 (4 bn in 1990)	
11	Extension of German Reunification Funds I	1990Q3	1990Q4	1.15	
12	Extension of German Reunification Funds II	1992Q1	1995Q1	6.9	
13	Housing Investment Program	2006Q1	2009Q4	5.9	
14	Excellence Initiative	2006Q3	ext. until 2017Q4	4.6	
15	University Package I	2007Q3	2010Q2	1.2	
16	Childcare Investment Funds	2007Q4	2014Q4	4.7	
17	Stimulus Package I	2008Q1	2009Q4	8.0	Yes
18	Stimulus Package II	2009Q1	2010Q4	14.0	Yes
19	University Package II	2011Q1	2014Q4	5.9	
20	Municipal Investment Fund: Infrastructure	2015Q2	2018Q4	3.5	
21	Municipal Investment Fund: School	2015Q2	2022Q4	3.5	
22	University Package III	2016Q1	2023Q4	8.8	
23	Public Transportation Investment Program	2016Q2	2030Q4	2.5	
24	Digitalization Program	2018Q1	2023Q4	5.0	

Table 1: Investment Programs in Germany 1970Q1-2018Q4. *Sources:* authors own calculations based on reports and legislation of the Federal Ministry of Finance, German Bundestag, and Joint Economic Forecast Group.

Another example is the University Package II (No. 19), by which the government aimed at increasing the performance of universities. The federal government granted lump-sum transfers to universities for the expansion of university places. It also supported physical teaching spaces with the Teaching Quality Pact. The federal government has earmarked 5bn for the expansion of study places (building investments) and 0.9bn for the Teaching Quality Pact (equipment investments).

2.3 Program classification

Based on the information, we classify the 24 programs along four criteria to construct an instrument series for public investment.

1. No reverse causality. We ensure that the instrument is not affected by reverse causality. The problem might arise if the government uses public investment to stabilize current, that is, within quarter output fluctuations. This would bias the estimates and distort the causal interpretation of the results. We carefully determine for each program the underlying political motivation stated in the text sources. We differentiate between exogenous and endogenous investment programs, following Romer and Romer (2010) and Gechert et al. (2021). The former are launched to meet medium and long term goals. The motivation can be potential growth and structural/regional policy, education infrastructure, or modernization. The latter programs contain short run investment funds as a reaction to macroeconomic shocks and are excluded.

2. No concurrent government consumption programs We verify that there are no concurrent government consumption programs. Public spending packages often contain both government consumption and investment. For each investment program, we check whether there was also a government consumption program or raises of public wages. If this is the case, we disregard the program. Section 2.7 of the companion paper provides the details of the process.

3. Quantifiability We check whether we can determine the size of the program. If so, we use the total amount that is stipulated by the government over the planing horizon. Thereby, we emphasize the information effect of new investment. The sensitivity analysis shows that the results are robust to weighting the program size by its inverse duration (Figure A.7). We normalize the program volume by nominal GDP. If we cannot quantify the program, we disregard it.

4. Datability We make sure that we can extract the exact start and expiration date of the program. Public funds can flow from the start date onward such that public institutions (federal, states, or municipalities) and private firms can invest immediately. The financial reports and draft laws usually contain both the announcement and the resolution dates.[6] For many programs, the two are within the same quarter. For the remaining ones, we use the resolution date.[7]

Overall, we exclude 7 investment programs that are either in response to business cycle fluctuations or contaminated by concurrent consumption programs. The exclusion is indicated in the final column of Table 1. This leaves us with 17 exogenous and pure investment programs.

2.4 The Instrument

The resulting instrument series is shown with bars in Figure 1. We have 24 non-zero observations. We have more positive than negative values as investment programs are often topped up and as several programs end after the sample. The instrument spikes in the 1970s, after reunificationcation in the 1990s, following the global financial crisis in the late 2000s, and with the renewed investment impetus at the end of the sample. The maximum is 1.12% of GDP in 1989Q1. The minimum is –0.69% in 1981Q4. The mean and standard deviation are 0.02 and 0.17, respectively.

The solid line with circles shows detrended public investment. The instrument captures

[6]Differences in the legal classification of an investment program as core or extrabudgetary do not play a role in the analysis since both investment expenditures are treated equally in both the government finance statistics and the national accounts. Section 2.9 of the companion paper provides more details.

[7]Fiscal foresight is unlikely to be a main problem. In Germany, investment programs are usually decided without public discussion on an ad-hoc basis by the incumbent government to strike a compromise within the coalition and, unlike tax changes, they are not deliberately pre-announced with long notice. The robustness analysis confirms this notion by showing that the results are essentially unaffected when including forward-looking variables into the model (Figure A.10). We set the expiration date according to the scheduled total duration of the program. We code positive and negative values of the same size at the start and expiration date of each program. Extensions or enlargements of existing programs are treated as new programs with potentially new expiration dates. If we cannot date the program, we disregard it.

movements in this series. Many non-zero instrument observations coincide with large changes in the data. For example, there are spikes in public investment in 1977Q1, 1978Q2, and 1989Q1, and visible drops in 1981Q4 and 2014Q4. In some instances, the instrument precedes the actual increase in public investment, as in 2006Q2 and 2009Q4, for example.

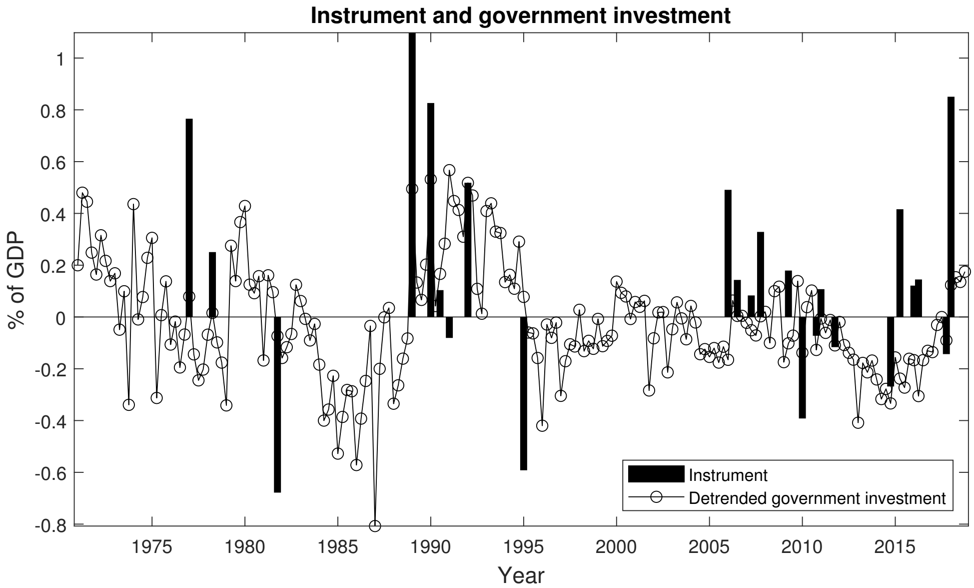

Figure 1: Instrument for government investment shocks and detrended government investment. *Notes:* A positive bar indicates additional public investment by the government. The line with circles shows detrended government investment. Investment includes public gross fixed capital formation and investment grants. The sample is from Germany for the period 1970Q1-2018Q4.

3 Estimation of the government investment multiplier

3.1 The Proxy-SVAR model

The econometric framework is based on the external instrument approach for SVARs developed by Stock and Watson (2012) and Mertens and Ravn (2013). These studies allow for several instrumental variables for the identification for more than one type of structural shocks. We use one instrument for one type of shocks: the instrument of Section 2 for the identification of government investment shocks. The reduced form VAR model is

$$y_t = c + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \Gamma x_t + u_t \tag{1}$$

and refers to quarterly endogenous variables in the $k \times 1$ vector y_t. The vector c includes constants, the matrices A_p and Γ lag and contemporaneous coefficients, respectively, the vector x_t exogenous variables, and the vector u_t serially uncorrelated reduced form innovations with $u_t \sim \mathcal{N}(0,\Sigma)$.

In the baseline specification, y_t includes government investment, private investment, private consumption, GDP, tax revenues, and government consumption for the period 1970Q1-2018Q4. All variables are seasonally adjusted, in real terms, and per capita. Moreover, they are scaled by real per capita trend GDP, using a fifth-order polynomial for computing the log-trend, and enter the model in levels. By de-trending, we focus on the temporary effects of government investment, following the literature on business cycle stabilization (Ramey, 2016; Ramey and Zubairy, 2018). Appendix A.1 contains details on the variables, definitions, and sources. We set $p = 4$ as is standard in SVARs with quarterly fiscal data (Ramey, 2011; Caldara and Kamps, 2017).[8]

The vector x_t includes quarter dummies and, following Gechert et al. (2021), a linear trend, a reunification dummy, and a financial crisis dummy. The linear trend captures the secular decline of government investment/GDP and the concurrent increase in government consumption/GDP (Figure A.1), which the model otherwise has difficulty matching. The quarter dummies capture potential remaining seasonality as we need to seasonally adjust several variables by hand. For example, the investment grants are not seasonally adjusted by the source. Appendix A.2.3 shows the robustness with respect to the SVAR specification.

The choice of the baseline variables follows the benchmark in the literature adapted to our research question. Blanchard and Perotti (2002) include government spending, tax revenues, and output. Their measure of government spending is the sum of public investment and public consumption. We break the sum up into its components as we want to estimate the effects of government investment shocks, while controlling for government consumption. We compute public investment as the sum of public gross fixed capital formation from the national accounts statistics and public grants to the private sector from the government finance statistics to align the definition with that of the instrument, which includes both components. If we neglected grants in the VAR variable, we would overestimate the government investment multiplier. Moreover, we add private investment and private consumption to determine crowding in/out effects.

We test the invertibility of the VAR using the Granger causality test proposed by Stock and

[8]The Ljung-Box test for autocorrelation never rejects the null hypothesis of no autocorrelation of the residuals at a significance level of 10% or lower for lags 1-4 or 1-8. White tests of the residuals reject the assumption of homoskedasticity only for government consumption (at 1%). Similarly, Engle's test rejects the assumption of no ARCH in the residuals at lags 1 to 1-4 only in case of private consumption (at the 5% for lag 1).

Watson (2018). We add $p = 4$ lags of the instrument to each VAR equation and test whether the lags jointly predict the endogenous variable. The largest F-statistic is 1.67 and the associated p-value is 0.16. Thus, the test results indicate that there is no statistically significant evidence against the null hypothesis of invertibility. Table A.1 contains the details.

The VAR innovations are assumed to be linearly driven by a government investment shock ϵ_t^{IG}, which we aim to identify, and other structural shocks ϵ_t^*, which are of no interest for this paper. The VAR innovations u_t are related to the structural shocks ϵ_t^{IG} and ϵ_t^* as

$$u_t = b^{IG}\epsilon_t^{IG} + B^*\epsilon_t^*. \tag{2}$$

We order the government investment shock first. This is without loss of generality as identification will not rely on a Cholesky decomposition. The $k \times 1$ vector b^{IG} captures the impulse vector to a government investment shock of size 1. We normalize the variances of the structural shocks to unity such that b^{IG} captures the responses to a one standard deviation shock, which allows measuring the efficacy of public investment.

For identification, we assume that the instrumental variable m_t constructed in Section 2 is correlated with the latent government investment shock and uncorrelated with the other structural shocks. Hence, it fulfills

$$E(m_t\epsilon_t^{IG}) \neq 0 \text{ and } E(m_t\epsilon_t^*) = 0. \tag{3}$$

If the relevance and exogeneity condition hold, the instrument is valid.

We use m_t to consistently estimate b^{IG} and identify ϵ_t^{IG}. In the first step, we estimate the relative impulse vector. It is defined as $\tilde{b}^{IG} = b^{IG}/b_1^{IG} = (1, b_2^{IG}/b_1^{IG}, \ldots, b_k^{IG}/b_1^{IG})'$. It captures the responses of the last $k-1$ variables relative to the first variable, which is government investment. We estimate $\tilde{b}^{IG}$ as $(1, \hat{\beta}_2/\hat{\beta}_1, \ldots, \hat{\beta}_k/\hat{\beta}_1)'$ through the regressions

$$\hat{u}_{it} = \alpha_i + \beta_i m_t + \eta_{it},\ i = 1, \ldots, k, \tag{4}$$

where $\hat{u}_{it}$ are the estimated VAR innovations of equation i of model (1) and $\hat{\beta}_i$ is an estimate of β_i. The consistency of the estimate for $\tilde{b}^{IG}$ follows from the fact that $E(u_t m_t) = b^{IG}\phi$ with $\phi = E(m_t\epsilon_t^{IG})$, due to (3). In the second step, we combine the estimate of $\tilde{b}^{IG}$ with the covariance restrictions $\Sigma = BB'$ with $B = [b^{IG}, B^*]$ to obtain the absolute impulse vector b^{IG}. Inference is based on a standard fixed-design residual wild bootstrap with 1000 replications. Figure A.20

shows that the results are robust to a moving block bootstrap.

One main advantage of the instrumental variable strategy is that it does not rely on exclusion restrictions. It allows for the possibility that the fiscal authority responds to business cycle fluctuations contemporaneously. Technically, it does not impose a recursive structure on the impact matrix B with government spending ordered first. Such an ordering is usually justified by legislative decision lags that prevent policy makers from responding within quarter (Blanchard and Perotti, 2002). However, the assumption is debatable given that fiscal policy may sometimes adapt spending quickly in response to the state of the economy. For example, many countries issued large stimulus packages during the global financial crisis and the Covid-19 pandemic in 2008Q4 and 2020Q1-Q2. Caldara and Kamps (2017) show that already a small contemporaneous response of government spending to output can have a large effect on the estimated government spending multiplier. Moreover, in our context a recursive structure is difficult to justify as it is unclear whether government investment or government consumption should be ordered first.[9]

To assess the validity of the instrument, we perform several tests. First, we determine whether it is autocorrelated or predictable. We regress it on 1 up to 1-4 lags of itself and of the endogenous variables and test whether the lags of the instrument are jointly significant or whether all predictors are jointly significant. The p-values of all tests exceed 0.1 and the F-statistics of the regressions never exceed 1 for all lag combinations. This suggests that the instrument is neither autocorrelated nor predictable. Table A.2 contains the details.

We evaluate the relevance of the instrument. We compute the F-statistic of the null hypothesis that $\beta_1 = 0$ (see 4). It is 12.15 with p-value of 0.00. Alternatively, we compute a Huber/White robust and a HAC F-statistic.These statistics are 32.54 and 32.71 with p-values of 0.00.[10] Finally, we compute the reliability measure of Mertens and Ravn (2013) by regressing the identified government investment shocks on the non-zero instrument observations. The R^2 of the regression is as high as 0.65 and the p-value on the coefficient of the instrument is 0.00, suggesting a high explanatory power of the instrument for the shocks. Overall, we conclude that the instrument is not autocorrelated or predictable and that it is strong. Table A.3 contains the details.

[9]Another important advantage of the instrumental variable approach is that it accounts for potential measurement error in the proxy series. While we construct the instrument with great care, coding the exact amount of additional public investment from the legislative documents is prone to measuremnt error given the forecast errors and political bias in these documents. Stock and Watson (2012) and Mertens and Ravn (2013) show that the Proxy-SVAR accounts for such problems provided that the instrument is valid.

[10]Figure A.2 shows the distributions of the F-statistics from 1000 bootstrap replications. The shares of the statistics below the 5% critical value of 3.89 are 0.06% (OLS), 0.01% (robust), and 0.01% (HAC). The shares of the statistics below 10 are 45.00% (OLS), 0.31% (robust), and 0.30% (HAC).

3.2 The macroeconomic effects of government investment shocks

3.2.1 The dynamic effects of government investment shocks

Figure 2 shows the responses of the baseline variables to a positive government investment shock of one standard deviation for 20 quarters. The shaded areas are one and two standard error confidence bands. The shock size implies that government investment increases by 0.18% of trend GDP upon impact. It drops quickly back to 0.07% within the first year, but stays significantly above trend until the end of the response horizon.

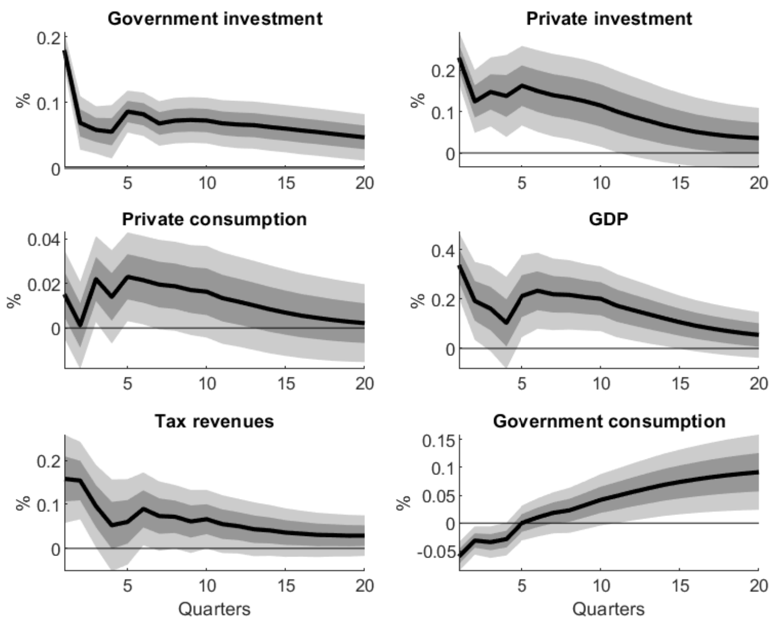

Figure 2: Dynamic effects of government investment shocks. *Notes:* The figure shows the responses of the baseline variables to a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are 1 and 2 standard error confidence bands based on 1000 bootstrap replications. All variables are expressed relative to trend GDP.

