What Have We Learned From Three Decades of Research on the Productivity of Public Capital?

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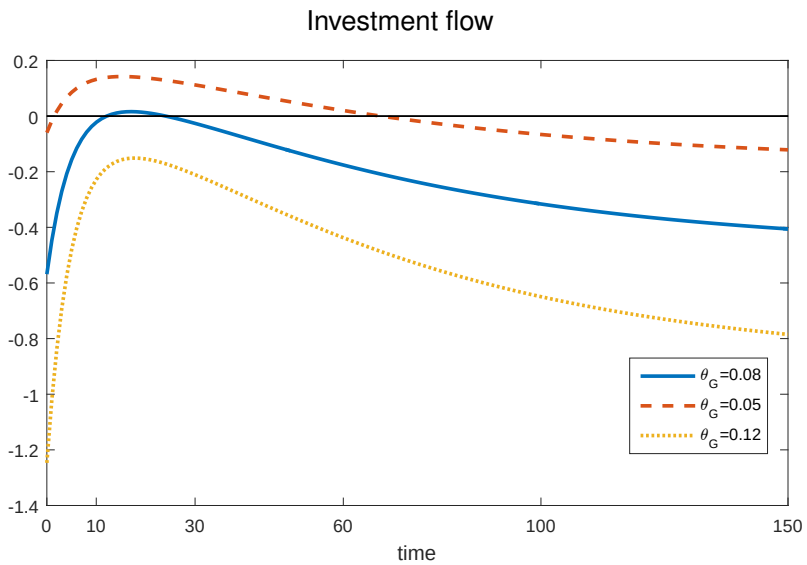
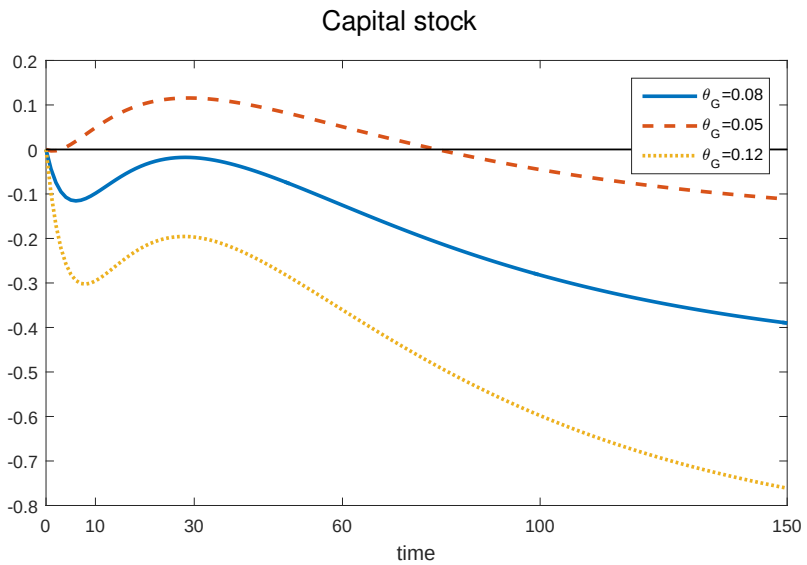
Motivation

- How important is public infrastructure capital in the production function of private firms?
- The output elasticity of public capital (OEPC) features as a key parameter in macro models with productive government spending
  - The macroeconomic effects of public investment shocks in DSGE models are typically very sensitive to the OEPC (e.g., Baxter and King, 1993; Bom and Ligthart, 2014)
  - Optimality conditions usually involve comparing the OEPC with public investment ratios (e.g., Barro, 1990)
- Large body of empirical literature estimating the OEPC, but very disparate results (size and sign)

Example from Bom (2016)

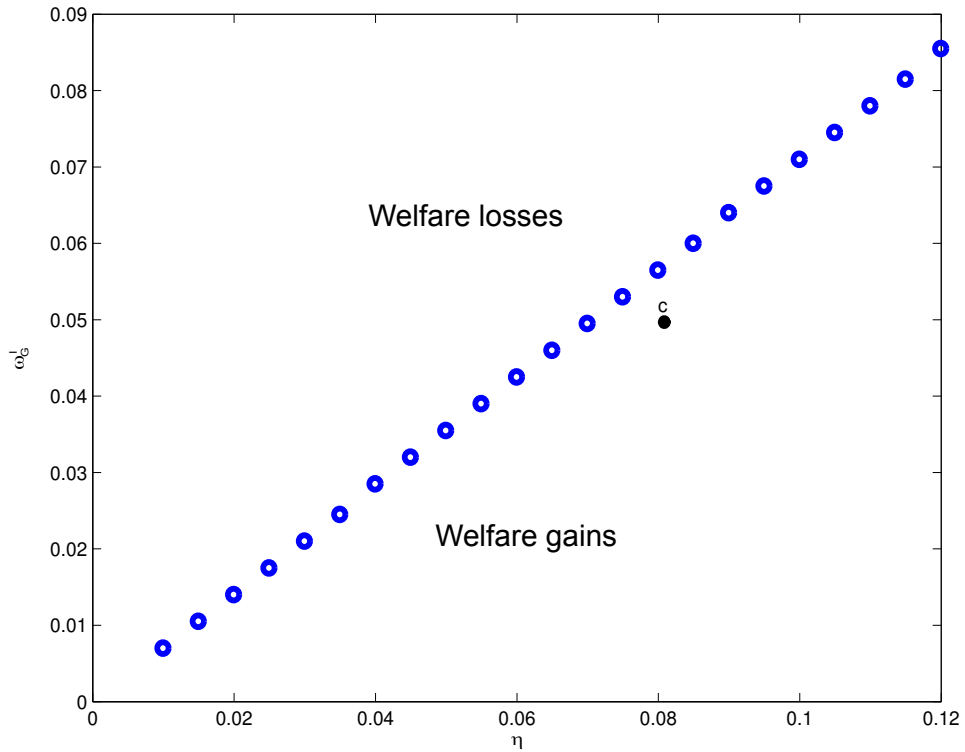
Crowing-in/out of public investment on private capital in a model with K-biased public capital for different OEPCs





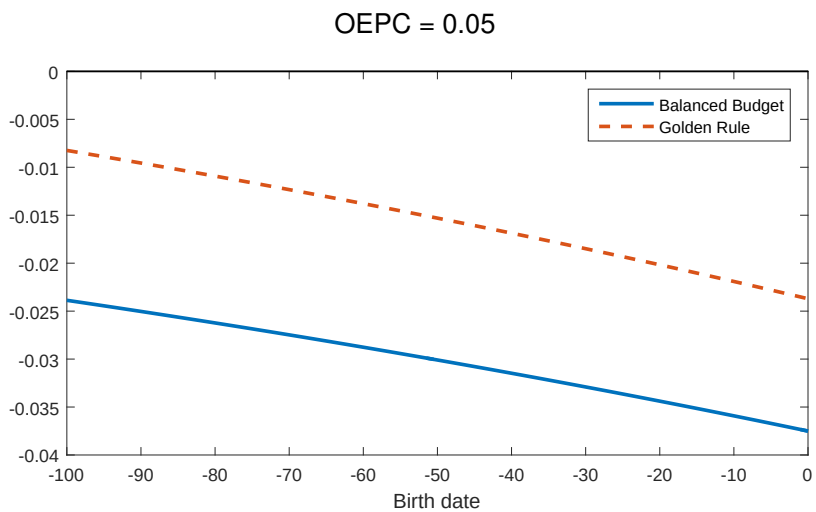
Example from Bom and Ligthart (2014)

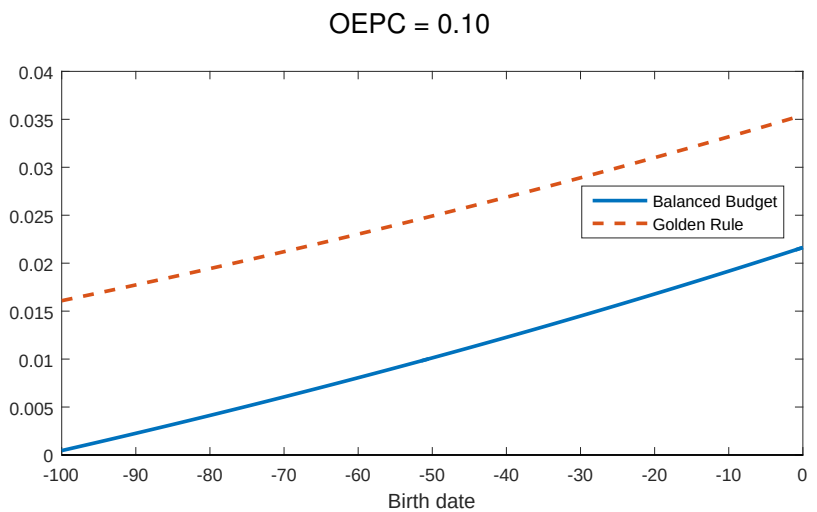
Optimal public investment ratio in a model with distortionary labor income taxes



Example from Bom (2016)

Welfare effects of public investment on existing generations for alternative fiscal rules





Contribution

This paper conducts a meta-analysis of 578 estimates of the OEPC collected from 68 empirical studies:

- meta-estimates the average OEPC in this empirical literature
- identifies the sources of variation across estimates/studies
- corrects for publication bias

The Production Function Approach

How to measure the OEPC?

Production function approach:

$$Y = AF(K, L, G), \qquad \text{OEPC} = \frac{\partial Y}{\partial G}\frac{G}{Y}$$

Several production specifications:

- Cobb-Douglas
- CES
- Translog

Problems in estimating the OEPC using the PF approach

- Definition problems: what is *productive* public capital?
- Measuring problems: how to measure the *effective* stock of public capital?
- Estimation problems:
  - Functional form: how does public capital interact with private production factors?
  - Timing: lagged effects and anticipation effects
  - Spillovers: how to model the externalities of public capital?
  - Data properties: non-stationarity
  - Endogeneity of public capital

Key contributions using the production function approach

Author(s)	Country	Min	Max	Mean
Ratner (1983)	US	0.277	0.277	0.277
Da Costa, Ellson, and Martin (1987)	US	0.160	0.281	0.204
Aschauer (1989)	US	0.240	0.560	0.379
Munnell (1990)	US	0.210	0.490	0.367
Eisner (1991)	US	−0.491	0.383	0.048
Tatom (1991)	US	−0.075	0.042	−0.017
Berndt and Hansson (1992)	Sweden	0.687	1.601	1.144
Garcia-Milà and McGuire (1992)	US	0.044	0.045	0.045
Evans and Karras (1994a)	US	−0.110	0.102	−0.023
Evans and Karras (1994b)	7 OECD countries	−0.465	0.182	−0.117
Baltagi and Pinnoi (1995)	US	−0.080	0.390	0.071
Holtz-Eakin and Schwartz (1995a)	US	−0.038	0.112	0.039
Holtz-Eakin and Schwartz (1995b)	US	−0.022	0.054	0.009
Vijverberg, Vijverberg, and Gamble (1997)	US	0.465	0.550	0.496
Boarnet (1998)	US	0.065	0.300	0.225
Otto and Voss (1998)	Australia	0.058	0.065	0.060
Cadot, Roller, and Stephan (2006)	France	0.080	0.086	0.083
Kamps (2006)	22 OECD countries	−1.726	1.369	0.395