The large impact effect might reflect that the financial situation of municipalities–which are particularly important for infrastructure investment–is traditionally tense. Municipalities first and foremost have to fulfill and finance their obligatory tasks like public safety, fire departments or the local administration. Investment projects can often only be financed if additional tax revenues or investment grants open unexpected financial leeway. Many municipalities therefore have 'drawer projects' that can be implemented immediately once the government releases new investment funds In addition, projects at municipal level are usually small. The procurement procedures are therefore less formal than for large infrastructure projects, such as the construction of highways, where a Europe-wide tender including time consuming administrative procedures is often required. For example, approximately 40 percent of the 'German Unity' fund benefited municipalities in the former GDR. The funds were immediately available to reconstruct public infrastructure and were exhausted 4 years after implementation. 4bn euro were used directly in the year 1990. The extension (1.2bn) of this fund in 1990Q3 was completely exhausted in 1990Q4.[11]

Private investment increases by 0.23% in the first quarter, drops back, and then shows a hump-shaped pattern. It remains significantly elevated for three years and returns to the pre-shock level after five years. The substantial increase upon impact could to some extent be explained by the fact that publicly owned firms benefit from the government investment programs but are treated as private sector firms in the national accounts. This applies, for example, to state-owned housing companies that benefited from several investment programs through, among others, grants for energy saving investments in the 1970s or the Housing Investment Program starting in 2006. Overall, however, the role of state-owned firms cannot be too large as their share in total private investment is below 10%. Thus, we return to the crowding-in of private investment below and provide a detailed account.

The response of private consumption is more sluggish and smaller. It does not respond much for the first two quarters. Then, it rises significantly and peaks at 0.02% in quarter 5. It returns to the level where it would have been without the shock after five years.

Reflecting the increase in public and private demand, GDP rises for five years as well, and significantly so for four years. The impact response is 0.34% and seems to be largely driven by the two investment components, given the muted initial reaction of private consumption. Thereafter, output drops to 0.10% above trend in quarter 4, probably reflecting the sharp fall in public investment, before increasing private investment and successively higher private consumption

[11] Consistent with this argument and the historic examples, Figure A.4 provides empirical evidence that non-federal government investment shocks have a quicker effect on GDP than federal government investment shocks. The peak output effect of the former is in the first year, while it is in the third year for the latter. The fast increase in public investment is also consistent with evidence for the US. Leduc and Wilson (2013) document that the time from federal grants to states contracting out and firms initiating projects is short and only the outlays lag. Hence, using the government finance statistics would be problematic, while the accrual-based national accounts definition of government investment that tracks the building process and not the cash flow avoids the problem. The integral below the shock response in Figure 2 measures the average investment package, which amounts to 1.4% of GDP over five years. The first quarter accounts for about one tenth. This could reflect a higher number of smaller investment projects upfront (including maintenance and renovation) and/or that for longer projects the building progress in the first quarter is about twice as quick as the mean progress afterwards. For US federal investment spending, Auerbach and Gorodnichenko (2012) also find the peak in the first quarter, but a somewhat slower fallback thereafter. For a sample of OECD countries, Boehm (2020) similarly detects the peak at impact and in addition a quick and strong drop subsequently, with the shock halved in the second quarter.

induce a hump-shaped response. The waveform of the GDP response is as in Leduc and Wilson (2013) who document a similar pattern for US state GDP following an infrastructure spending shock. The authors use a theoretical model to attribute the initial rise to nominal frictions and demand effects, which dissipate over time, and the medium run rise to the productivity of public capital. We add two theoretical channels in Section 4 to explain the empirical GDP response: a private investment adjustment costs effect and a network effect of public investment.

Consistent with the increase in GDP, tax revenues rise significantly over the full response horizon. The impact response is roughly half of the increase in GDP. Combining this with an average tax-to-GDP ratio in Germany of 0.4 yields an estimate of about 1 for the elasticity of tax revenues to output fluctuations. This is closely in line with OECD estimates of this elasticity obtained from an alternative approach and suggests that the government does not contemporaneously adjustment other tax instruments to finance the public investment shock.

Finally, government consumption drops slightly upon impact. The drop suggest a substitution between the two public spending categories. The sensitivity analysis shows that this effect is specific to an investment packages just before reunification. If we remove it (or weight the instrument inversely with the duration of the program), the response of government consumption is essentially zero in the first year (Figures A.5 and A.6). Thereafter, it rises persistently above trend, likely mirroring a higher public wage bill and additional demand for intermediate goods, given a higher public capital stock following the strong and persistent increase in government investment. For example, Leduc and Wilson (2013) argue that more highway investment requires additional police services, traffic control, snow removal, and future maintenance. Similar outlays are triggered by railway investments. In case of public facilities, the government needs to hire cleaning and maintenance services and buy fitments.

Based on the impulse responses, we estimate the output multiplier. We compute the ratio of the cumulative sum of output to the cumulative sum of public investment to obtain the euro-per-euro effect of exogenously higher public investment on GDP. We do this also for each bootstrap replication to produce error bands that take into account the correlation between the two impulse responses. Figure 3 shows the multiplier for 20 quarters. The multiplier is significantly positive and larger than one over the full horizon. It is 1.9 upon impact. Then, it increases to 2.3 in the first year. It slowly rises further to about 2.5 for years two and three, before falling slowly. The long run multiplier after ten years (not shown in the figure) is 1.7.

The estimated multiplier around 2 is in line with the meta study of Gechert (2015). He

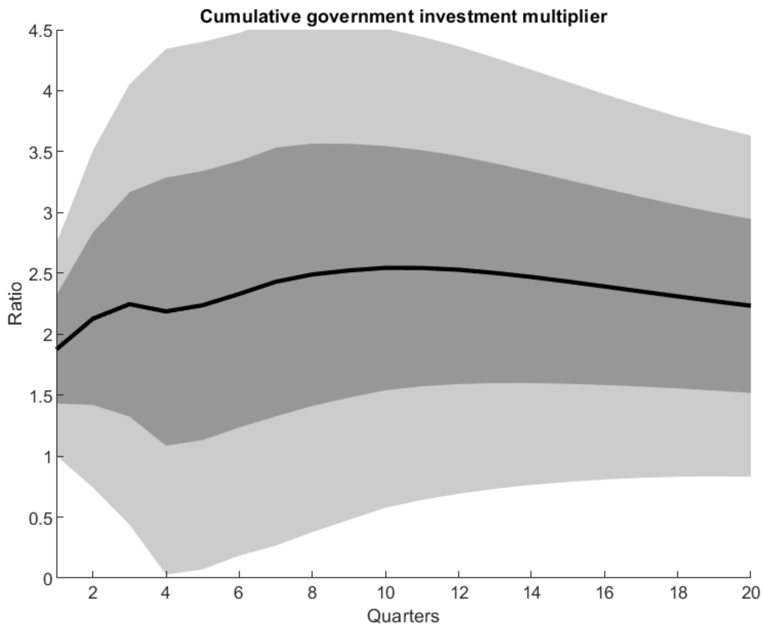

Figure 3: Cumulative government investment multiplier. *Notes:* The figure shows the cumulative government investment to output multiplier following a positive government investment shock identified with an external instrument over 20 quarters. The shaded areas are 1 and 2 standard errors based on 1000 bootstrap replications. The multiplier is computed as the cumulative sum of the output response divided by the cumulative sum of the government investment response shown in Figure 2.

documents an average multiplier of 1.4 with a standard deviation of 0.9. But his study does not distinguish between short and medium run effects. Our medium run multiplier is within the typical range (Ramey, 2021). Our short run multiplier of 2 is close to the value of Auerbach and Gorodnichenko (2012) for the US, but about 1 points larger than in Ilzetzki et al. (2013) for a sample of developed countries, and 2 points larger than in Boehm (2020) for a sample of OECD countries.[12] The last three studies are all based on recursive identification schemes. Caldara and Kamps (2017) show analytically that this scheme tends to underestimate multipliers identified with external instruments. Our estimates may also reflect circumstances specific to Germany. We explore these possibilities in the next subsection.

3.2.2 Multiplier estimate in perspective

We compare the estimated multiplier along three dimensions: (1) internationally to see whether the results based on German data can be generalized to other Western European countries, (2) to

[12] It is also larger than the multipliers obtained from calibrated DSGE models (Leeper et al., 2010; Ramey, 2021), which are mostly between 0 and 1.

a Cholesky decomposition to see how much differences with previous studies are due to different identification strategies, (3) to the government consumption multiplier in Germany to see how much the type of public spending matters.

In Figure 4, the solid line with circles and the shaded areas repeat our baseline estimate. First, we compare it to the government investment multiplier in the euro area. We use an indirect instrumental variable identification since we lack valid instruments for government investment shocks in these countries. The underlying SVAR includes the same endogenous variables as the baseline model (see Equation 1) with the same transformations. The sample contains all original euro area countries except Germany and Ireland and covers the period 1999Q1-2018Q4. We exclude Germany because we want to compare the results for the other countries to the estimate for Germany. We exclude Ireland because of strong methodological changes in the national accounts statistics during the sample. The model includes country and year fixed effects as well as quarter and financial crisis dummies.

The indirect instrumental variable approach follows Caldara and Kamps (2017) and Angelini et al. (2024). It consists of estimating the government investment reaction function and using the residual of that equation as a measure of government investment shocks. The standard approach in the literature assumes no contemporaneous response of government investment to the business cycle and justifies the assumption with implementation lags in the political process (Blanchard and Perotti, 2002). Technically, this amounts to ordering government investment first in the SVAR, using a Cholesky decomposition of Σ, and interpreting the first shock to the system as a government investment shock. We relax the assumption and allow for a contemporaneous response of policy to output. During the global financial crisis and the corona pandemic, for example, fiscal policy responded to the recession within the same quarter. Caldara and Kamps (2017) show that a simple rule gives similar results as more complicated rules that allow for direct fiscal responses to other shocks since these will ultimately show up in the output gap.

In the SVAR, the fiscal reaction function is specified in terms of the residuals, that is, the variation in government investment and output net of the effects of the lags and exogenous variables. The regressand is the government investment residual and the regressor is the output residual. To obtain an unbiased estimate of the reaction of the former to the latter, we need exogenous variation in the latter. We use a two-stage instrument strategy. In the first stage, we regress the output residual on the quarterly growth rate of the global real price of oil. We measure the real oil price as the nominal growth rate of the average US refiner acquisition crude

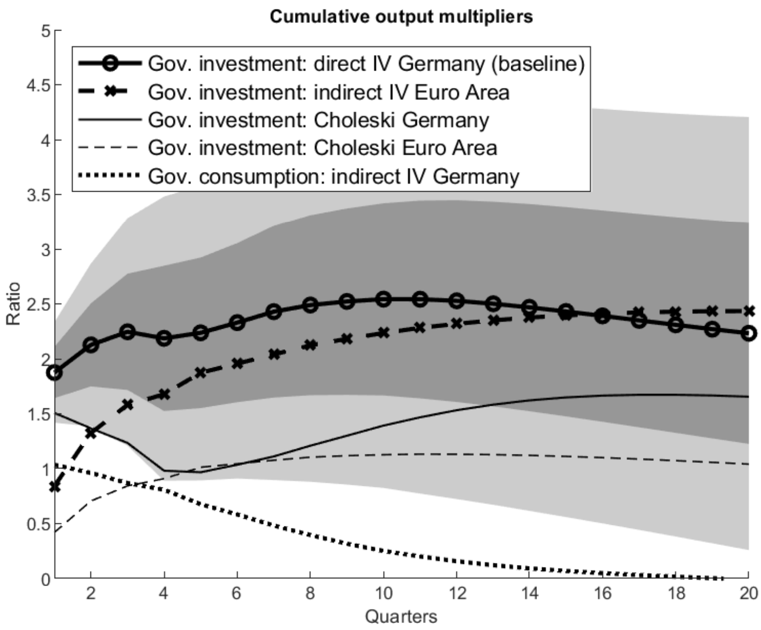

Figure 4: Comparison of cumulative government spending multipliers. *Notes:* The figure shows government spending-to-output multipliers in Germany and other euro area countries over 20 quarters. The solid line with circles (o) shows the baseline estimate, that is, the government investment multiplier in Germany identified with an external instrument. The corresponding shaded areas are 1 and 2 standard error confidence intervals based on 1000 bootstrap replications. The dashed line with crosses (x) shows the government investment multiplier in all euro area countries except Germany and Ireland based on an indirect instrumental variable identification. The solid (–) and dashed (- -) line show the government investment multiplier in Germany and the euro area countries, respectively, based on a Cholesky decomposition. The dotted line (:) shows the government consumption multiplier in Germany based on an indirect instrumental variable identification. The multipliers are computed as the cumulative sum of the output response divided by the cumulative sum of the government spending response.

oil import price in US dollar minus US GDP deflator inflation. We assume that oil price growth correlates with the output residual but not with the government investment shock. The instrument is strong. The first-stage F-statistics are 10.48 (OLS) and 11.45 (robust). The estimate of the contemporaneous response of government investment to output is –0.07, in line but a bit below the estimate of Caldara and Kamps (2017) for the US and total public spending of –0.15.

The resulting multiplier is depicted by the dashed line with crosses. In the first year, it is on average 1.2 vis-à-vis a baseline estimate of 2.1. In the second year, the average multipliers are 1.8 and 2.4 for the euro area and Germany, respectively. Thereafter, the point estimates converge further to a value of about 2. Generally, the euro area estimate is within the error bands of the baseline estimate, except for the first two quarters, suggesting that the two are not statistically different from each other. The initial difference can reflect several factors: sampling error, different identification strategies, or structural economic differences between the samples.

The dashed and solid thin line show the multiplier for the euro area and Germany, respectively, when using a Cholesky factorization of Σ. This identification assumes no contemporaneous response of public investment to the business cycle. For the euro area, the difference between both identification strategies is 0.5 initially and widens to 1. For Germany, the gap is similar, with larger differences in-between. The comparisons suggest that recursive identification underestimates the government investment multiplier, in line with the arguments of Caldara and Kamps (2017).[13]

Finally, the dotted line shows the government consumption multiplier in Germany. It is based on the indirect approach. We order government consumption first in the SVAR and instrument the output residual in that equation with the growth rates of US real GDP and world industrial production. The F-statistics are 10.44 (OLS) and 18.48 (robust).[14] The government consumption multiplier in Germany is on average 0.9 in the first year. Its halflife is one year, falling to 0.5 in the second year and to 0.23 in the third year. The estimate is consistent with previous evidence for Germany (Tenhofen et al., 2010; Cimadomo and Bénassy-Quéré, 2012). Over the full horizon, the consumption multiplier is smaller than the investment multiplier. At impact, the difference is 1. Thereafter, it widens as the consumption multiplier declines more quickly. This difference suggests another reason for why estimates of the total government expenditure multiplier, which dominate the literature, tend to be lower than our baseline estimate of the government investment multiplier. These estimates mix the larger and more persistent output effects of government investment with the smaller and less persistent output effects of government consumption shocks.

3.2.3 The importance of government investment shocks

We return to the baseline model and measure the average economic importance of government investment shocks for macroeconomic fluctuations. Table 2 shows the forecast error variance decomposition. It gives the percentage contribution of the government investment shocks to the unexpected variation of the endogenous variables at forecast horizons of 4, 8, 20, and 100 quarters, where the last value approximates the unconditional variance decomposition. At the one-year horizon, the shocks explain 9-22% of the variation in private investment and GDP but only 4% of

[13]The large short run multiplier of the baseline may reflect economic conditions that are specific to Germany and the sample period. First, the public capital stock was relatively low in East Germany before reunification. A lower initial public capital stock typically implies higher output multipliers. But we show in the sensitivity analysis that the multiplier is robust to excluding the reunification packages. Second, risk premia and interest rates are low and stable in Germany, which reduces crowding-out and non-Keynesian effects. Third, there was an important labor market reform in 2005 that led to many years of extreme wage moderation. This potentially tempered real wage increases and crowding-out effects.

[14]The real oil price growth as instrument yields F-statistics of only 1.04 (OLS) and 2.14 (robust).

private consumption. Thereafter, their importance decreases slightly for private investment, to 17%, but increases for private consumption and output. For the latter two variables, the variance shares are 6% and 17% after five years. In the long run, the shocks account for roughly 19%, 14%, and 17% of the variability in private investment, private consumption, and GDP, respectively. The explanatory power of the shocks for the variability of taxes and government consumption is about 10% in the short run and 14-23% in the long run.

Horizon	Gov. inv.	Priv. inv.	Priv. cons.	GDP	Taxes	Gov. cons.
4	52.6	21.6	3.6	9.0	10.3	11.3
8	52.0	21.9	6.4	13.2	10.2	5.9
20	48.0	17.3	6.0	17.4	11.7	11.6
100	42.9	18.9	14.2	17.3	13.6	22.7

Table 2: Percentage variance contribution of government investment shocks. *Notes:* The table shows the percent contribution of the government investment shocks to the forecast error variance of the endogenous variables in y_t over horizons of 4, 8, 20, and 100 quarters ahead.

Overall, these numbers seem consistent with the size of the estimated output multiplier. Furthermore, they imply that government investment shocks account for a large portion of the fluctuations in the data. Appendix A.2.2 provides an analysis of the government investment shocks and a historical decomposition of GDP, showing that the estimated shocks and their contribution to GDP correspond to the history of public investment in Germany and to the narrative of the instrument. This is a solid basis for the impulse response matching below, which estimates the DSGE model only on this component of the variation in the data.

3.2.4 Shock propagation through the economy

We add variables to the baseline model one-by-one to study how the output effects come to pass. This approach follows Ramey (2011) and is a particularly flexible. It does not require a Bayesian perspective, nor a panel or factor structure to deal with the curse of dimensionality, given that the baseline model already contains 165 parameters. In all augmented models, the instrument is strong. The lowest robust F-statistics is 15.17.

Figure 5 collects the responses of a first set of additional variables. The top panels look at the financing of the additional public outlays. The budget balance/GDP increases shortly and then undershoots slightly, but the response is mostly insignificant. The one-year and ten-year government bond rate both increase significantly upon impact and remain elevated for two years. The next panels indicate why private investment is not crowded-out. Both the corporate bond rate and the bank bond rate increase only mildly. They rise by essentially the same amount as the one-year government bond rate. The credit spread, which is computed as the differences between the corporate bond yield and the one-year rate, actually drops a bit. As the GDP deflator first remains constant and then slightly rises, the ex-post real interest rate spikes only shortly and then falls persistently below trend. Hence, real interest rates relevant for firms financing decisions remain roughly constant.

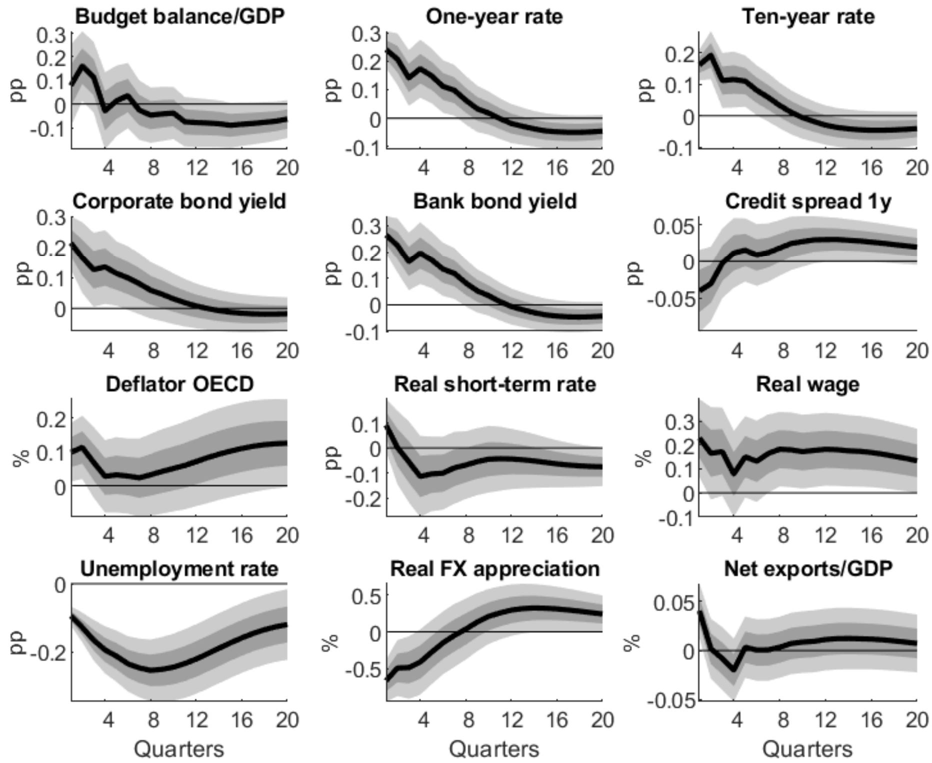

Figure 5: Economy-wide effects of government investment shock. *Notes:* The figure shows the responses of macroeconomic variables following a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are 1 and 2 standard errors based on 1000 bootstrap replications. The variables are added, one at a time, to the baseline SVAR.

The next two panels show the real wage and the unemployment rate. Their responses are important for distinguishing labor demand and supply effects and thereby real business cycle (RBC) from New Keynesian (NK) effects. RBC models typically predict a fall in the real wage because the government extracts resources from the private sector, which implies a negative wealth effect. Households lower consumption and leisure and increase labor supply, leading to a fall in the real wage. In contrast, NK models with labor market frictions imply that output and labor are demand determined such that the real wage rises. We find an increase in the real wage by 0.2% and a strong and persistent decline in the unemployment rate by close to 0.3% points.

These patterns are consistent with NK models in which demand dominate supply effects in the short run. The final two panels look at the external sector of the economy. The real effective exchange rate depreciates and then overshoots after two years. Consistently with the initial dip, the net export/GDP ratio rises upon impact. But then it is insignificant.

Figure 6 shows specific investment components.[15] The top panels show the responses of the three national accounts subcomponents of public investment: construction, equipment, and other investment. Government construction investment (infrastructure, residential and non-residential buildings) reacts most. It increases by nearly the same amount as total government investment and with a similar shape subsequently (compare Figure 2). Government equipment investment (machines, equipment, and vehicles) also rises significantly for most of the horizon but accounts for only a small fraction of the total increase. Other government investment (research, development, software, and patents) tends to fall, although largely insignificantly.

The middle panels contain the reaction of the three corresponding private investment categories. Private construction and equipment investment mirror the public components closely. Private other investment increases as well. All three private investment categories are crowded-in. The next three panels decompose the main private investment driver, construction, further into residential and non-residental investment. Both subcomponents increase persistently and by similar amounts. Non-residential investment can further be decomposed into civil construction and building construction. Again, both parts rise persistently and similarly.

The last two panels return to public investment and look at public grants to the private sector and one of the main components of these, grants to the state-owned railway company. Total grants increase by only 0.03%, of which 0.02% points go to the national railway company. The two responses are not directly comparable to the others, however, as the data start only in 1991Q1.

Overall, the investment responses paint a clear picture. More than 80% of the exogenous increase in government investment goes into construction. This is nearly one-to-one reflected in the reaction of private investment. Here, 80% of the overall increase is due to private construction. Within this category, the crowding-in is broad-based, falling similarly on both residential and non-residential and in the latter on civil and building construction. The role of public grants to privately-owned companies is negligible.

[15] The instrument is strong in all augmented models for the full sample. The lowest robust F-statistic is 25.27. The inclusion of the last two variables in the figure reduces the sample to begin in 1991Q1. The robust F-statistic falls to 8.95.

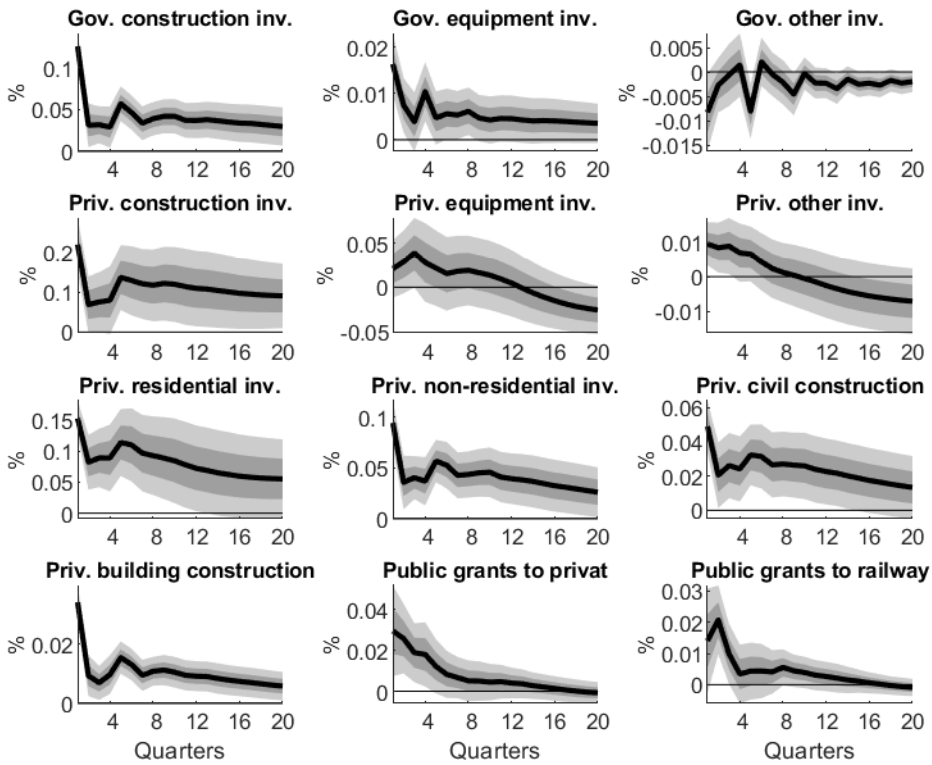

Figure 6: Investment responses to government investment shock. *Notes:* The figure shows the responses of public and private investment components following a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are 1 and 2 standard errors based on 1000 bootstrap replications. The variables are added, one at a time, to the baseline SVAR.

3.2.5 Facets of investment packages

We illustrate alternative facets of the narratively identified investment packages. Most of the packages contain several investment measures. The three broadest categories are non-education infrastructure, education infrastructure, and grants to the private sector. We classify each package that goes into the baseline proxy into one category based on its main components.[16]

Figure 7 contains the results.[17] The line with circles and shaded areas repeat the baseline multiplier based for comparison. The line with asterisk shows the multiplier for 15 predominantly infrastructure packages. It is slightly above the baseline in the first few years, suggesting

[16]While the resulting three proxies are mutually exclusive over time, their economic content is not. For example, all the packages that go into the education proxy also contain either some non-education investment or grants. A construction of orthogonal proxies is not possible because of a lack of sufficient mutually exclusive instrument variation. Nevertheless, the alternative instruments are instructive for gauging the size and timing of the output effects of different investment types.

[17]The robust F-statistic for the non-education infrastructure, education infrastructure, grants, and endogenous investment instrument is 33.04, 8.47, 8.43, and 6.20, respectively.

that non-education infrastructure generates a bit larger output effects in the short run than education/childcare infrastructure investments or investment grants.

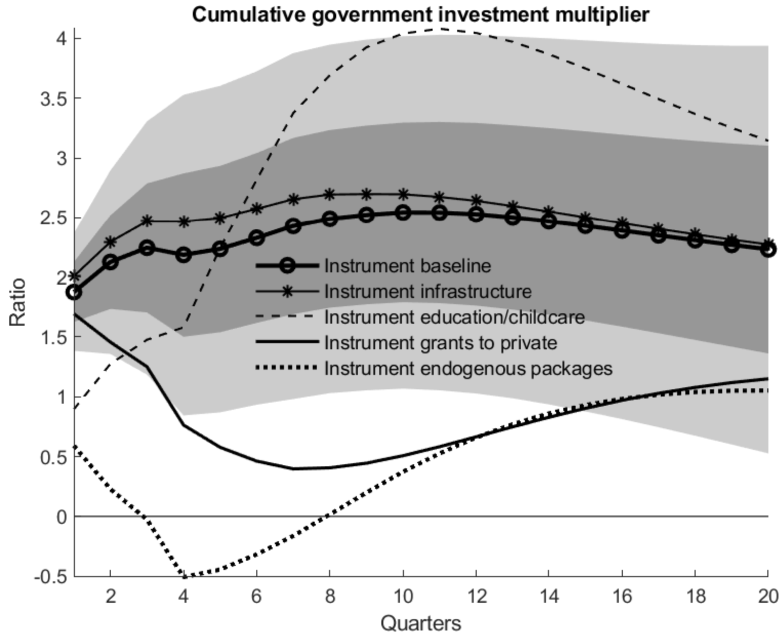

Figure 7: Comparison of cumulative government investment multipliers. *Notes:* The figure shows government investment-to-output multipliers in Germany over 20 quarters. The solid line with circles (o) shows the baseline estimate. The corresponding shaded areas are 1 and 2 standard errors based on 1000 bootstrap replications. The line with asterisk (*) shows the multiplier based on an instrument for public infrastructure investments, the dashed line (- -) is based on an instrument for public education/childcare investments, the solid line (–) is based on an instrument for grants to the private sector, and the dotted line (:) is based on an instrument for total government investment endogenous to the business cycle. The multipliers are computed as the cumulative sum of the output response divided by the cumulative sum of the government spending response.

The impression is confirmed by the dashed line that refers to the instrument based on 7 predominantly education infrastructure packages. The multiplier is clearly below the baseline for the first year but then overshoots it substantially, peaking at 4 after three years. The solid line shows the multiplier based on the instrument for packages that contain mostly grants (only 2). While the initial output effect is similar to the ones of the other two types of government investment, it quickly dies out and falls below unity (before increasing again), suggesting some front loading of the private responses and then crowding-out.

Finally, the dashed line is based on an instrument that includes only the endogenous investment packages to see whether the narrative separation between endogenous and exogenous packages bears out in the data and whether the spending composition differs between the two. While the impact multiplier is shortly positive, it turns negative quickly and output only recovers after two years. The dynamics affirm the classification as endogenous since this instrument picks up periods of low growth and recessions that are not fully counteracted by the fiscal impulse. Second, besides the downward shift in the first 10 quarters, the dynamic of the multiplier is similar to that for grants to firms. This impression is substantiated when looking at the components of these stimulus packages. The most important part are grants to the private sector, which are often used in stimulus packages to stabilize private demand in times of crisis.

The comparison of the exogenous programs suggests that non-education infrastructure investments are the best short run stimulus and a decent medium run output boost. Education infrastructure yields the largest medium run multiplier. Grants to the private sector can be effective in the very short run but are dominated by infrastructure investments already after a few quarters.

3.3 Sensitivity analysis

We conduct an extensive sensitivity analysis, which we summarize in Appendix A.2.3.

4 Decomposition of the government investment multiplier

In this section, we build a DSGE model that aims to capture the crowding-in of private investment and private consumption documented above. Hence, the model is of the New Keynesian type. It includes a fiscal and monetary authority, rule-of-thumb consumers, physical capital, nominal rigidities and real frictions, as well as a network production structure. Given the limited empirical role of the external sector, we assume a closed economy.

4.1 Public investment in a New Keynesian DSGE model

The model builds on Leeper et al. (2017). It has a rich fiscal sector that includes consumption taxes, labor taxes, capital taxes, transfers, government consumption, long-term government debt, and substitutability/ complementarity between private and government consumption. We add government investment and a production network. Public investment has three main effects. The first is standard in the literature since Baxter and King (1993). Intermediate good producer i uses public capital K_t^G together with private physical capital $K_t(i)$ and employment $L_t(i)$ to produce value added $VA_t(i)$:

$$VA_t(i) = \exp(e_{a,t})\, K_t(i)^{\alpha}\, L_t(i)^{1-\alpha} (K_{t-1}^G)^{\alpha^{kg}} - \bar{O}, \tag{5}$$

where α^{kg} and α is the production elasticity of public and private physical capital, respectively. $e_{a,t}$ is deterministically growing total factor productivity and $\bar{O}$ are fixed costs to production. This specification assumes constant returns to private inputs. α^{kg} determines the productivity of public capital. If $\alpha^{kg} > 0$, public capital is productive. If $\alpha^{kg} \leq 0$, it is unproductive because there is congestion or waste. The parameter is crucial for the medium run effects of public investment but there is considerable uncertainty in the literature about its size (Bom and Ligthart, 2014). Thus, a main goal of the subsequent analysis is the estimation of this parameter.

To the standard effect of public investment, we add a short run effect to account for the immediate crowding-in of private investment found in the data. Specifically, we assume that public investment affects private investment adjustment costs $\Phi_t(j)$ of household j who is the owner of private physical capital:

$$\Phi_t(j) = 1 - \frac{\kappa^k}{2}\left(1 - \kappa^g - \frac{I_t(j)}{I_{t-1}(j)} + \kappa^g \frac{I_t^G}{I_{t-1}^G}\right)^2, \tag{6}$$

where $I_t(j)$ is private investment, I_t^G public investment, and the parameters κ^k and κ^g measure the sensitivity of the adjustment costs to changes in these investment components. Hence, κ^g affects the short run dynamics. If $\kappa^g > 0$, public investment reduces private investment adjustment costs. $\kappa^g \times 100$ can be interpreted as the percentage reduction in private costs.

The mechanism captures the economic definition of public capital: an enlargement of public infrastructure, investment into schooling and child care, as well as grants to state-owned firms reduce the costs of installing new capital in the private sector. For example, the building of roads, telephone lines, and highways that connected West and East Germany after reunification lowered private transportation time and trade costs of equipment and machinery. Similarly, public infrastructure provision spurred private construction investment. Moreover, the modernization and enlargement of public universities as well as child-care in schools and playschools in the late 2000s may have increased labor supply and thereby spurred private investment. In addition, federal investment programs typically include investment grants to lower layers of the government and their public service firms. This may stimulate private investment. Conversely, if $\kappa^g < 0$ there is congestion. Hence, our second central goal is estimating the value of this parameter.

As a third channel, we consider a production network. At the upstream, we distinguish between intermediate goods and manufacturing goods. The latter are used downstream to produce final consumption and capital goods. At each level, production units are in monopolistic competition and bundlers in perfect competition. All firms use private and public inputs. This assumption relfects that in practice essentially all firms in an economy use public goods to some extent. For example, they use public infrastructure (transport networks, digital infrastructure, public leisure facilities) or public investment in equipment and R&D (software, basic research, patents). At the same time, we impose the constraint that production units can only use as much public goods as the government offers price-inelasticly. An individual firm will use all public investment offered to reduce its production costs. Hence, the additional constraint is always binding.

The public investment usage function of the representative firm j in sector Y is:

$$I_t^{YG} = s^{YG}\left(\left(1+\theta_t^Y\right)\left(\frac{P_t}{MC_t^Y P_t^Y}\right)\right)^{-\sigma^Y} Z_t^Y, \tag{7}$$

where Z_t^Y is the final good produced in the respective sector. θ_t^Y is the shadow price of the public investment good, expressed relative to the sector's good price. The shadow price is positive as the input constraint on public investment is always binding. Thus, more public investment reduces the shadow price and the marginal costs of firms in the sector, which are given by

$$MC_t^Y = \left[(1-s^{YG})\left(\frac{P_t}{P_t^Y}\right)^{1-\sigma^Y} + s^{YG}\left(\frac{P_t}{P_t^Y}\left(1+\theta_t^Y\right)\right)^{1-\sigma^Y}\right]^{\frac{1}{1-\sigma^Y}}, \tag{8}$$

where s^{YG} is the public investment share. σ^Y is the elasticity of substitution between private and public inputs. It is another key parameter that we estimate. If σ^Y is small, private and public input factors are complements, for example, because it is difficult to privately maintain national railroad or highway systems. If σ^Y is high, the two inputs are substitutes.

The dynamics are also determined by the persistence of the public investment shocks. To mimic the empirical shock, we allow the theoretical shock to follow an exogenous AR(3) process: $\log(I_t^G) = \bar{c} + \sum_{k=1}^{3}\rho_k^{ig}\log(I_{t-k}^G) + u_t^{ig}$, where ρ_k^{ig} are the AR-coefficients and u_t^{ig} are *iid* innovations. The persistence is important for the two wealth effects and, hence, for the output multiplier. The first wealth effect implies a positive relation between ρ_k^{ig} and the output multiplier. The more persistent the shocks, the more persistent are the appropriations needed to finance them. This makes households poorer and induces them to work and produce more. The second effect works in the opposite direction. More persistent public investment enhances the production capacity of the economy for longer and makes households richer. The duration of the shock also shapes how long-lasting are the demand effects of public spending. Which effects dominate is a priori unclear and depends on the size of ρ_k^{ig}, the horizon, and the other parameters of the model.

Now, we outline the other blocks of the model. Appendix A.3.3 contains the details.