Other Approaches

- Behavioral approaches:
  - Cost function
  - Profit function
- Growth regressions
- VAR models

The production function approach

Most studies estimate a special case of

$$\ln Y_{it} = c + \chi_t + \nu_i + \alpha \ln K_{it} + \beta \ln L_{it} + \theta \ln G_{it} + \delta X_{it} + \varepsilon_{it},$$

where $\theta =$ OEPC

Why so much variation in estimated OEPCs?

- type of data
- definitions of Y_{it} and G_{it}
- model specification
- estimation technique

Heterogeneity factors: data type and aggregation

Type of data:

- Time-series
- Panel data (majority)
- cross-section (very few)

Aggregation level:

- National level
- Regional/local level

Heterogeneity factors: definition of output

- Private sector output (vast majority)
- Total GDP (a few studies, especially for developing countries)
- Sectoral output (e.g., manufacturing output)

Heterogeneity factors: definition of public capital

- Non-military infrastructure stock owned by the general government (most common)
- Capital stocked installed at the regional/local level of government
- Subcomponents: ‘core’ infrastructure or transportation infrastructure
- Including capital of neighboring regions

Heterogeneity factors: model specification

- CRTS restrictions:
  - across private inputs: $\alpha + \beta = 1$
  - across all inputs: $\alpha + \beta + \theta = 1$
- Other controls: capacity utilization, raw materials, energy prices/quantities, education, public capital of neighboring regions, etc.
- Production frontier model

Heterogeneity factors: econometric issues

- Time-series studies:
  - variables in levels without cointegration test (early studies)
  - cointegration relation claimed
  - first differences
- In panel data studies:
  - fixed unit effects
  - fixed time effects
  - long differences
- Time trend
- Instrumental variables

The Meta-Sample

Meta-sample

Inclusion criteria:

- production function approach
- VAR embedding a production function
- monetary measure of public capital
- standard errors reported

Meta-sample

Retrieving strategy:

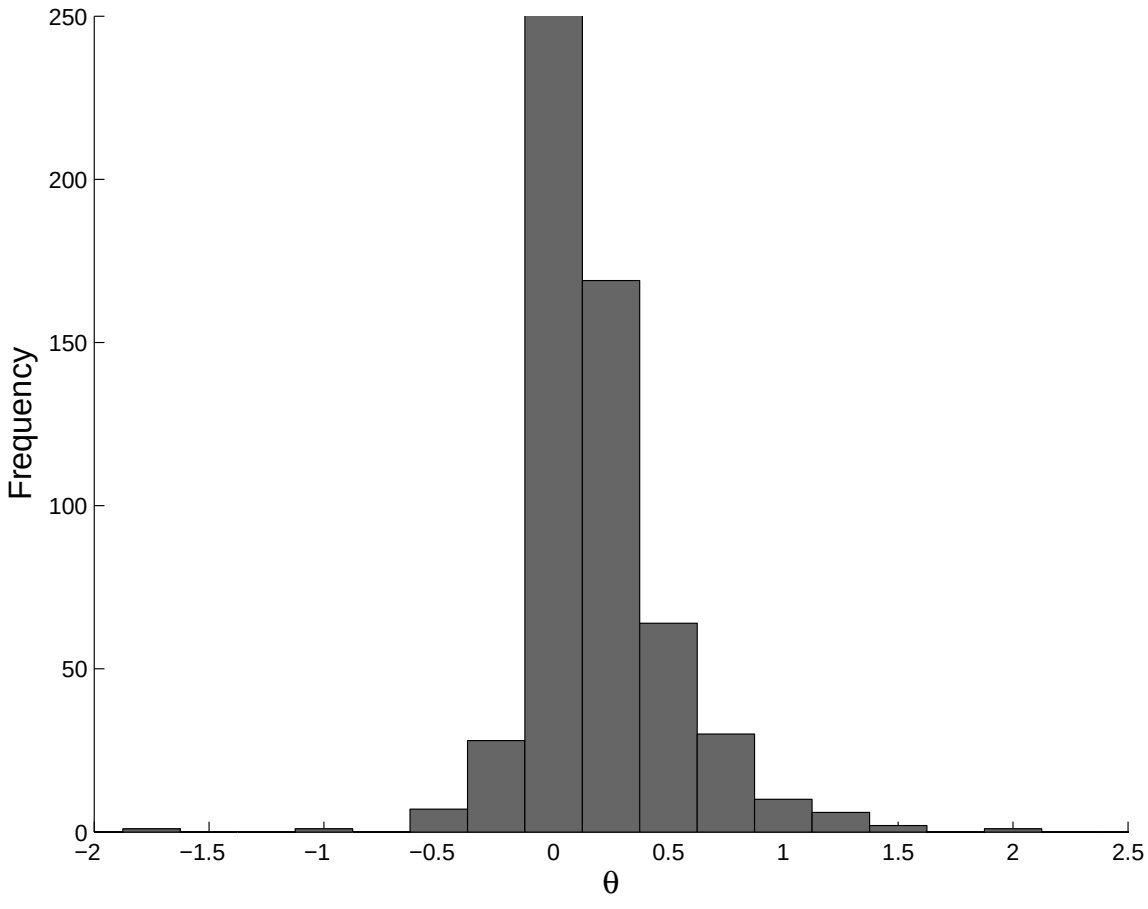
- Overview papers such as Sturm et al. (1998) and Romp and De Haan (2007) $\rightarrow$ 47 usable papers
- Thomson's *Web of Science*, by searching for papers citing Aschauer (1989) $\rightarrow$ 7 usable papers
- Google Scholar $\rightarrow$ 14 usable papers