Private households. A continuum of households is defined over the interval $[0,1]$, consisting of a fraction n of non-saving households (indexed by N) and a fraction $1-n$ of saving households (indexed by S). A saving household j obtains utility through composite consumption $C_t^S(j)$ and suffers utility losses due to hours worked $L_t^S(j)$. Total composite consumption $C_t^S(j)$ consists of private and public consumption $C_t^S(j) = C_t^{S,P}(j) + \alpha^g G_t$, where α^g describes the degree of substitutability between both consumption types. Furthermore, utility obtained by composite consumption depends on the relative comparison between one's own consumption and the consumption of all saving households in the previous period, with the relative importance of the other savers' consumption determined by h: $E_0 \sum_{t=0}^{\infty} \beta^t \left(\log(C_t^S(j) - hC_{t-1}^S) - \chi \frac{(L_t^S(j))^{1+\psi}}{1+\psi} \right)$. The budget constraint of saving households is

$$(1+\tau^c)P_t^C C_t^S(j) + P_t^I I_t(j) + P_t^B B_t(j) + R_t^{-1} B_{s,t}(j) = (1+\rho P_t^B) B_{t-1}(j) + B_{s,t-1}(j)$$
$$+ (1-\tau^W) \int_0^1 W_t(l) L_t^S(j,l) dl + (1-\tau^K) R_t^k \nu_t(j) \tilde{K}_{t-1}^S(j) - \Psi(\nu_t) \tilde{K}_{t-1}^S(j) + P_t Z_t^S(j) + \Pi_t(j),$$

where nominal consumption expenditures $P_t^C C_t^S(j)$ include consumption taxes $\tau^c P_t^C C_t^S(j)$. Nominal investments are divided among the physical capital stock $P_t^I I_t(j)$, one-period private discount bonds $R_t^{-1} B_{s,t}(j)$ which are in zero net-supply, and long-term government bonds $P_t^B B_t(j)$ with decay rate ρ. Expenditures are financed through after tax labor income $(1-\tau^W) \int_0^1 W_t(l) L_t^S(j,l) dl$, interest payments from bond holding $(1+\rho P_t^B) B_{t-1}(j) + R_{t-1} B_{s,t-1}(j)$, the sum of all sector-specific profits $\Pi_t(j)$, and effective capital income $(1-\tau^K) R_t^k \nu_t(j) \tilde{K}_{t-1}^S(j) - \Psi(\nu_t) \tilde{K}_{t-1}^S(j)$, as well as from government transfers $P_t Z_t^S(j)$, where P_t is the output deflator. The effective private capital stock $K_t^S(j)$ is determined by the private capital stock and the utilization rate $K_t^S(j) = \nu_t(j) \tilde{K}_{t-1}^S(j)$. The utilization involves unit costs of $\Psi(\nu_t)$, which are zero in steady state where private capital is fully used. The effective private capital stock evolves according to $\tilde{K}_t^S(j) = (1-\delta) \tilde{K}_{t-1}^S(j) + I_t(j) \Phi_t(j)$, where $\Phi_t(j)$ is given by (6). The nominal consumption of liquidity-constrained household j is defined by the budget constraint:

$$(1+\tau^c)P_t^C C_t^N(j) = \left(1-\tau^W\right)\int_0^1 W_t(l)L_t^N(j,l)dl + P_t Z_t^N(j).$$

We assume that tax rates for saving and non-saving households are identical.

Each household supplies a continuum of differentiated labor services indexed by l. These services are supplied by both saving and non-saving households. A competitive labor agency combines the differentiated services into a homogeneous sector-specific labor input that is sold to the intermediate firms. The labor demand function for different labor types is $L_t(l) = L_t\left(W_t(l)/W_t\right)^{-\epsilon^w}$, where L_t is the demand for composite labor services and W_t is the aggregate nominal wage that satisfies $W_t = \left(\int_0^1 W_t(l)^{1-\epsilon^w} dl\right)^{\frac{1}{1-\epsilon^w}}$. Solving the optimization problem of both household types yields in the symmetric equilibrium the marginal utility of consumption, the intertemporal Euler equation, the price relation between long-term and short-term bonds, the relative price of private capital, and the nominal wage setting equation.

Production network. We assume a multi-stage production network. Intermediate goods (like raw materials) are produced using private and public capital as well as labor. The intermediate goods are further processed by a manufacturing industry that also uses public capital goods (like machine parts or software). The manufacturing goods are bought by the private retail sector that consists of consumption and investment producers, which both also use public capital goods in production (such as railroads or roads). The private consumption and investment goods are sold to households. Private capital is rent back to intermediate firms. Within each stage of the network, there are monopolistic firms that produce differentiated goods and perfect competitive packers that bundle these goods into homogeneous goods that are sold to the next stage.

Intermediate goods. A continuum of intermediate firms indexed by $i \in [0,1]$ produces differentiated goods according to (5). Cost minimization under an identical production technology implies that firms have identical marginal costs per unit of output: $MC_t = (1-\tilde{\alpha})^{\tilde{\alpha}-1}\,\tilde{\alpha}^{-\tilde{\alpha}}\, W_t{}^{1-\tilde{\alpha}}\, R_t^{k^{\tilde{\alpha}}} (K_t^G)^{\frac{\alpha^{kg}}{\alpha^{kg}-1}}$ with $\tilde{\alpha} = \frac{\alpha}{1-\alpha^{kg}}$. Firms have the chance to re-optimize the price each period with the probability $(1-\theta_p)$. They maximize profits according to

$$E_t \sum_{s=0}^{\infty} (\beta\theta_p)^s \frac{\lambda_{t+s}}{\lambda_t}\left[\left(\Pi_{k=1}^s (\pi_{t+k-1}^H)^{\chi_p} (\overline{\pi}^H)^{1-\chi_p}\right) P_t(i) VA_{t+s}(i) - MC_{t+s} VA_{t+s}(i)\right], \quad (9)$$

where firms that cannot reset partially index to past inflation. The perfectly competitive intermediate goods packers bundle the differentiated goods according to $VA_t = \left(\int_0^1 VA_t^{(\epsilon_p-1)/\epsilon_p}(i)di\right)^{\epsilon_p/(\epsilon_p-1)}$. Thus, the demand for intermediate firm i's output is given by $VA_t(i) = (P_t(i)/P_t)^{-\epsilon_p} VA_t$. We use P_t as numeraire.

Manufacturing goods. Homogeneous intermediate goods are used by monopolistic manufacturing firms together with the public infrastructure in a CES technology:

$$X_t(i) = \left(\left(s^{VA}\right)^{\frac{1}{\sigma^X}} VA_t(i)^{\frac{\sigma^X-1}{\sigma^X}} + \left(s^{XG}\right)^{\frac{1}{\sigma^X}} \left(I_t^{XG}(i)\right)^{\frac{\sigma^X-1}{\sigma^X}}\right)^{\frac{\sigma^X}{\sigma^X-1}},$$

where s^{VA} and s^{XG} are the production shares of the inputs. σ^X is the substitution elasticity between both factors. Firm i can re-optimize its price each period with probability $(1-\theta_p)$ and, thus, has the same optimization problem in structure as an intermediate good firm. Marginal cost are: $MC_t^X = [s^{VA}\left(MC_t^{VA}\right)^{1-\sigma^X} + s^{XG}\left(P_t^{XG}\left(1+\theta_t^X\right)\right)^{1-\sigma^X}]^{\frac{1}{1-\sigma^X}}$. The perfectly competitive manufacturing packers have the same production structure as the intermediate packers.

Private investment and consumption goods. Homogeneous manufacturing goods X_t are used by a monopolistic retail sector that consists of private consumption goods producers and private investment goods producers, demanding C^F and I_t^F, respectively, such that $X_t = C_t^F + I_t^F$. The retailers use a CES production function to produce the final private goods $V = C, I$ with the manufacturing good and the public infrastructure I_t^{VG} :

$$V_t(j) = \left((s^V)^{\frac{1}{\sigma^V}} \left(V_t^F(j)\right)^{\frac{\sigma^V-1}{\sigma^V}} + (s^{VG})^{\frac{1}{\sigma^V}} (I_t^{VG}(j))^{\frac{\sigma^V-1}{\sigma^V}}\right)^{\frac{\sigma^V}{\sigma^V-1}}, \tag{10}$$

where s^V and $s^{VG} = 1 - s^V$ are the input shares. σ^V is the elasticity of substitution between production factors. Given household preferences, firm j faces a demand function $V_{j,t} = \left(\frac{P_{j,t}^V}{P_t^V}\right)^{-\epsilon} V_t$. We assume identical technologies across all consumption and investment goods producers. The price setting problem has the same structure as for intermediate good firms and symmetric marginal costs are $MC_t^V = (s^V\left(p_t^{vy}\right)^{1-\sigma^V} + s^{VG}\left(p_t^{vy}\left(1+\theta_t^V\right)\right)^{1-\sigma^V})^{\frac{1}{1-\sigma^V}}$, where p_t^{vy} is the relative price of the input factor in terms of the respective final good price level (P_t^X, P_t^I, P_t^C).

Fiscal and monetary policy. In each period t, the government collects tax revenues from labor income $\tau^W W_t L_t$, capital income $\tau^k R_t^k K_t$, and consumption $\tau^c P_t C_t$ and issues bonds to finance interest payments and expenditures. The latter consist of consumption G_t, transfers $P_t Z_t$, and investment $I_t^G = I_t^{XG} + I_t^{CG} + I_t^{IG}$. Government debt evolves as

$$P_t^B B_t = P_t Z_t + P_t G_t + P_t I_t^G + (1 + P_t^B \rho) B_{t-1} - \tau^k R_t^k K_t - \tau^W W_t L_t - \tau^c P_t C_t,$$

where transfers are identical across households $Z_t = \int_0^1 Z_t(j)dj = Z_t^S = Z_t^N$. The public capital stock evolves according to $K_t^G = \left(1 - \delta^G\right) K_{t-1}^G + I_t^G$ where δ^G is the public depreciation rate. We assume that the government follows a non-distortionary transfer rule of the form $Z_t = (Z_{t-1})^{\phi_\tau} \left((S_{t-1} - \bar{S})^{\gamma_S}\right)^{1-\phi_\tau}$, where $S_t = \frac{P_t^B B_t}{P_t Y_t}$ is the debt-to-GDP ratio. According to the fiscal rule, the government reduces transfers if the ratio is above its steady state, where γ_S and ϕ_τ measure the debt elasticity and the speed of convergence. The central bank sets the short-term nominal interest rate R_t according to: $R_t = {R_{t-1}}^{\phi^R} \left[\frac{1}{\beta}\left(\frac{\pi_t^C}{\bar{\pi}}\right)^{\phi^\pi} \left(\frac{y_t}{\bar{y}}\right)^{\phi^y}\right]^{1-\phi^R}$.

Aggregation. Consumption, employment, and transfers $Q_t(j) = \{C_t(j), L_t(j), Z_t(j)\}$ are aggregated according to $Q_t = \int_0^1 Q_t(j)$ and can be decomposed into household-specific components via the share of non-saving households n: $Q_t = (1-n)Q_t^S + nQ_t^N$. Because only the saver households have access to capital markets, the aggregation for $T_t(j) = \{K_t(j), B_t(j), B_{s,t}(j), \Pi_t(j)\}$ is $T_t = \int_0^1 T_t^{(1-n)}(j)$. Finally, goods market clearing provides the aggregate resource constraint: $X_t = C_t^F + I_t^F + I_t^G + G_t + \Psi(\nu_t)\tilde{K}_{t-1}^S$.

4.2 Parameterization and estimation approach

We estimate the parameters that are central to the effects of government investment shocks: the persistence of the shocks ρ_k^{ig}, the parameter governing the short run effects of government investment on private investment adjustment costs κ^g, the output elasticity of public capital α^{kg}, and the substitution elasticities between private and public investment in the CES production functions of the network structure $\sigma^X, \sigma^C, \sigma^I$. Furthermore, we estimate the degree of habit formation h, the inverse labor supply elasticity ψ, and the Calvo price parameter θ_p. We also aimed at estimating the Calvo wage parameter θ_w and the share of non-Ricardian households n but obtained corner solutions of 1 and 0, respectively. Hence, we calibrate them to 0.99 and 0.

We parameterize all other parameters as well. Most of these can either be directly observed in the data or are not identified by the impulse response matching. Section A.3.4 shows that the estimates for the core parameters do not depend much on the values of the calibrated parameters.[18] Table A.4 lists the calibrated parameters. We set them to values within the typical

[18] Alternatively, we could estimate more parameters as the size of the government spending multiplier depends on

range for estimated or calibrated DSGE models of fiscal policy (Leeper et al., 2010, 2017; Ramey, 2021). Regarding households, we set the time discount factor $\beta = 0.996$ to match a steady-state annualized real interest rate of 1.5 percent. The degree of substitutability of private and public consumption in utility is $\alpha^g = -0.24$, implying weak complementarity.

The second block consists of parameters that determine the dynamics of production and prices. The capital share $\alpha = 0.33$ corresponds to the average capital-to-output ratio in Germany. The quarterly depreciation rate for private and public investment is $\delta = 0.02$ and $\delta^G = 0.015$ to match annualized depreciation rates of 8% and 6%, respectively. The private capital adjustment costs parameter is $\kappa^k = 6$. The degrees of indexation are $\chi_p = \chi_w = 0.5$. The elasticity of substitution between different types of goods or labor is $\epsilon_p = \epsilon_w = 6$. The shares of public investment in the CES production functions of the network structure are based on input-output tables for Germany of the Federal Statistical Office. The tables list the quantity of intermediate inputs that goes into domestic production in various sectors and in the economy as a whole. The tables do not list the input share of public investment explicitly. Therefore, we approximate it as the product of the government share (9%) and the total investment share (9%). This gives a benchmark of about 0.8% or $s^{XG} = s^{IG} = s^{CG} = 0.008$. Furthermore, we assume an equal attribution of public investment to each sector as we lack data on these shares.

The third block contains long run ratios and policy parameters. The shares of government consumption, government investment, and transfers in GDP match their empirical counterparts: $G/Y = 0.17$, $I^G = 0.03$, and $Z/Y = 0.22$. Similarly, the consumption, capital, and labor tax rates equal their empirical averages: $\tau^c = 0.15$, $\tau^k = 0.22$, and $\tau^W = 0.19$. The steady state debt-to-GDP ratio is 60% on an annual basis to mimic the Stability and Growth Pact. The response of transfers to deviations of government debt from this target is $\gamma_S = -0.26$ to ensure fiscal solvency. The smoothing term is $\phi_\tau = 0.5$. The duration of public debt is 5 years. In the monetary policy rule, we set the weight for interest rate smoothing $\phi^R = 0.9$ and the stabilizing weights to $\phi^\pi = 1.2, \phi^y = 0$.

We collect the parameters to be estimated in the vector ζ. We estimate ζ by minimizing the distance between the empirical impulse response functions $\hat{\Theta}$ and the ones implied by the model, $\hat{\Theta}(\zeta)$, which are a function of ζ. We consider the first 20 elements of each response, excluding the impact reaction of government investment which is set by assumption. Following Christiano

many features of the model (Leeper et al., 2017). However, this would rather require a full information approach. It also risks that the estimates for the core parameters are driven by potentially extreme values of the other parameters, which are less relevant for our research question.

et al. (2005), the estimator of ζ solves

$$J = \min_{\zeta} [\hat{\Theta} - \Theta(\zeta)]' V^{-1} [\hat{\Theta} - \Theta(\zeta)], \tag{11}$$

where V is a matrix with the estimated variances of the elements in $\hat{\Theta}$ on the diagonal, which are obtained from the bootstrap. This weighting matrix implies that the minimization aims at centering the model responses within the confidence intervals of the empirical responses by choosing ζ. We focus on the responses of government and private investment, private consumption, and output.

4.3 The estimated effects of government investment shocks

This section presents the parameter estimates, the matched impulse response functions, and the decomposition of the government investment multiplier. Table 3 shows the point estimates of the parameters in ζ. Appendix A.3.4 contains the distributions of the estimates for each of the 1000 bootstrap draws for the empirical responses. These distributions are the basis for the standard errors, which we use the gauge the precision of the estimates.

Parameter	Notation	Estimate	S.E.
Persistence government investment shocks	ρ_1^{ig}	0.409	0.144
	ρ_2^{ig}	0.289	0.145
	ρ_3^{ig}	0.225	0.104
Elasticity of output to government capital	α^{kg}	0.041	0.131
Substitution elasticity public inv. CES	σ^I	0.289	1.573
	σ^X	0.215	0.423
	σ^C	0.203	0.405
Sensitivity private inv. adj. costs to gov. inv.	κ^g	0.154	0.041
Habit formation	h	0.505	0.242
Inverse labor elasticity	ψ	0.491	0.085
Calvo price parameter	θ_p	0.862	0.306

Table 3: Parameter estimates. *Notes:* The table shows the estimated parameter values obtained by matching the impulse response functions of the DSGE model to those of the Proxy-SVAR by minimizing (11). It also shows the standard errors of the estimates obtained from 1000 bootstrap replications.

We find a high autocorrelation of the government investment shocks, reflected in the estimates of $\rho_1^{ig}, \rho_2^{ig}, \rho_3^{ig}$, although the individual parameters of the AR(3) are difficult to interpret. The persistence reflects the secular movements in the public investment ratio, which fluctuates between 0.06 at the beginning of the sample and 0.03 toward the end.

The estimated output elasticity of public capital is $\alpha^{kg} = 0.041$. But the parameter is not precisely estimated. The point estimate suggests positive productivity effects of public capital over the medium term, which raises the marginal productivity of labor and private capital and leads to an increase in the demand for private goods. For example, a state-financed expansion of the road network simplifies and accelerates the transport and trade of goods and services. The estimate is lower than the average estimate of 0.11 found in the meta analysis of Bom and Ligthart (2014) and the mean value of 0.09 that Ercolani and e Azevedo (2014) obtain from estimating an RBC model using full information methods. It is in the middle of the range considered in calibrated DSGE models of 0-0.1 (Baxter and King, 1993; Leeper et al., 2010; Ramey, 2021).

The elasticities of substitution between private and public capital in the CES production function at each stage of the production network σ^X,σ^C,σ^I are similar and between 0.2-0.3. Very large values for these parameters would imply perfect substitutability, values close to 1 would imply a Cobb-Douglas production function, and values close to 0 imply a Leontief production function. Hence, our estimates suggest that private and public investment are rather complements than substitutes in the production network. However, all three parameters are not precisely estimated.

The estimate for the effect of public investment on private investment adjustment costs is $\kappa^g = 0.154$. Public investment reduces private investment adjustment costs by 15%. The parameter is precisely estimated. The significantly positive value implies a crowding-in of private investment in the short run. The cost-reducing effect may reflect better public infrastructure that allows transporting investment goods more easily, lower investment costs due to enhanced energy or water supply, or a higher efficiency of administrative processes through digitization that accelerates tenders, contracts, and authorizations. At the same time, there can also be congestion due to the additional, public investment activities. But the significantly positive point estimate of κ^g suggests that this effect is dominated by the cost-reducing effect.

The habit persistence parameter h, the inverse labor supply elasticity ψ, and the Calvo price parameter θ_p are 0.505, 0.491, and 0.862, respectively. They are in the range of typical estimates.

Figure 8 shows the response functions of the estimated DSGE model. It also repeats the empirical responses and their confidence bands from Figures 2 and 3 for comparison. Overall, the model accounts well for the dynamics following the identified government investment shocks. It replicates them qualitatively and quantitatively. Most of the responses lie within one standard error. The estimated AR(3) generates a large impact, quick relapse, and then a slowly decaying response of public investment. The DSGE model also replicates the response of private investment and output closely. It has some difficulty in matching the response of private consumption upon impact but does so well subsequently. The bottom panel shows the output multiplier. The model replicates the estimated multiplier over the full horizon.

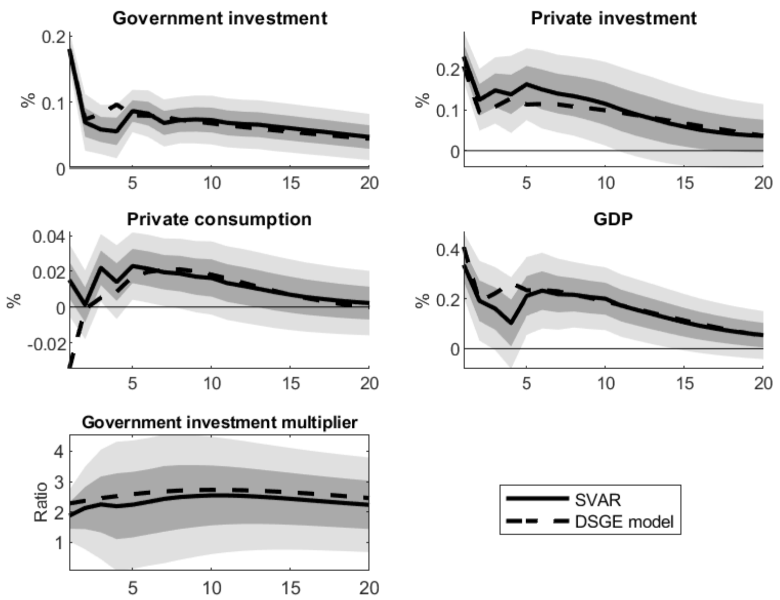

Figure 8: DSGE model and Proxy-SVAR impulse response functions. *Notes:* The figure shows the responses of government investment, private investment and consumption, output, and the cumulative government investment multiplier following a positive government investment shock of one standard deviation over 20 quarters. The solid lines and shaded areas are the point estimates and confidence intervals, respectively, which are from the Proxy-SVAR. The dashed lines are the impulse responses from the DSGE model.

Section A.3.4 contains a sensitivity analysis. It shows that the estimates of the core parameters do not depend much on the calibration of the others. It also documents that the estimates likely reflect a lower bound of the importance of public investment. If we include the endogenous variables in the SVAR in logs (instead of scaling them by trend output) and exclude the exogenous variables, in the DSGE model the importance of all three transmission channels increases.

4.4 The transmission of government investment shocks

To gain further intuition for the effect of the estimated parameters on the size and shape of the multiplier, we perform several counterfactuals. Figure 9 shows the model impulse responses for alternative calibrations. The solid lines replicate the DSGE responses at the estimated values of ζ. The dashed lines show a case where the persistence of the shock is lowered by setting the AR(3) coefficients to $\rho_1^{ig} = 0.5, \rho_2^{ig} = \rho_3^{ig} = 0$. The shock is essentially back at trend after two years.

The shorter stimulus is associated with smaller and less persistent increases in private demand and output compared to the baseline. Therefore, the multiplier is less hump-shaped and falls quicker.

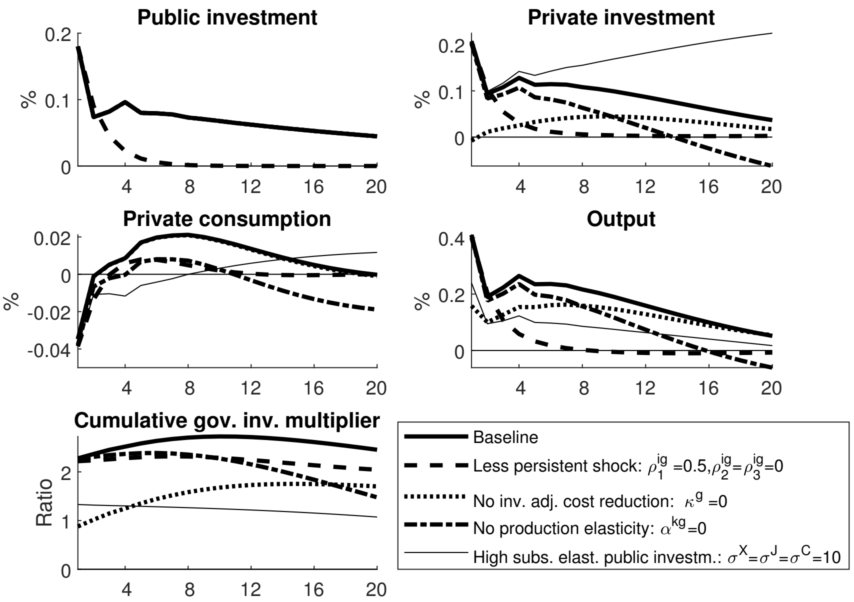

Figure 9: Decomposition of government investment multiplier. *Notes:* The figure shows the model impulse response functions of government investment, private investment and consumption, output, and the cumulative government investment multiplier following a positive government investment shock of one standard deviation over 20 quarters. The solid lines refer to the estimates for ζ. The other lines show counterfactuals where we change the value of one parameter at a time: dashed lines - lower autocorrelation of shock ($\rho_1^{ig} = 0.5, \rho_2^{ig} = \rho_3^{ig} = 0$); dotted lines - no effect of public investment on private investment adjustment costs ($\kappa^g = 0$), dash-dotted lines - no public capital in production function ($\alpha^{kg} = 0$), thin solid lines - high substitution eslasticity between public and private investment in CES production functions of network ($\sigma^X = \sigma^C = \sigma^I = 10$).

The dotted lines summarize a case where the effect of government investment on private investment adjustment costs is eliminated by setting $\kappa^g = 0$. This modification has no effect on the shock dynamics. However, it has a strong impact on private investment. The latter barely reacts upon impact and rises only gradually as the increase in the public capital stock raises the marginal product of private investments and generates demand effects at different stages of the production network. The alternative path of private investment relative to the baseline feeds nearly one-to-one into the response of output, given that private consumption is essentially the same. The impact response of GDP is about halved and it takes three years before the counterfactual response converges to the baseline response. This time span gives an indication about the duration of the short run effects implied by the investment adjustment cost reduction of government investment. As the differences to the baseline mainly occur at the beginning of the horizon, the multiplier is essentially shifted down and then runs parallel to the baseline multiplier.

The dash-dotted lines refer to a case in which the elasticity of output to public capital is zero,

$\alpha^{kg} = 0$. As before, this change does not affect the shock evolution. The response of government investment is indistinguishable from the baseline. Now, there is hardly any effect on the impact reaction of private investment. Then, the differences to the baseline increase as private investment returns to trend more quickly. Moreover, private consumption drops mostly below its initial level without the positive wealth effect. Output mimics the private demand dynamics and decays more rapidly. Accordingly, the multiplier declines after three years.

Finally, the thin solid line depicts a calibration where the elasticity of substitution between public and private investment in the CES production functions is $\sigma^X = \sigma^C = \sigma^I = 10$. This assumption eliminates the complementarity between the two investment goods and most of the additional demand effects of the network structure. It halves the multiplier over the full horizon, reducing both the short and medium run output effects of public investment.

The counterfactuals illustrate that all three transmission channels are relevant for understanding the size and shape of the multiplier. In the short run, government investment reduces private investment adjustment costs. This leads to a crowding-in of private investment and pushes up the short run multiplier. In the medium run, government investment raises the production capacity of the economy. This increases the marginal product of private investment and wealth. Both spurs private demand over time. In both the short and medium run, the complementarity between public and private investment at different stages of the production process raise private demand.[19]

5 Conclusion

In many advanced countries, demographic change raises the need for government investment in digitization, education, and health. Furthermore, achieving the climate protection targets requires large investments in CO2-neutral production and infrastructure. At the same time, fiscal policy aims at strengthening economic activity in the short term. In this paper, we estimate the macroeconomic effects of exogenous changes in government investment based on a new narrative instrument. We find a crowding-in of private investment and an output multiplier of about 2. We rationalize the results in a New Keynesian DSGE model and shed light on the transmission channels of government investment shocks. Our results suggest that government investment can

[19] The DSGE models of Baxter and King (1993), Leeper et al. (2010), and Ramey (2021) do not have the first and third channel, which both lift the multiplier upward in the first years. Hence, these models typically predict low output effects in the short run, but large medium to long run effects. For example, Ramey (2021) obtains a long run multiplier of 3 for a calibration of $\alpha^{kg} = 0.05$ in an New Keynesian model, values that are both similar to ours.

be an effective stimulus in both the short and medium run.

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Supplemental Appendix to 'An Estimation and Decomposition of the Government Investment Multiplier'

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January 31, 2025

Abstract

The supplemental appendix contains additional material for the article 'An Estimation and Decomposition of the Government Investment Multiplier'.

JEL: E62, E65, H54

Keywords: Fiscal policy, public investment, structural vector autoregression, instrumental variable, general equilibrium model, Germany.

A.1 Data description

Bank bond yield: Corporate Benchmarks, Bank Debt Securities, Yield, Macrobond.

Budget balance: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Budget balance, 1Q1970-4Q2018.

CPI inflation rate: Federal Statistic Office, National Accounts Statistics, Series 18 1.2, Private consumption price deflator, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Consumption: Federal Statistic Office, National Accounts Statistics, Series 18 1.2, Private Consumption,

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price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Corporate bond yield: Corporate Benchmarks, Bank Debt Securities, Yield, Macrobond.

Credit spread: Difference between corporate bond yield and one-year rate.

Euro area data: Same six variables as baseline model for Germany, same transformations except that trend GDP is calculated as linear trend, data are from 'Quarterly non-financial accounts for general government' and 'GDP and main components (output, expenditure and income)' of Eurostat, ESA 2010. Government investment P51, government consumption P.2+D.1, government taxes D.5r, private consumption is final consumption expenditure of households, private investment total investment - government investment.

GDP deflator: OECD MEI, National Accounts, National Accounts Deflators, Gross Domestic Product, GDP Deflator, SA, Index, Macrobond.

Gross domestic product: Federal Statistic Office, National Accounts Statistics, Series 18 1.2, Gross Domestic Product, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Government investment: Sum of government gross fixed capital formation (NAS) and grants to private sector (GFS). The source of the first component is Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Governmental investments, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018. Grants are from the GFS. We seasonally adjust the data and transform them to real euros by dividing by the GDP deflator. The GFS data start in 1991Q1. From this period onward, government investment is the sum of public GFCF (NAS)+grants to private sector excluding public railway operators (GFS). Before 1991Q1, we scale the GFCF (NAS) upward by the fraction of private grants in total public investment outlays according to the GFS series, which is 22%.

Government construction investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Governmental construction investments, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Government equipment and machinery investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Governmental equipment and machinery investments, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Government other investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Governmental other investments, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Net exports: Differences between exports and imports, Bundesbank, Germany, National Accounts, Use of Gross Domestic Product, Exports (Imports) of Goods & Services 1, 2, 3, Calendar Adjusted, Constant Prices, SA, Index, Macrobond.

Oil price growth: q/q growth of real oil price computed as difference between nominal oil price growth and US GDP deflator inflation, United States, Commodities & Energy Prices, Refiner Acquisition, Crude Oil, Imported, Average Price, USD/Barrel, Energy Information Administration (EIA); United States, Implicit Price Deflator, Gross Domestic Product, SA, Index, U.S. Bureau of Economic Analysis (BEA).

One-year rate: Government Benchmarks, Bundesbank, Yield on Debt Securities Outstanding, Yield, Macrobond.

Private investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Non-governmental investments, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Private investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Non-governmental investments, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Private construction investment components: Federal Statistic Office, National Accounts Statistics, Private construction investment residential and non-residential, civil construction, building construction, price-adjusted (chain-linked volume), seasonally-adjusted, 1991Q1-2018Q4. Data are extrapolated backward using growth rates of West Germany analogues from Federal Statistic Office National Accounts Statistics, Fachserie 18 Reihe S.27.

Private equipment and machinery investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Private equipment and machinery investment, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Private other investment: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Private other investment, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Ten-year rate: OECD MEI, Interest Rates, Long-Term Government Bond Yields, 10-Year, Main (Including Benchmark), Macrobond.

Total revenues: Federal Statistic Office, National Accounts Statistics, Series 18 1.3, Total revenues, price-adjusted (chain-linked volume), seasonally-adjusted, 1Q1970-4Q2018.

Nominal interest rate: FRED, Immediate Rates: Less than 24 Hours: Call Money/Interbank Rate for Germany, 1Q1970-4Q2018.

Real effective exchange rate: FX Indices, BIS, Real Effective Exchange Rate Index, Narrow, Macrobond.

Real short-term rate: Difference between ECB main refinancing rate and realized GDP deflator inflation.

Real short-term rate: OECD MEI, Labour Compensation, Wage Rate, Manufacturing, Hourly, Index, Macrobond.

Unemployment rate: OECD MEI, Labour Force Survey - Quarterly Rates, Unemployment Rate, Aged 15 & Over, All Persons, SA, Macrobond.

US GDP growth: Growth rate q/q, United States, Gross Domestic Product, Total, Constant Prices, SA, Chained, AR, USD, U.S. Bureau of Economic Analysis (BEA).

World industrial production growth: q/q growth rate global industrial production, World, Advanced, IMF IFS, Real Sector, Economic Activity, Industrial Production, Total, seasonally adjusted manually (X-11), monthly values averaged to quarterly values.

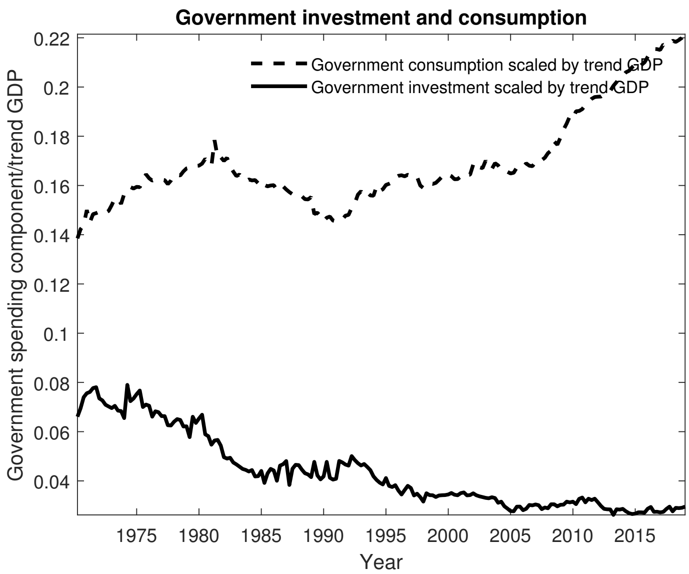

Figure A.1: Government investment and consumption. *Notes:* The figure shows government investment scaled by trend GDP (solid line) and government consumption scaled by trend GDP (dashed line) in Germany 1970Q1-2018Q4.

A.2 Supplement SVAR analysis

A.2.1 Specification tests

Equation	Gov. inv.	Priv. inv.	Priv. cons.	GDP	Revenues	Gov. cons.
F-statistic	1.670	0.643	0.816	1.449	0.561	0.738
p-value	0.160	0.632	0.517	0.221	0.692	0.567

Table A.1: Tests for VAR invertibility. *Notes:* The table shows robust F-statistics and p-values testing the null hypothesis that the coefficients on four lags of the instrument for government investment shocks are jointly equal to zero in each of the VAR equations.

Lags	1	1-2	1-3	1-4
F-statistic regression	0.954	0.717	0.519	0.375
p-value regression	0.466	0.756	0.960	0.998
p-value lags instrument	0.162	0.270	0.383	0.725

Table A.2: Tests for instrument predictability. *Notes:* The table shows robust F-statistics and p-values testing the null hypothesis that the coefficients on 1 up to 1-4 lags of the instrument and the endogenous variables are jointly equal to zero. The dependent variable is the instrument.

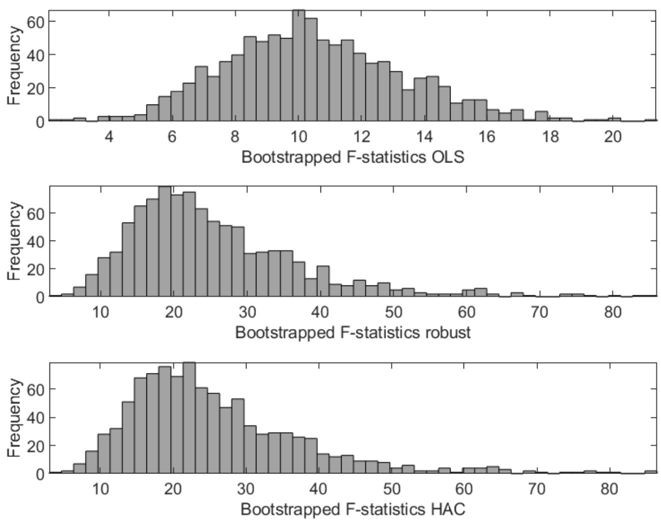

Figure A.2: Distribution of bootstrap F-statistics. *Notes:* The figure shows the frequency distributions of the F-statistic OLS, robust, and HAC, respectively, obtained from 1000 bootstrap replications testing the strength of the instrument for government investment shocks.

	F-test OLS	F-test robust	F-test HAC	Reliability	
F-statistic	12.15	32.54	32.71	$R^2(\epsilon_t^{IG}, m_t^{\neq 0})$	0.65
p-value	0.00	0.00	0.00	p-value β_m	0.00

Table A.3: Tests for instrument strength. *Notes:* The table shows OLS, Huber/White and HAC (with 1 lag) F-statistics and corresponding p-values testing the null hypothesis that the coefficient on the instrument for government investment shocks is zero in a regression of the residual of the government investment equation on the instrument. It also contains the R^2 of a regression of the structural government investment shocks on the non-zero instrument observations and the p-value of the coefficient for the instrument.