Meta-sample

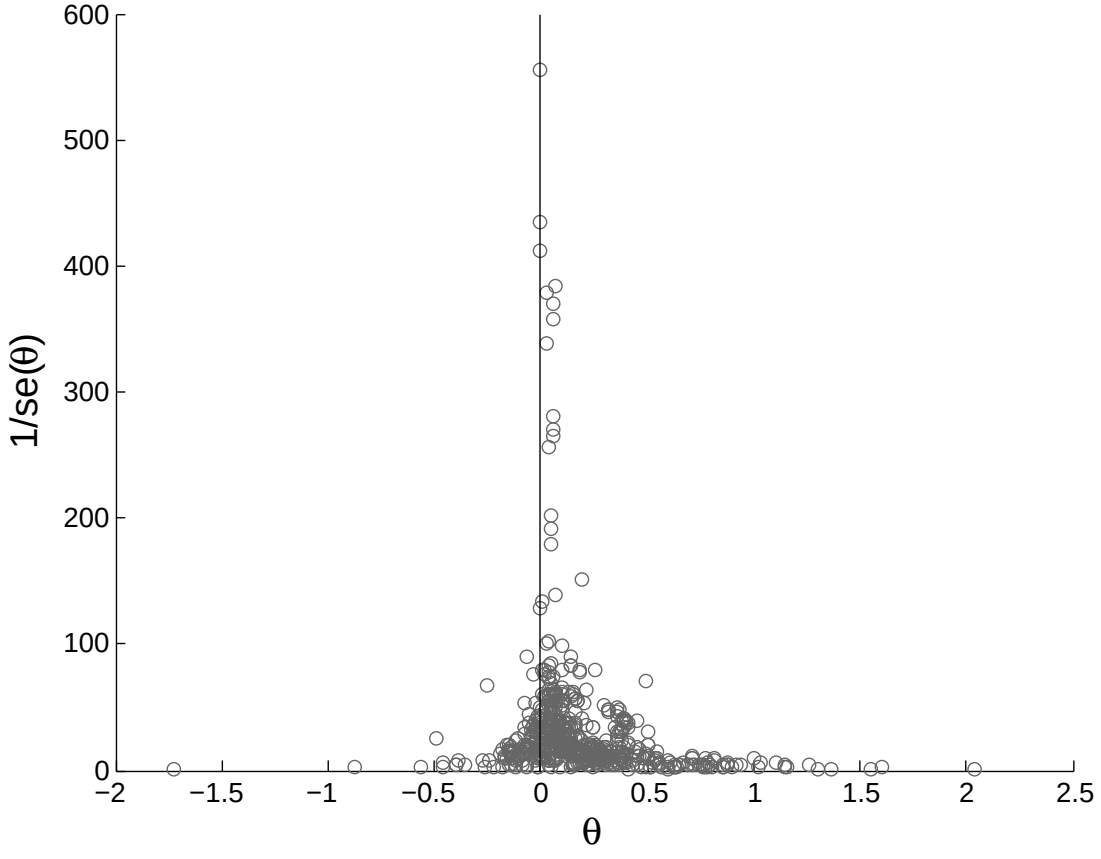
- 68 included papers, of which:
  - 60 published in journals or books
  - 8 unpublished
- 578 estimates, of which:
  - 464 positive
  - 114 negative
- Some descriptive statistics:

Min.	−1.726
Max.	2.040
Average	0.184
Median	0.120
Std. dev.	0.306

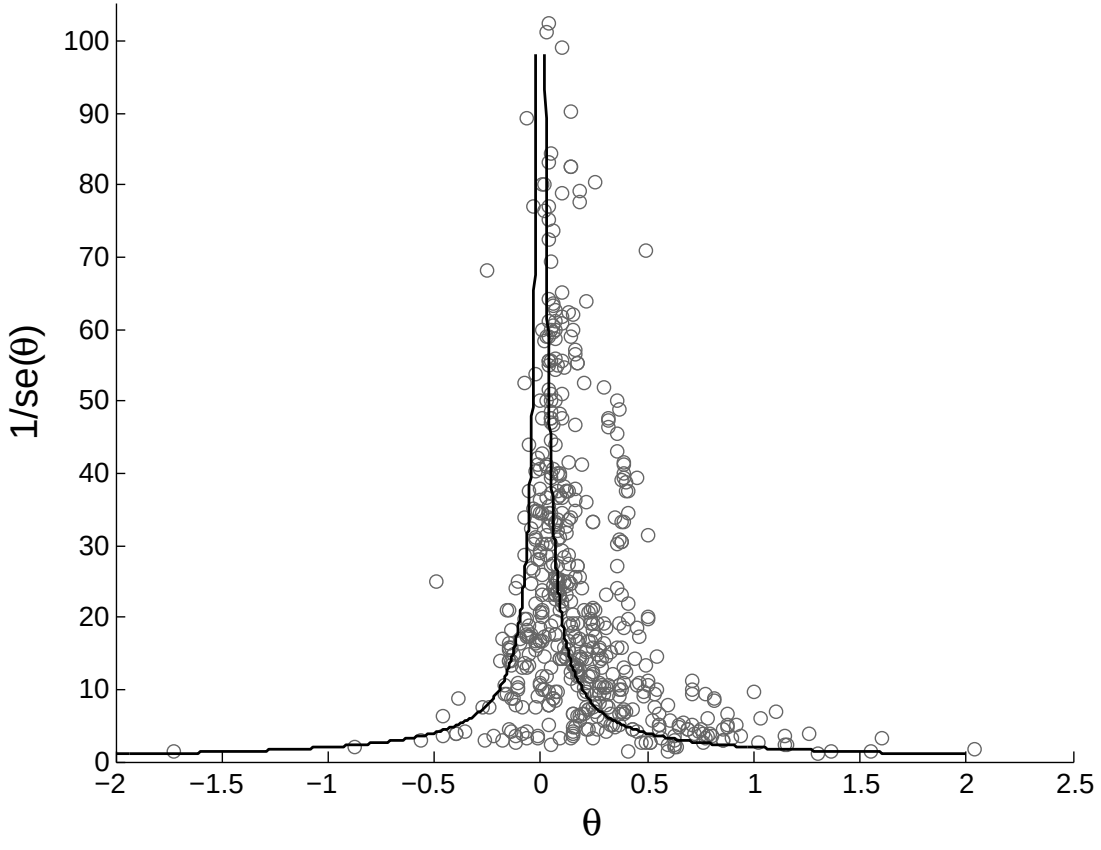
Histogram of OEPCs



Funnel plot

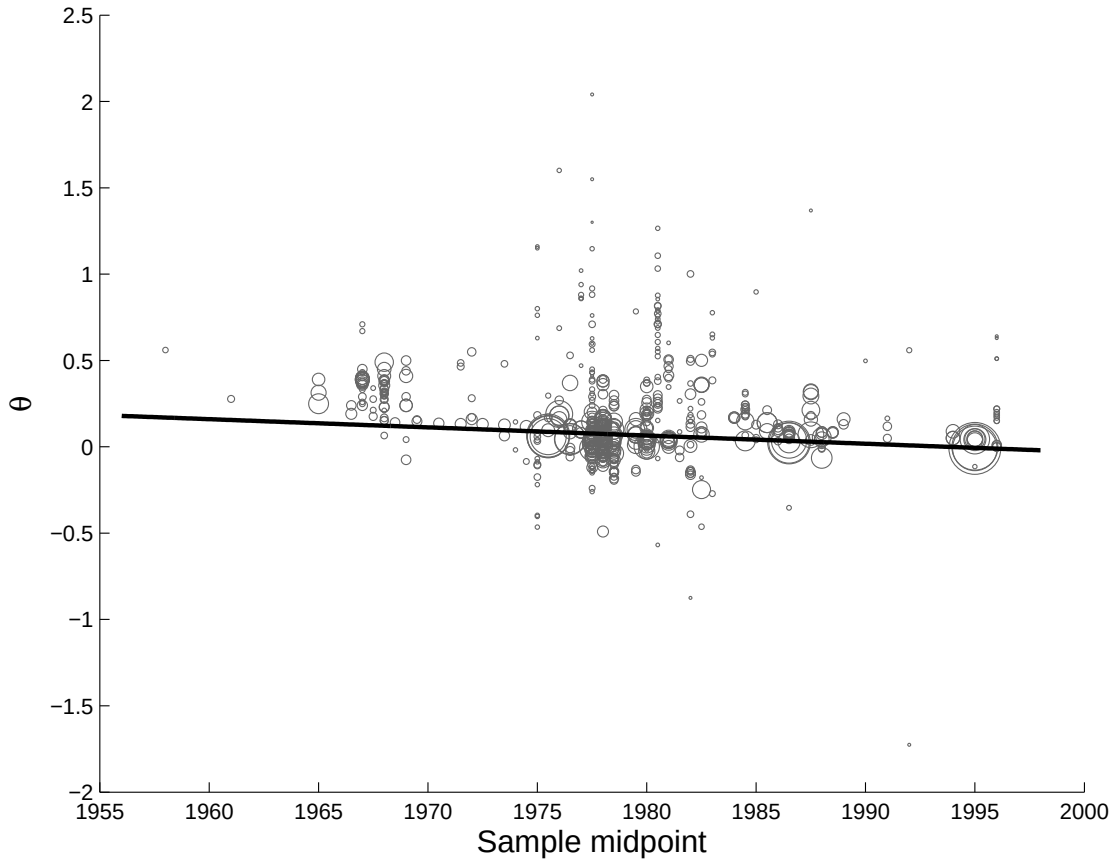


Funnel plot (trimmed at the top)