A.2.2 Additional results SVAR model

We investigate whether the identified public investment shocks and their effects on GDP square with the economic narrative for Germany in the sample and the selected episodes that the instrument captures. The upper panel of Figure A.3 shows the cumulative shocks. The sample can roughly be divided into three phases. First, the large swings in the first twenty years reflect an initially large welfare state in the 1970s that was starved in the 1980s. Second, reunification led to a boom in the 1990s. Third, the long sequence of predominantly negative shocks since 2000 corresponds to a cutback of public investment after the boom, which only ends toward the end of the sample, when the attrition of the public infrastructure became unmissable.

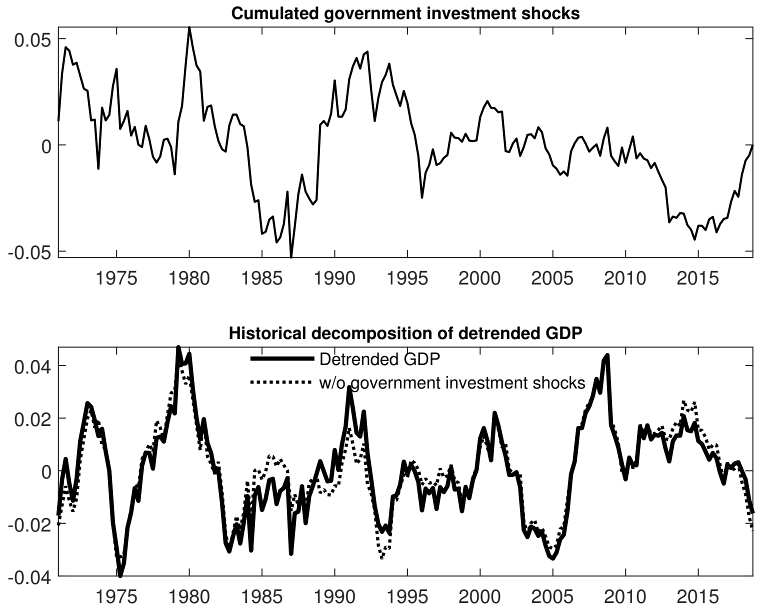

Figure A.3: Estimated shocks and historical decomposition. *Notes:* The upper panel shows the identified cumulative government investment shocks. The lower panel shows detrended GDP and detrended GDP without the contribution of government investment shocks, obtained from a historical decomposition. In the lower panel, both series neglect the base, or transients, due to the initial conditions.

The bottom panel of Figure A.3 shows detrended GDP (solid line) and a historical decomposition of it (dotted line), where the contribution of government investment shocks to GDP is eliminated. The comparison allows gauging the importance of the shocks to output fluctuations during specific episodes. It also gives a rough idea about whether the shocks identified with the instrument correspond to the underlying investment programs. Consistent with the cumulative shocks, public investment shifts increased output at the end of the 1970s and lowered it during the phase of market liberalization in the 1980s. The strongest contribution to GDP is after reunification. In

1991, government investment shocks nearly doubled the output gap. The long shadow of the boom was a mostly negative contribution from the end of the 1990s until the mid-2000s. Overall, the estimated shocks and their contribution to GDP correspond to the history of public investment in Germany and to the narrative of the instrument.

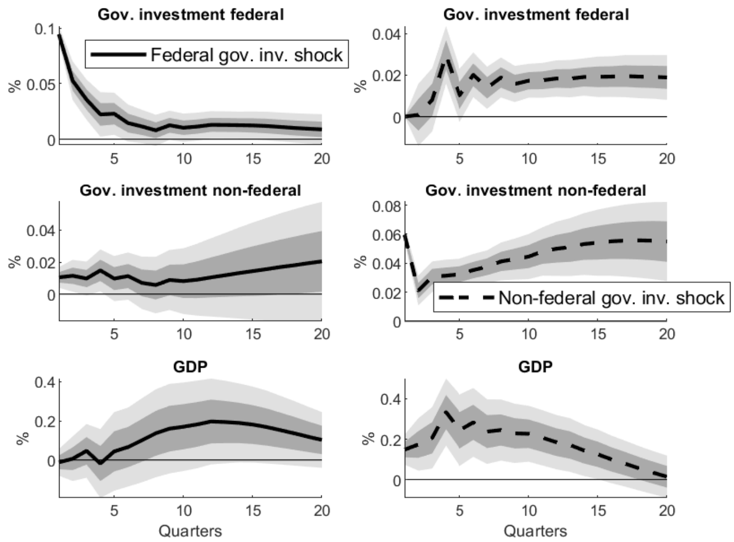

Figure A.4: Comparison of federal and non-federal government investment shock. *Notes:* The figure shows the effects of federal (left column) and non-federal (right column) government investment shocks of one standard deviation identified recursively over 20 quarters. The shaded areas are 1 and 2 standard error confidence intervals based on 1000 bootstrap replications. The model orders federal government spending first, non-federal spending second, and uses a Cholesky decomposition. In addition, it contains the same endogenous variables as the baseline model except of government investment. The first shock is interpreted as a shock to federal spending and the second as a shock to non-federal spending, assuming that federal does not respond to non-federal spending contemporaneously. The sample is 1991Q1-2018Q1 as data for the construction of federal spending including grants is only available from 1991Q1 onward, that is, after reunification. The model contains four lags of the endogenous variables and the same exogenous variables as the baseline model (quarter, reunification, and Lehman Brothers dummies and a linear trend).

A.2.3 Sensitivity analysis SVAR model

We conduct an extensive sensitivity analysis, which we summarize here. First, we show that the main results hold when we use alternative versions of the instrument. Specifically, we either construct the instrument from the information of the government finance reports only to increase internal consistency, or we scale the programs inversely by the duration, or we exclude the investment programs around reunification (Figure A.7). Moreover, the results are robust to dealing with outliers by Winsorizing the non-zero instrument observations at the 90th or 80th

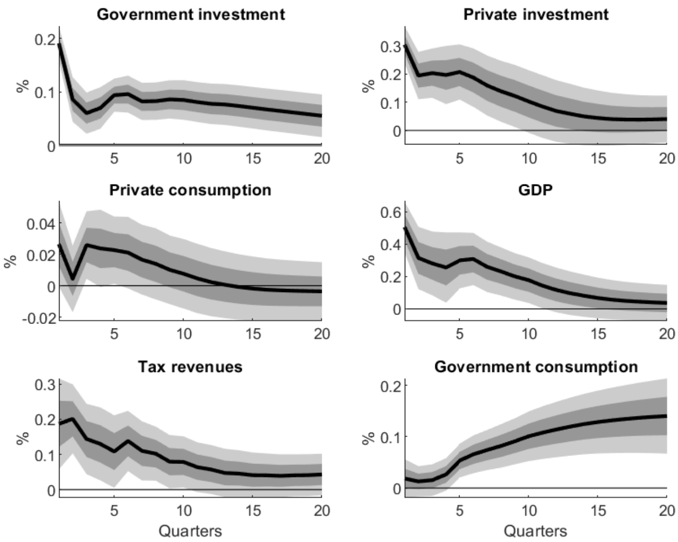

Figure A.5: Sensitivity of baseline model to removing instrument observations 1989Q1. *Notes:* The figure shows the responses of the baseline variables to a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are 1 and 2 standard error confidence intervals based on 1000 bootstrap replications. The specification is the same as the baseline specification except that we dummy out the largest non-zero instrument observation (the one in 1989Q1).

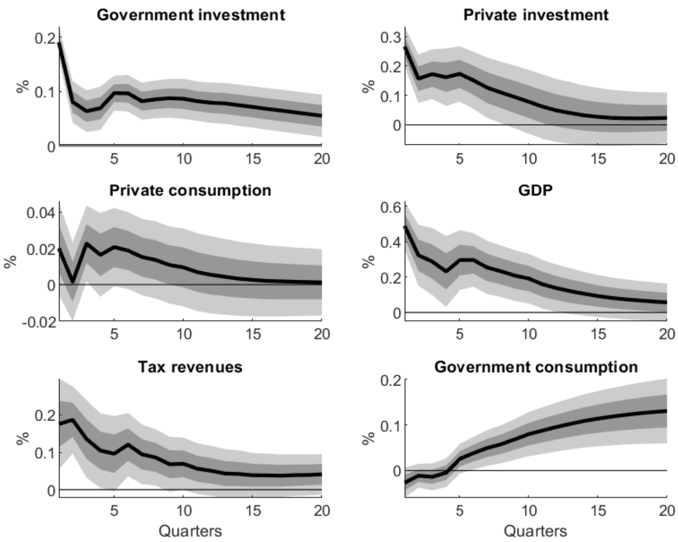

Figure A.6: Sensitivity of baseline model to alternative weighting of instrument. *Notes:* The figure shows the responses of the baseline variables to a positive government investment shock of one standard deviation identified with a modified external instrument over 20 quarters. The shaded areas are 1 and 2 standard error confidence intervals based on 1000 bootstrap replications. The specification is the same as the baseline specification. The instrument differs. It weighs the announced package size inversely by its duration.

percentile (Figure A.8), and they hold when excluding one non-zero instrument observation at a time, suggesting that no single investment package drives the results (Figure A.9).

Next, we account for fiscal foresight (Figure A.10). This can arise when households and firms react to news about impending future government investment plans. Then, we might not be able to recover the unexpected spending shock because the information sets of agents in the sample and us are misaligned (Leeper et al., 2013). The literature has proposed different solutions for this problem. First, we add stock prices as endogenous variable because they are forward looking and incorporate expectations about future policy actions (Beetsma and Giuliodori, 2011). Second, we include two factors: one financial factor computed as the first principal component of a large set of financial variables and one real factor. Third, we include a series of government investment forecasts to the model, following Auerbach and Gorodnichenko (2012).

Finally, we perform a large number of specification tests. We add endogenous variables to the model (Figure A.11), change the lag length to $p = 3,5,6,7,8$ (Figure A.12), change the trend assumption (Figure A.13), use aggregate instead of per capita variables and employ log-levels instead of ratios (Figure A.14), compute trend GDP with slightly lower order polynomials (Figure A.15), exclude the dumies for reunification, crisis, or quarters (Figure A.16), start the sample after the Fall of the Wall (Figure A.17), construct Efron's and Hall's confidence bands—or use the moving block bootstrap of Jentsch and Lunsford (2019) for the responses of the variables (Figures A.18, A.19, A.20) and the multiplier (Figures **??**, **??**, **??**). We also use the local projections one-step and three-step approach of Ramey and Zubairy (2018), with the same set of control variables as in the Proxy-SVAR and four lags of the instrument (Figure A.21).

Overall, the estimated one-year multiplier is relatively stable. It mostly lies around the baseline estimate. The multiplier after 2-5 years is a bit more sensitive. It is particularly affected by the trend assumption and estimator.

A.3 Supplement DSGE analysis

A.3.1 Calibration

A.3.2 Equilibrium definition

Given a sequence of shocks $\{G_t, I_t^G\}$, we define a symmetric equilibrium in which the central bank set the policy rate $\{R_t\}_{t=0}^{\infty}$ and the fiscal policy uses lump-sum transfers $\{Z_t\}_{t=0}^{\infty}$ to set public

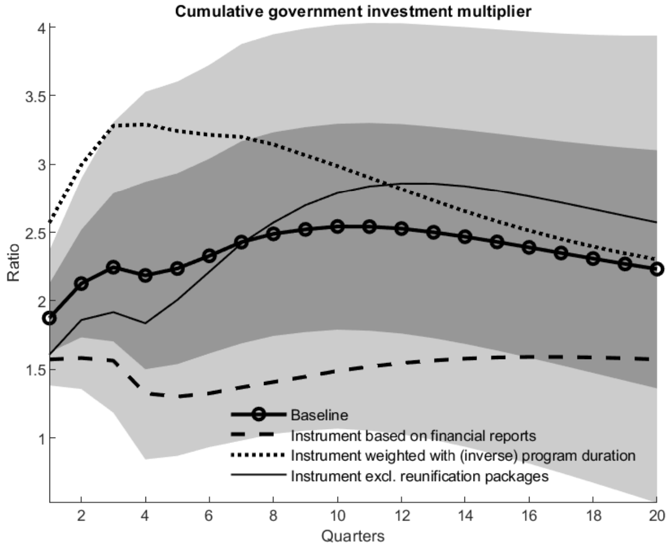

Figure A.7: Sensitivity of output multiplier to alternative constructions of the instrument. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative instruments. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline specification where we extend and update the investment program amounts of financial reports by values found in draft laws and other official documents of the German Bundestag and the Joint Economic Forecast. The dotted line shows the multiplier when the total volume of each investment program is related to the program duration. The dashed line shows the multiplier when we construct the instrument only with investment programs from one source, the financial reports. The solid line shows the multiplier when we exclude the investment programs around reunification in 1990Q1, 1990Q3, 1991Q1, and 1992Q1 from the instrument.

debt $\{B_t\}_{t=0}^{\infty}$ as an allocation $\{C_t, C_t^S, C_t^{S,P}, C_t^N, L_t, L_t^S, L_t^N, K_t^S, \tilde{K}_t^S, K_t^G, I_t, \nu_t, MC_t, Y_t\}_{t=0}^{\infty}$ and a vector of prices $\{P_t^B, P_t, Q_t^K, R_t^k, W_t\}_{t=0}^{\infty}$ such that the households and firms solve their respective maximization problem and all markets clear.

A.3.3 Model equations

Marginal utility of consumption

$$\lambda_t^S(1+\tau^C) = \frac{1}{C_t^S - hC_{t-1}^S} \tag{A.1}$$

Euler equation bonds

$$\lambda_t^S = \beta R_t E_t \frac{\lambda_{t+1}^S}{\pi_{t+1}^C} \tag{A.2}$$

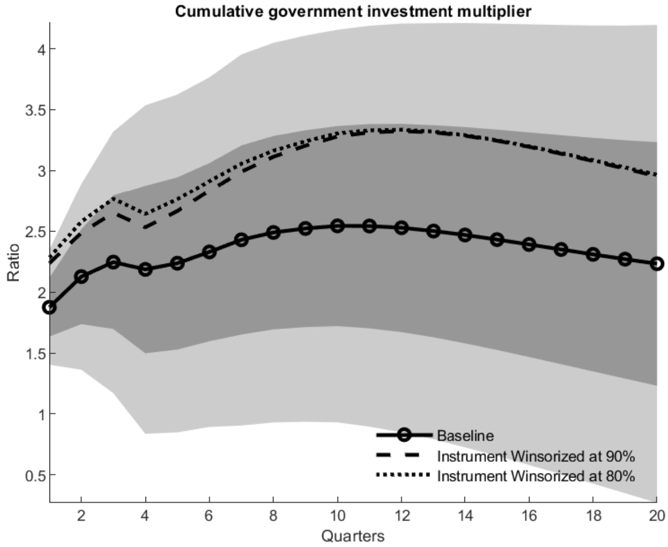

Figure A.8: Sensitivity of output multiplier to Winsorization of the instrument. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative Winsorization of the non-zero instrument observations. The line with circles and the shaded areas (1 and 2 standard errors based on 1000 bootstrap replications) refer to the baseline specification. The dashed and dotted line shows the multiplier when the instrument is Winsorized at the 90th and 80th percentile, respectively.

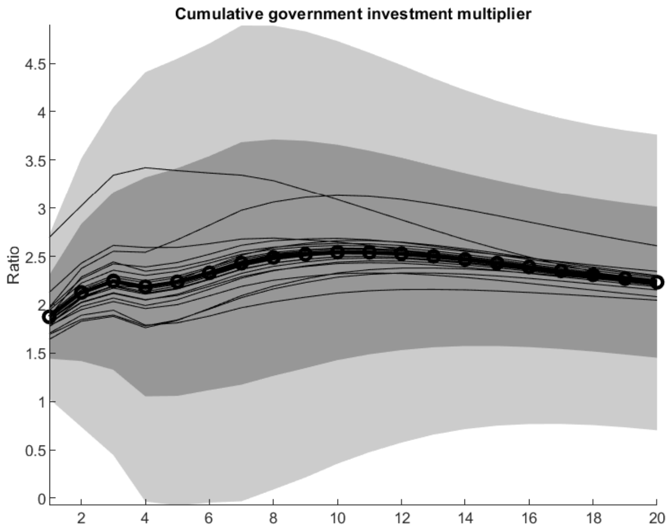

Figure A.9: Sensitivity of output multiplier to dropping non-zero instrument observation. *Notes:* The thin lines show the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters when dropping one non-zero instrument observation at a time. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline specification.

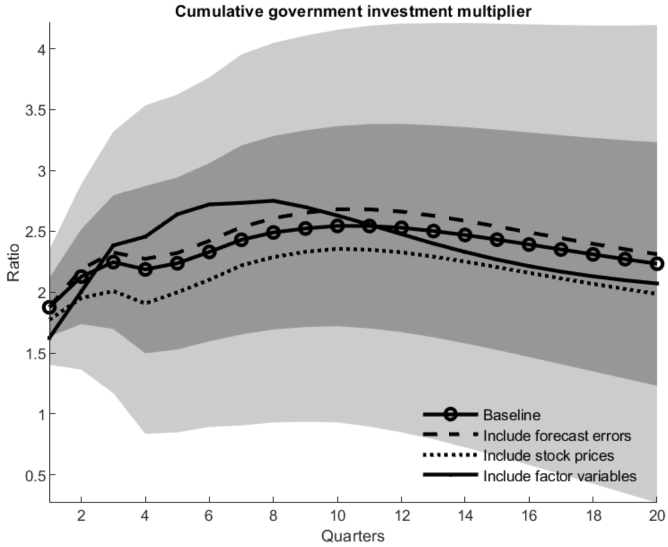

Figure A.10: Sensitivity of multiplier to fiscal foresight. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative endogenous variables. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline specification. The dashed, dotted, and dash-dotted line is the point estimate when including forecast errors, stock prices of middle and large firms (MSCI mid & large cap index), or two factor variables (1 financial and 1 real factor), respectively. We calculate the forecast errors from the Joint Economic Forecast Group, which estimates twice a year the semiannual 1-year and 2-years ahead public investment amount based on all available government information. In preparation of the projection the Group requests the Bundesbank and the German government to inform about actual and planned policy measures. We compute the difference between the 1-year ahead forecast of public investment and the first released series.

Euler equation capital

$$\frac{P_t^I}{P_t^C} Q_t^K = \beta E_t \frac{\lambda_{t+1}^S}{\lambda_t^S} \left[\left(1-\tau^k\right) R_{t+1}^k \nu_{t+1} - \Psi\left(\nu_{t+1}\right) + (1-\delta) \frac{P_{t+1}^I}{P_{t+1}^C} Q_{t+1}^K \right] \tag{A.3}$$

Price relation between long-term and short-term bonds

$$P_t^B = \frac{1}{R_t} \left(1 + \rho E_t P_{t+1}^B \right) \tag{A.4}$$

Composite consumption

$$C_t^S = C_t^{S,P} + \alpha^g G_t \tag{A.5}$$

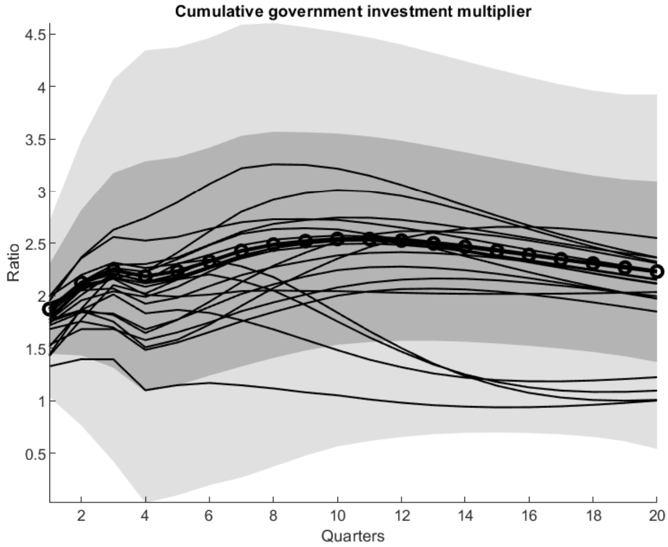

Figure A.11: Sensitivity of output multiplier to alternative endogenous variables. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative sets of endogenous variables. The line with circles and the shaded areas (1 and 2 standard errors based on 1000 bootstrap replications) refer to the baseline specification. The other lines show the multiplier when the variables are added one at a time to the baseline model. The additional variables are those of Figures 5 and 6, except for grants which are available only sinse 1991Q1.

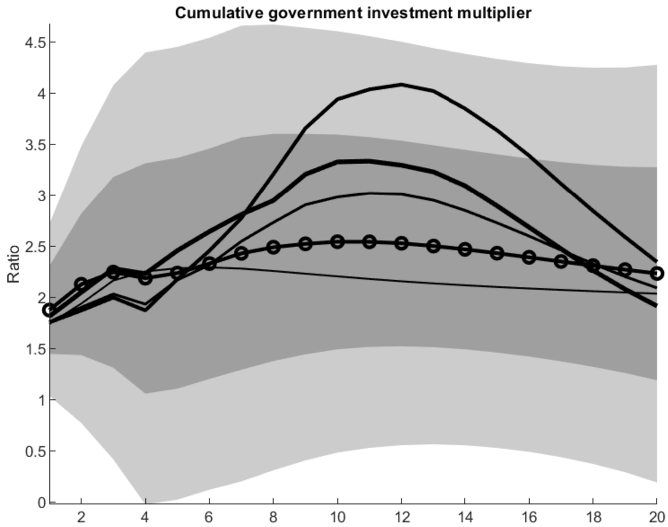

Figure A.12: Sensitivity of multiplier to alternative lag length. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative lag length of the SVAR. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline specification with 4 lags. The other lines are the point estimates for $p = 3,5,7,8$. The width of the lines increase with the lag length.

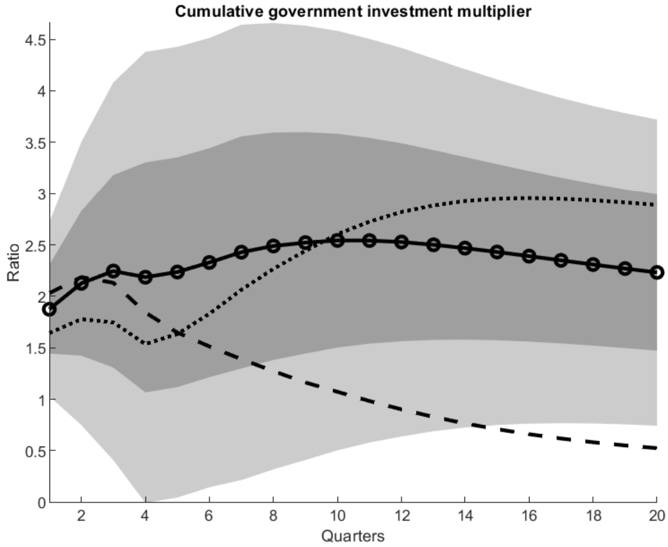

Figure A.13: Sensitivity of multiplier to trends. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative trends assumptions. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline specification with linear trend. The dashed and dotted line is the point estimate when excluding the linear trend or including a quadratic trend, respectively.

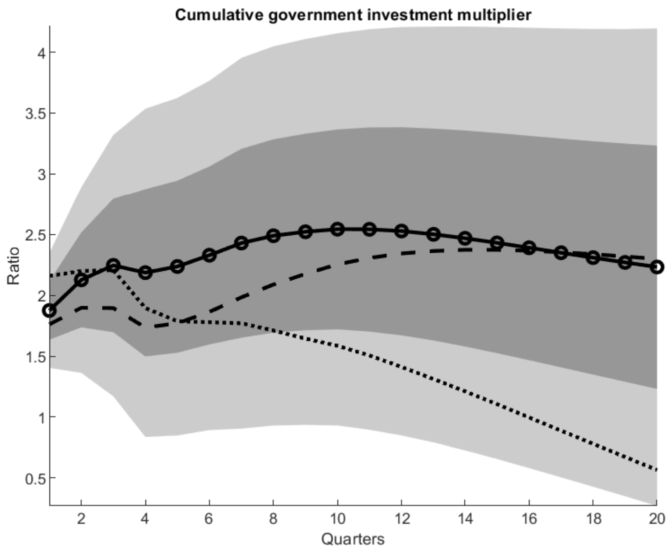

Figure A.14: Sensitivity of multiplier to using aggregate variables or logs. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative transformations of the endogenous variables. The line with circles and the shaded areas (1 and 2 standard errors based on 1000 bootstrap replications) refer to the baseline specification in per capita terms and ratios to trend GDP. The dashed and dotted line is the point estimate when using aggregate instead of per capita variables or log-levels instead of trend ratios, respectively.

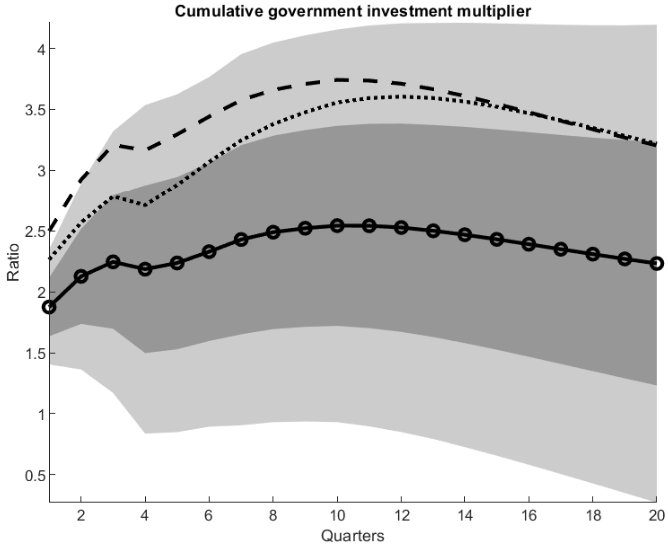

Figure A.15: Sensitivity of multiplier to alternative GDP de-trending. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative de-trending of GDP. The line with circles and the shaded areas (1 and 2 standard errors based on 1000 bootstrap replications) refer to the baseline specification using a fifth-order polynomial for computing the trend of log real per capita GDP. The dashed and dotted line is the point estimate when using a third or fourth-order polynomial, respectively.

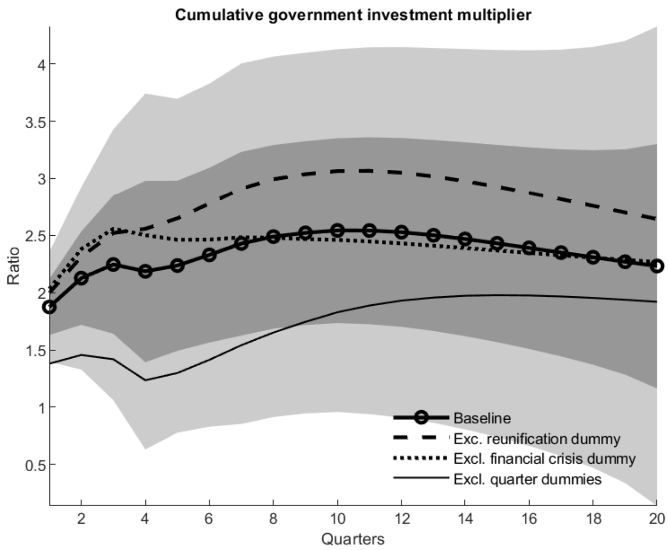

Figure A.16: Sensitivity of multiplier to dropping reunification or financial crisis dummy. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters for alternative specifications of the variables. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline specification. The dashed, dotted, and solid line is the point estimate when excluding the reunification dummy (1989Q4-1992Q4), or the financial crisis dummy (2008Q3-2009Q1), or the quarter dummies, respectively.

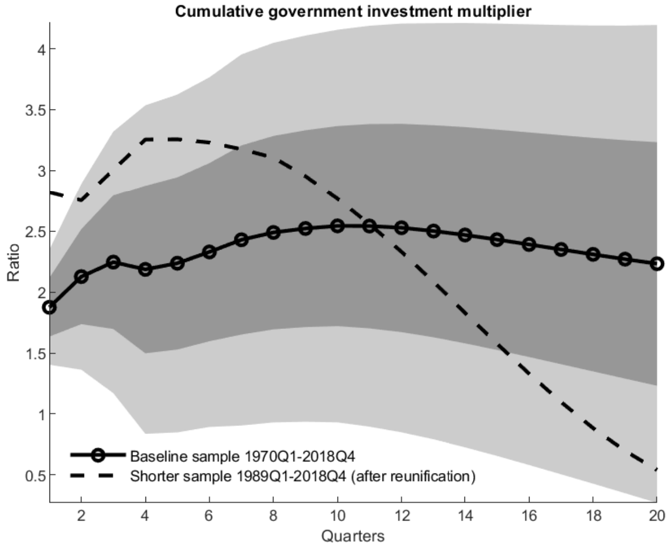

Figure A.17: Sensitivity of multiplier to starting sample after Fall of the Wall. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters. The line with circles and the shaded areas (1 and 2 standard errors based on 1000 bootstrap replications) refer to the baseline sample 1970Q1-2018Q4. The dashed line is the point estimate for the alternative sample 1989Q1-2018Q4. Although the Fall of the Berlin Wall was in 1989Q4, we start in 1989Q1 to not lose the non-zero instrument observations in 1990 due to the lag structure of the SVAR and to obtain a F-statistic of 10.00. Otherwise the F-statistic would drop to 4.61, generating weak instrument problems. Moreover, we drop the reunification dummy. Given the short sample, we compute trend GDP with a second-order polynomial.

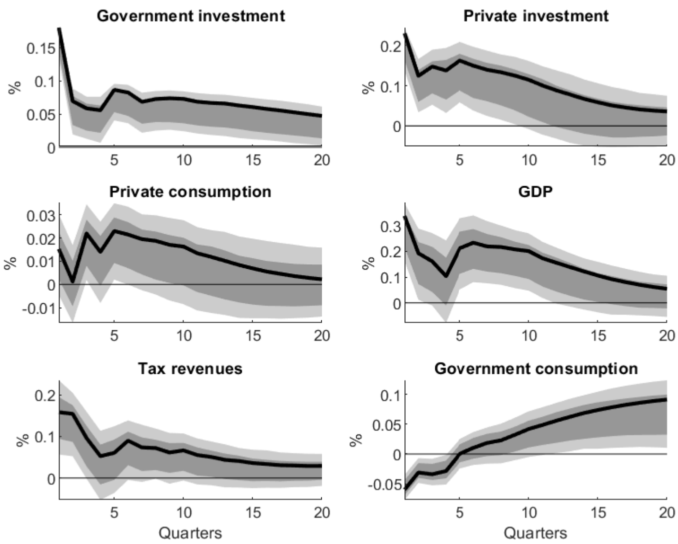

Figure A.18: Sensitivity of impulse responses to using Efron's confidence bands. *Notes:* The figure shows the responses of the baseline variables to a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are Efron's 68% and 95% confidence bands based on 1000 bootstrap replications. All variables are expressed relative to trend GDP.

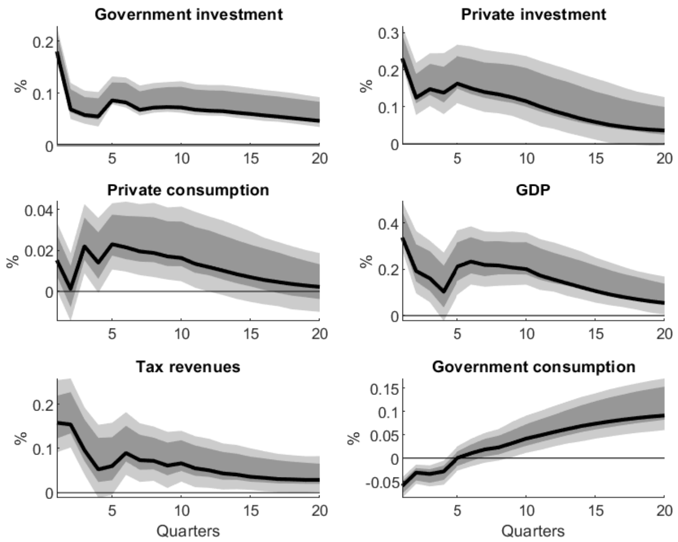

Figure A.19: Sensitivity of impulse responses to using Hall's confidence bands. *Notes:* The figure shows the responses of the baseline variables to a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are Hall's 68% and 95% confidence bands based on 1000 bootstrap replications. All variables are expressed relative to trend GDP.

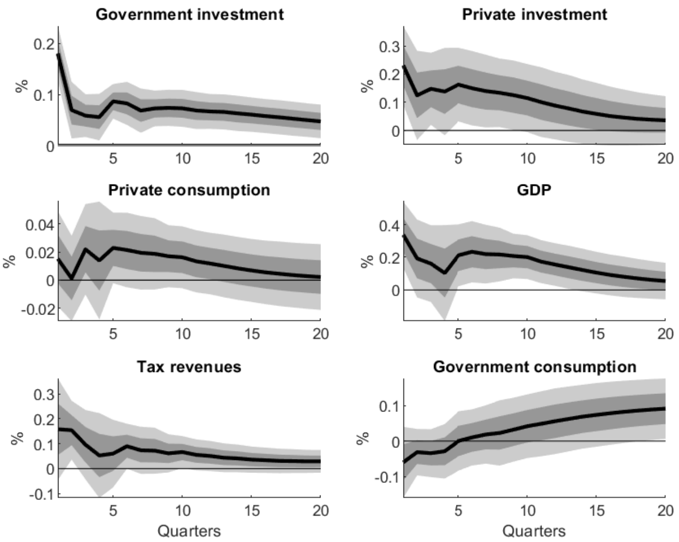

Figure A.20: Sensitivity of impulse responses to using moving block bootstrap. *Notes:* The figure shows the responses of the baseline variables to a positive government investment shock of one standard deviation identified with an external instrument over 20 quarters. The shaded areas are 68% and 95% Efron confidence bands based on 1000 moving block bootstrap replications with a block length of 19. All variables are expressed relative to trend GDP.

Private investment demand

$$Q_t^K\left(1-\Psi\left(\frac{I_t}{I_{t_1}}-\kappa^g\frac{I_t^G}{I_{t_1}^G}\right)-\Psi'\left(\frac{I_t}{I_{t_1}}-\kappa^g\frac{I_t^G}{I_{t_1}^G}\right)\frac{I_t}{I_{t-1}}\right.$$
$$\left.+E_t\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{Q_{t+1}^K}{Q_t^K}\left(\Psi'\left(\frac{I_{t+1}}{I_t}-\kappa^g\frac{I_{t+1}^G}{I_t^G}\right)\right)\left(\frac{I_{t+1}}{I_t}\right)^2=1+\kappa^k \right. \quad \text{(A.6)}$$

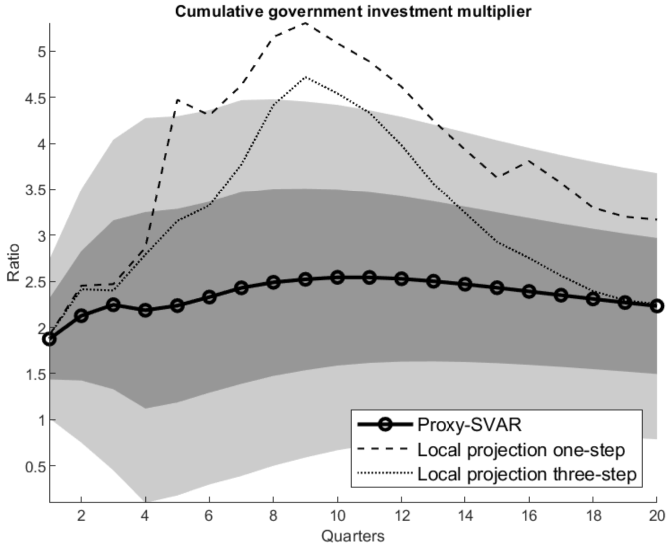

Figure A.21: Sensitivity of output multiplier to using local projections. *Notes:* The figure shows the cumulative output multiplier of government investment shocks identified with an external instrument over 20 quarters. The line with circles and the shaded areas (1 and 2 standard error confidence intervals based on 1000 bootstrap replications) refer to the baseline Proxy-SVAR. The dashed and dotted line shows the estimated multiplier when using the local projection one-step and three-step approach of Ramey and Zubairy (2018), respectively.