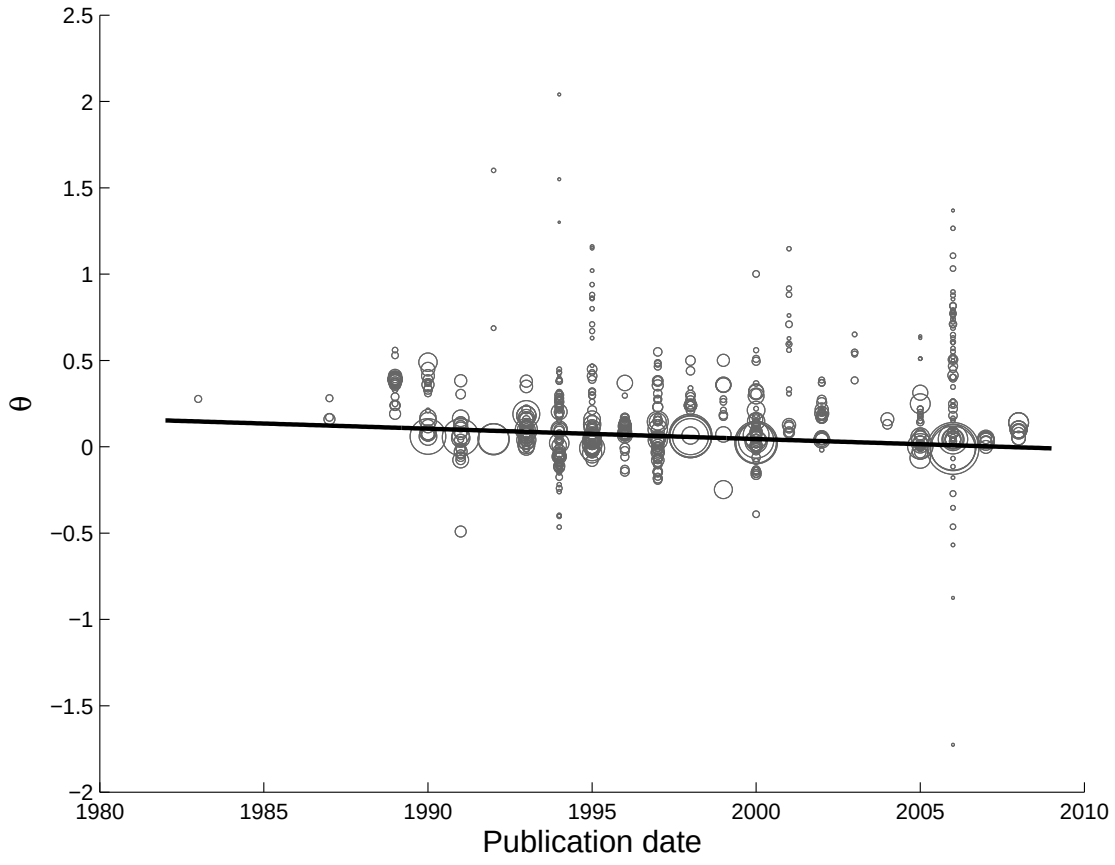
Sample midpoint

Smaller OEPCs in more recent samples:



Publication date

Also, smaller OEPCs in more recent papers:

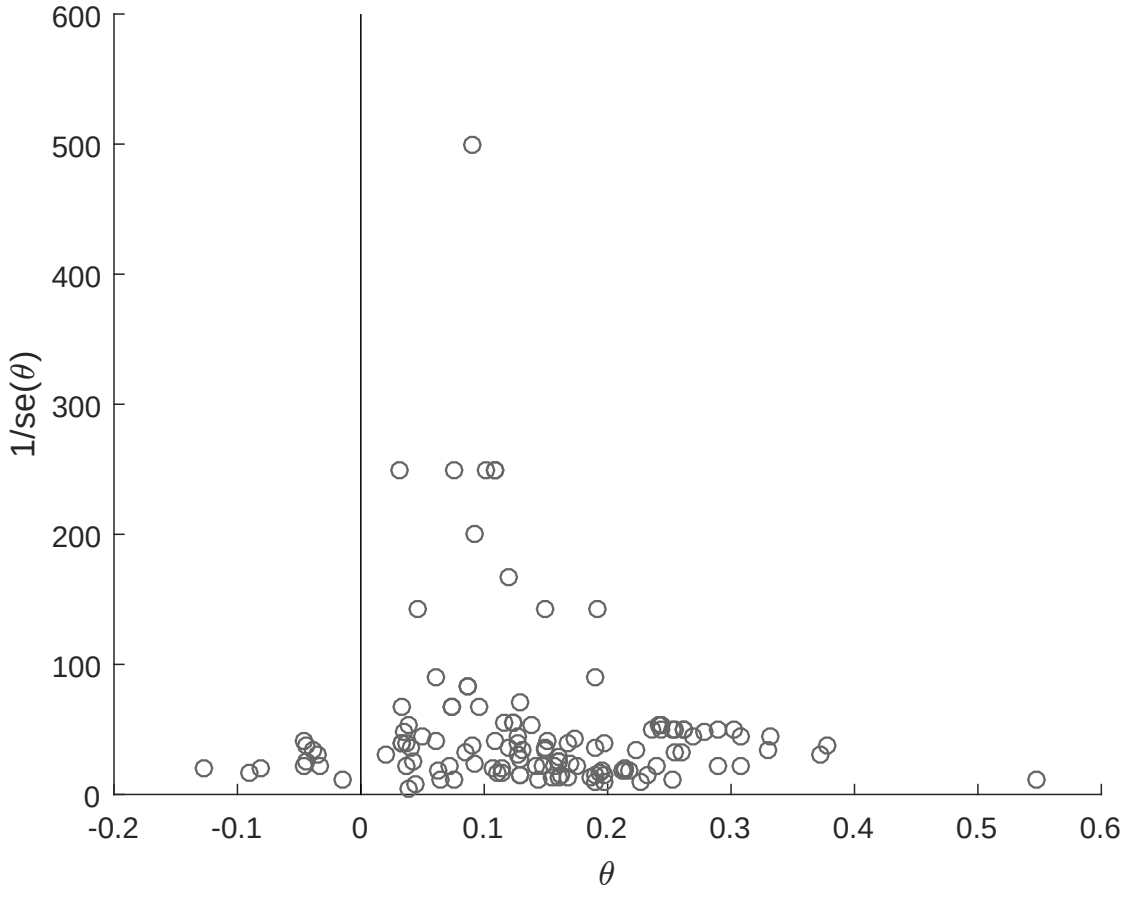


Update: a few more recent studies (2009-2016)