Effective private capital stock

$$K_t^S = \nu_t \tilde{K}_{t-1}^S \tag{A.7}$$

Private capital stock

$$\tilde{K}_t = (1-\delta)\,\tilde{K}_{t-1} + I_t \Phi_t \tag{A.8}$$

with $\Phi_t = 1 - \frac{\kappa^k}{2}\left(1 - \kappa^g - \frac{I_t}{I_{t-1}} + \kappa^g \frac{I_t^G}{I_{t-1}^G}\right)^2$.

Capacity utilization

$$(1-\tau^k) R_t^k = \Psi'(\nu_t) \tag{A.9}$$

Public capital stock

$$K_t^G = \left(1 - \delta^G\right) K_{t-1}^G + I_t^G \tag{A.10}$$

Non-saving households budget constraint

$$(1+\tau^c) P_t^C C_t^N = \left(1 - \tau^W\right) W_t L_t^N + P_t^C Z_t^N \tag{A.11}$$

Table A.4: Parameterization for a quarterly frequency

Parameter	Notation	Value
Households		
Discount factor	β	0.996
Substitutability private and public consumption	α^g	–0.24
Share non-saving households	n	0
Production and pricing		
Production elasticity private physical capital	α	0.33
Depreciation rate private capital	δ	0.02
Depreciation rate public capital	δ^G	0.015
Private investment adjustment cost parameter	κ^k	6
Calvo parameter wage adjustments	θ_w	0.99
Price indexation	χ_p	0.5
Wage indexation	χ_w	0.5
Elasticity of substitution between good types	ϵ_p	6
Elasticity of substitution between labor types	ϵ_w	6
Share public inv. in CES function	s^{XG}, s^{IG}, s^{CG}	0.008
Share public inv. to each sector	$sI^{XG}, sI^{IG}, sI^{CG}$	1/3
Policy		
Government consumption/GDP	G/Y	0.17
Government investment/GDP	I^G/Y	0.03
Transfers/GDP	Z/Y	0.22
Consumption tax rate	τ^c	0.15
Capital tax rate	τ^k	0.22
Labor tax rate	τ^W	0.19
Annual debt/GDP	$4\bar{S}$	60%
Debt elasticity transfers	γ_S	–0.26
Transfer smoothing term	ϕ_τ	0.5
Duration long-term bonds	ρ	20
Interest rate smoothing	ϕ^R	0.9
Monetary policy response to inflation	ϕ^π	1.1
Monetary policy response to output	ϕ^y	0

Wage Phillips curve

$$\left(\frac{K_{2,t}}{F_{2,t}}\right) = \left(\frac{1-\theta_w\,\pi_t^{w\,\epsilon_w-1}}{1-\theta_w}\right)^{\frac{1+\psi\epsilon_w}{\epsilon_w-1}} \tag{A.12}$$

where $K_{2,t} = MRS_t Y_t + \frac{\lambda_{t+1}\theta_w\beta\pi_{t+1}^{w\;\epsilon_w-1}}{\lambda_t} K_{2,t+1}$ and $F_{2,t} = Y_t + \frac{\lambda_{t+1}\theta_w\beta\pi_{t+1}^{w\;\epsilon_w(1+\psi)}}{\lambda_t} F_{2,t+1}$ are auxiliary variables and $MRS_t = \chi L_t^{\psi}(C_t - hC_{t-1})$ is the marginal rate of substitution between leisure and consumption.

Production function

$$VA_t = {K_t}^{\alpha}\,{L_t}^{1-\alpha}(K_{t-1}^G)^{\alpha^{kg}} - \bar{O}, \tag{A.13}$$

Real marginal costs

$$MC_t = (1-\tilde{\alpha})^{\tilde{\alpha}-1}\,\tilde{\alpha}^{-\tilde{\alpha}}\,W_t{}^{1-\tilde{\alpha}}\,\left(R_t^k\right)^{\tilde{\alpha}}\,(K_t^G)^{\frac{\alpha^{kg}}{\alpha^{kg}-1}} \tag{A.14}$$

with $\tilde{\alpha} = \frac{\alpha}{1-\alpha^{kg}}$.

Capital-labor ratio

$$\frac{K_t}{L_t} = \frac{\alpha}{1-\alpha}\frac{W_t}{R_t^k} \tag{A.15}$$

Price Phillips curve

$$\left(\frac{K_{1,t}}{F_{1,t}}\right)^{\frac{1-\alpha}{1-\alpha+\alpha\epsilon_p}} = \left(\frac{1-\theta_p\,\pi_t{}^{\epsilon_p-1}}{1-\theta_p}\right)^{\frac{1}{1-\epsilon_p}} \tag{A.16}$$

where $K_{1,t} = \mu MC_t Y_t + \frac{\theta_p\,\beta\,\pi_{t+1}{}^{\frac{\epsilon_p}{1-\alpha}}\,\lambda_{t+1}}{\lambda_t} K_{1,t+1}$ and $F_{1,t} = Y_t + \frac{\lambda_{t+1}\,\theta_p\,\beta\,\pi_{t+1}{}^{\epsilon_p-1}}{\lambda_t} F_{1,t+1}$ are auxiliary variables.

Monetary policy

$$R_t = R_{t-1}{}^{\phi^R}\left[\frac{1}{\beta}\left(\frac{\pi_t^C}{\bar{\pi}}\right)^{\phi^\pi}\left(\frac{y_t}{\bar{y}}\right)^{\phi^y}\right]^{1-\phi^R} \tag{A.17}$$

Government budget

$$BD_t = P_t^B B_t = P_t Z_t + P_t G_t + P_t I_t^G + (1+P_t^B\rho)B_{t-1} - K_t R_t^k \tau^k - L_t W_t \tau^W - \tau^c P_t^C C_t \tag{A.18}$$

Debt rule

$$Z_t = (Z_{t-1})^{\phi_\tau}\left((S_{t-1}-\bar{S})^{\gamma_S}\right)^{1-\phi_\tau} \tag{A.19}$$

where $S_t = \frac{P_t^B B_t}{P_t Y_t}$ is the debt-to-GDP ratio.

Aggregate resource constraint

$$Y_t = C_t + I_t^F + I_t^G + G_t \tag{A.20}$$

Aggregate consumption

$$C_t = (1-n)C_t^{S,P} + nC_t^N \tag{A.21}$$

Aggregate labor supply

$$L_t = (1-n)L_t^S + nL_t^N \tag{A.22}$$

Aggregate public investment

$$I_t^G = I_t^{XG} + I_t^{IG} + I_t^{CG} \tag{A.23}$$

Manufacturing producers value added demand

$$VA_t = s^{VA} \left(\left(\frac{P_t}{MC_t^X P_t^X} \right) \right)^{-\sigma^X} X_t. \tag{A.24}$$

Manufacturing producers public investment good usage

$$I_t^{XG} = s^{XG} \left(\left(1 + \theta_t^X \right) \left(\frac{P_t}{MC_t^X P_t^X} \right) \right)^{-\sigma^X} X_t. \tag{A.25}$$

Manufacturing producers marginal costs

$$MC_t^X = \left[s^{VA} \left(\frac{P_t}{P_t^X} \right)^{1-\sigma^X} + s^{XG} \left(\frac{P_t}{P_t^X} \left(1 + \theta_t^X \right) \right)^{1-\sigma^X} \right]^{\frac{1}{1-\sigma^X}} \tag{A.26}$$

Manufacturing price Phillips curve

$$\left(\frac{K_{1,t}^X}{F_{1,t}^X} \right) = \left(\frac{1 - \theta_p \, {\pi_t^X}^{\epsilon_p - 1}}{1 - \theta_p} \right)^{\frac{1}{1-\epsilon_p}} \tag{A.27}$$

where $K_{1,t}^X = \mu MC_t^X X_t + \frac{\theta_p \, \beta \, \pi_{t+1}^X \, \lambda_{t+1}}{\lambda_t} K_{1,t+1}^X$ and $F_{1,t}^X = X_t + \frac{\lambda_{t+1} \, \theta_p \, \beta \, {\pi_{t+1}^X}^{\epsilon_p - 1}}{\lambda_t} F_{1,t+1}^X$ are auxiliary variables.

Investment goods producers value added demand

$$I_t^F = s^I \left(\left(\frac{P_t^X}{MC_t^I P_t^I} \right) \right)^{-\sigma^I} I_t. \tag{A.28}$$

Investment goods producers public investment good usage

$$I_t^{IG} = s^{IG} \left(\left(1 + \theta_t^I \right) \left(\frac{P_t}{MC_t^I P_t^I} \right) \right)^{-\sigma^I} I_t. \tag{A.29}$$

Investment goods producers marginal costs

$$MC_t^I = \left[s^I \left(\frac{P_t^X}{P_t^I} \right)^{1-\sigma^I} + s^{IG} \left(\frac{P_t}{P_t^I} \left(1 + \theta_t^I \right) \right)^{1-\sigma^I} \right]^{\frac{1}{1-\sigma^I}} \tag{A.30}$$

Investment goods producer Price Phillips curve

$$\left(\frac{K_{1,t}^I}{F_{1,t}^I} \right) = \left(\frac{1 - \theta_p \, {\pi_t^I}^{\epsilon_p - 1}}{1 - \theta_p} \right)^{\frac{1}{1-\epsilon_p}} \tag{A.31}$$

where $K_{1,t}^I = \mu MC_t^I X_t + \frac{\theta_p \beta \pi_{t+1}^I \lambda_{t+1}}{\lambda_t} K_{1,t+1}^I$ and $F_{1,t}^I = X_t + \frac{\lambda_{t+1} \theta_p \beta {\pi_{t+1}^I}^{\epsilon_p - 1}}{\lambda_t} F_{1,t+1}^I$ are auxiliary variables.

Consumption goods producers value added demand

$$C_t^F = s^C \left(\left(\frac{P_t^X}{MC_t^C P_t^C} \right) \right)^{-\sigma^C} C_t. \tag{A.32}$$

Consumption goods producers public investment good usage

$$I_t^{CG} = s^{CG} \left(\left(1 + \theta_t^C \right) \left(\frac{P_t}{MC_t^C P_t^C} \right) \right)^{-\sigma^C} C_t. \tag{A.33}$$

Consumption goods producers marginal costs

$$MC_t^C = \lambda_t^C = \left[s^C \left(\frac{P_t^X}{P_t^C} \right)^{1-\sigma^C} + s^{CG} \left(\frac{P_t}{P_t^C} \left(1 + \theta_t^C \right) \right)^{1-\sigma^C} \right]^{\frac{1}{1-\sigma^C}} \tag{A.34}$$

Consumption goods producer Price Phillips curve

$$\left(\frac{K_{1,t}^C}{F_{1,t}^C} \right) = \left(\frac{1 - \theta_p \, {\pi_t^C}^{\epsilon_p - 1}}{1 - \theta_p} \right)^{\frac{1}{1-\epsilon_p}} \tag{A.35}$$

where $K_{1,t}^C = \mu MC_t^C X_t + \frac{\theta_p \beta \pi_{t+1}^C \lambda_{t+1}}{\lambda_t} K_{1,t+1}^C$ and $F_{1,t}^C = X_t + \frac{\lambda_{t+1} \theta_p \beta {\pi_{t+1}^C}^{\epsilon_p - 1}}{\lambda_t} F_{1,t+1}^C$ are auxiliary variables.

A.3.4 Sensitivity analysis DSGE model

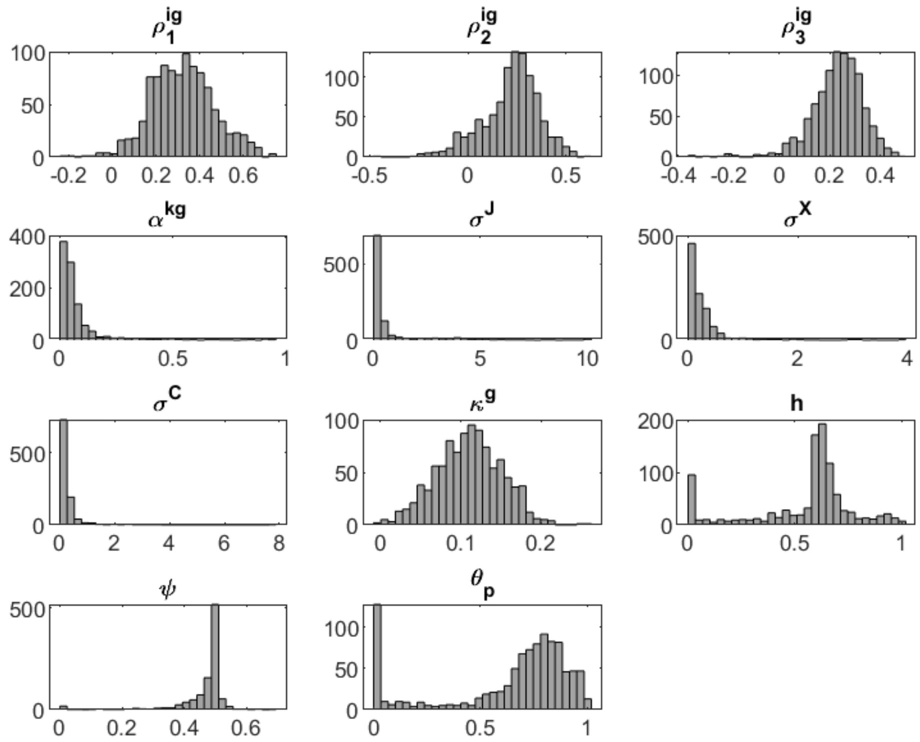

Figure A.22: Distribution parameter estimates. *Notes:* The figure shows the distribution of the estimates for the parameters in ζ for each of the 1000 bootstrap draws that are the basis for the confidence intervals of the empirical responses shown in Figure 2.

We perform a sensitivity analysis. We change the values of selected calibrated parameters and re-estimate ζ. Table A.5 summarizes the results. The first column lists the calibrated parameter. The next columns contain the estimates conditional on the alternative calibration. The last two columns report the model-implied cumulative output multiplier at one year and five years. The first row of the results repeats the baseline estimates for comparison.

First, we change two parameters related to the households, one at a time. We either increase the share of non-saving households to $n = 0.1$. Or, we assume weak substitutability of private and public government consumption in utility, $\alpha^g = 0.2$, instead of complementarity. Next, we change some parameters related to production and pricing. We lower the production elasticity of private capital to $\alpha = 0.3$. We increase the depreciation rates to $\delta = \delta^G = 0.025$. We eliminate price and wage indexation by setting $\chi_p = \chi_w = 0$. In the final block, we change the policy ratio

Calibrated	Estimate											Output multiplier	
	ρ_1^{ig}	ρ_2^{ig}	ρ_3^{ig}	α^{kg}	σ^J	σ^X	σ^C	κ^g	h	ψ	θ_p	1 year	5 years
Baseline	0.4115	0.2893	0.2266	0.0403	0.2956	0.2181	0.2037	0.1536	0.4609	0.4897	0.8684	2.5059	2.4445
$n = 1$	0.3262	0.3031	0.2555	0.0000	0.0824	0.1291	0.1616	0.1055	0.5703	0.4862	0.3881	3.0181	3.1198
$\alpha^g = 0.2$	0.4038	0.3003	0.2231	0.0400	0.2520	0.2716	0.1881	0.1525	0.5843	0.4944	0.8556	2.5091	2.4541
$\alpha = 0.3$	0.4190	0.2924	0.2155	0.0409	0.2219	0.3546	0.1735	0.1692	0.4378	0.4874	0.8775	2.4861	2.4275
$\delta = \delta^G = 0.025$	0.4051	0.2999	0.2240	0.0401	0.2375	0.2568	0.1880	0.1485	0.5987	0.4948	0.8521	2.4984	2.4053
$\chi_p = \chi_w = 0$	0.4031	0.3030	0.2169	0.0633	0.1801	0.2687	0.1548	0.1488	0.6815	0.4782	0.8281	2.5415	2.5268
$I^G/Y = 0.04$	0.3283	0.2838	0.2653	0.0527	0.1722	0.2144	0.1552	0.1328	0.6275	0.4862	0.8594	2.1237	2.3855
$\phi_\tau = -1$	0.4254	0.2850	0.2165	0.0379	0.3784	0.2269	0.2216	0.1538	0.3925	0.4925	0.8853	2.4999	2.4287
$\phi^\pi = 1.2$	0.4510	0.2448	0.2446	0.0404	2.5409	0.0817	0.4086	0.1698	0.0564	0.4426	0.8632	2.1807	2.0227
$\phi^y = 0.05$	0.3804	0.2889	0.2593	0.2444	0.1031	0.0192	0.1196	0.1465	0.8904	0.4807	0.7386	2.4594	2.3868

Table A.5: Sensitivity analysis. *Notes:* The table shows the estimates of ζ and the cumulative government investment to output multiplier at the one-year and five-year horizon for alternative calibrations of the non-estimated parameters.

or parameters. We increase the government investment/GDP ratio to $I^G/Y = 0.04$. We make fiscal policy more responsive by setting the elasticity of transfers to debt to $\phi_\tau = -1$, we increase the reponse of monetary policy to inflation to $\phi^\pi = 1.2$, and we allow for a positive response of the central bank to output fluctuations through the choice of $\phi^y = 0.05$.

Overall, the size of the multiplier does not change much across alterations. It is typically between 2-3. The parameter estimates are also stable, with a few exceptions. The estimated output elasticity of public capital drops to zero if the share of non-Ricardian households is higher than in the baseline and it increases to 0.24 if the monetary authority responds to the output gap. The CES substitution parameters drop uniformly if private and public consumption are substitutes in the utility function and they change in different directions if the central banks responds more aggressively to inflation.

Parameter	Notation	Estimate baseline	Estimate alternative
Persistence government investment shocks	ρ_1^{ig}	0.409	0.460
	ρ_2^{ig}	0.289	0.157
	ρ_3^{ig}	0.225	0.253
Elasticity of output to government capital	α^{kg}	0.041	0.224
Substitution elasticity public inv. CES	σ^J	0.289	0.042
	σ^X	0.215	0.024
	σ^C	0.203	0.044
Sensitivity private inv. adj. costs to gov. inv.	κ^g	0.154	0.241
Habit formation	h	0.505	0.882
Inverse labor elasticity	ψ	0.491	0.000
Calvo price parameter	θ_p	0.862	0.482

Table A.6: Alternative parameter estimates. *Notes:* The table shows the baseline estimated parameter values and the estimates obtained from matching the impulse response functions of the DSGE model to a Proxy-SVAR that includes the endogenous variables in log-levels (instead of detrending them by potential output beforehand) and excludes all exogenous variables.

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