Author(s)	Country	Min	Max	Mean
Bronzini and Piselli (2009)	Italy	−0.128	0.192	0.100
Fedderke and Bogetić (2009)	South Africa	−0.047	0.196	0.094
Rodríguez-Vález et al. (2009)	Spain	−0.046	0.308	0.142
Arslanalp et al. (2010)	48 countries	0.021	0.129	0.062
Cohen (2010)	US	0.062	0.107	0.084
Heintz (2010)	US	0.212	0.218	0.215
Marrocu and Paci (2010)	Italy	0.075	0.119	0.096
Mitzuani and Tanaka (2010)	Japan	0.073	0.086	0.080
Ramirez (2010)	Mexico	0.160	0.170	0.163
Hämäläinen and Malinen (2011)	Finland	−0.044	0.548	0.103
Gómez-Antonio and Fingleton (2012)	Spain	0.139	0.139	0.139
Bottasso, Castagnetti, and Conti (2013)	21 OECD countries	0.060	0.150	0.120
Gupta et al. (2013)	52 devel. countries	0.143	0.253	0.192
Kortelainen and Leppänen (2013)	Russia	−0.090	0.377	0.146
Shi and Huang (2014)	China	0.127	0.289	0.215
Han, Ryu, and Sickles (2015)	21 OECD countries	0.236	0.332	0.261
Jiang et al. (2015)	China	0.031	0.129	0.094
Álvarez, Barbero, and Zofío (2016)	Spain	0.034	0.034	0.034
Saidi (2016)	Tunisia	0.071	0.161	0.116

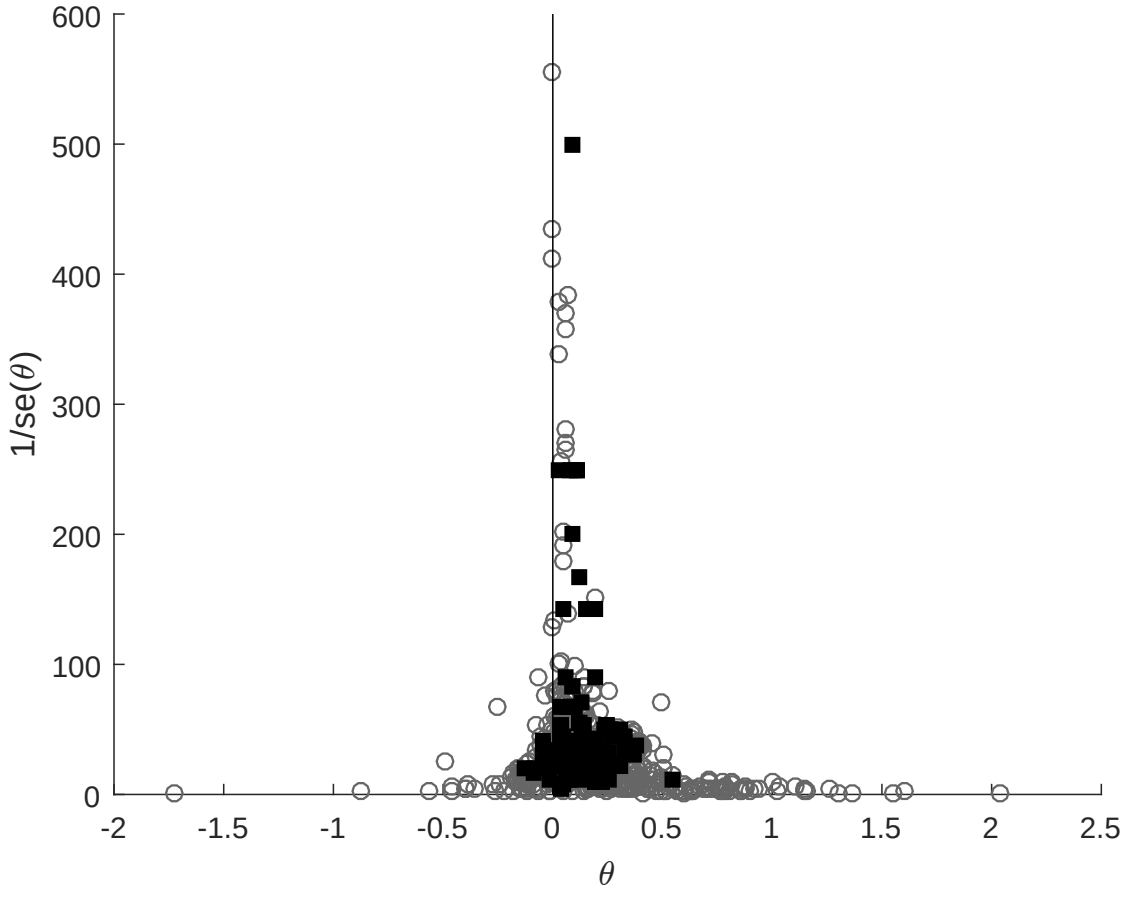
Update: funnel plot of recent OEPCs

127 estimates from 19 studies published in 2009-2016



Update: all OEPCs

705 estimates from 87 studies published in 1983-2016



The Meta-Regression

Meta-regression model

We specify a meta-regression model of the form:

$$\hat{\theta}_i = \theta_i + (\delta_p P_{pi} + \delta_n P_{ni})\text{se}(\hat{\theta}_i) + \mu_i,$$

- $\hat{\theta}_i =$ estimate of the true parameter θ_i
- $\text{se}(\hat{\theta}_i) =$ standard error of $\hat{\theta}_i$
- $P_{pi} = 1$ if $\hat{\theta}_i > 0$ (0 otherwise)
- $P_{ni} = 1$ if $\hat{\theta}_i < 0$ (0 otherwise)
- $\mu_i =$ sampling error, satisfying $\text{E}(\mu_i) = 0$ and $\text{V}(\mu_i) = \sigma^2_{\mu i}$

Observable and unobservable heterogeneity

The variation in θ_i is partly observable and partly unobservable:

$$\theta_i = \bar{\theta} + \sum_{j=1}^{M} \phi_j D_{ji} + \upsilon_i, \qquad \mathrm{E}(\upsilon_i) = 0,\ \mathrm{V}(\upsilon_i) = \sigma_\upsilon^2 \geq 0,$$

where:

- D_{ji}'s are (demeaned) moderator variables capturing observable heterogeneity
- υ_i captures unobserved heterogeneity. Two cases:
  - Fixed effects: $\sigma_\upsilon^2 = 0$
  - Random effects: $\sigma_\upsilon^2 > 0$

Estimation of the meta-regression model

The meta-regression model is then:

$$\hat{\theta}_i = \bar{\theta} + \sum_{j=1}^{M} \phi_j D_{ji} + (\delta_p P_{pi} + \delta_n P_{ni})\text{se}(\hat{\theta}_i) + \mu_i + \upsilon_i,$$

Weighted Least Squares estimation:

- Fixed effects weights: $\omega_i = \frac{1}{\hat{\sigma}^2_{\mu i}}$
- Random effects weights: $\omega_i = \frac{1}{\hat{\sigma}^2_{\mu i} + \hat{\sigma}^2_v}$

Estimation of sampling error variances

Sampling error variances are obtained from the fitted values of

$$\ln \mathrm{se}(\hat{\theta}_i)^2 = \tau_0 + \tau_1 \ln \mathrm{df}_i + \sum_{j=1}^{\tilde{M}} \rho_j D_{ji} + \epsilon_i$$

where $\mathrm{df}_i =$ degrees of freedom involved in estimating $\hat{\theta}_i$

Variance of the random effects component

Variance of the random effects component:

$$\hat{\sigma}_v^2 = \frac{N[Q/(N-J)-1]}{\sum_{i=1}^{N} \omega_i},$$

where:

- $Q =$ RSS of the fixed effects model
- $J =$ number of meta-regression parameters estimated
- ω_i's $=$ weights of the fixed effects model

Moderators included in the meta-regression

Moderator (D_j)	Definition	$\sum_{i=1}^{N} D_{ji}$
Public capital definition:		
Core	Core public capital	72
Transp	Transportation capital	125
Reg-gov	Regional/local public capital	126
Spill-agg	Public capital of neighboring regions is included	19
Output definition:		
Private	Private sector gross output	332
Manufact	Output of the manufacturing sector	59
Agric	Output of the agricultural sector	7
Model specification:		
CRTS-all	Constant returns to scale on all inputs	143
CRTS-priv	Constant returns to scale on private inputs	30
Cap-util	Capacity utilization is controlled for	225
Pfrontier	Production frontier model	3
Raw	Imported raw materials are controlled for	3
Energy-p	Energy prices are controlled for	12
Energy-q	Quantity of energy use in production is controlled for	8
Education	Education is controlled for	6
Spill-disag	Public capital of neighboring areas is controlled for	56

Moderators included in the meta-regression (cont.)

Moderator (D_j)	Definition	$\sum_{i=1}^{N} D_{ji}$
Econometric issues:		
Coint	Cointegration relationship is found	44
Spurious-ts	Time-series in levels without cointegration test	72
Spurious-pd	Panel data in levels without cointegration test	282
Fixed-eff	Unit-specific fixed effects	139
Long-diff	Variables in long differences	24
Trend	A time trend is included	165
Time-eff	Time-specific effects are employed	189
Endog	Instrumental variables	47
Data:		
Cross	Cross-section data are used	12
Reg-data	Regional data are used	347
Country k	Fixed effect for country *k*	–
Sample-med	Median year of the sample	–
Publication:		
Date	Date of the study (in years)	–
Published	Published in a journal or book	421

Meta-regression results: main moderators

	OLS		Fixed Effects		Random Effects		Restricted	
$\bar{\theta}$	0.112	(0.016)***	0.084	(0.013)***	0.096	(0.012)***	0.106	(0.007)***
Reg-gov	-0.007	(0.020)	0.019	(0.014)	0.027	(0.015)*	0.023	(0.010)**
Core	0.041	(0.031)	0.017	(0.020)	0.037	(0.027)	0.047	(0.024)**
Transp	-0.020	(0.022)	-0.011	(0.013)	-0.013	(0.015)		–
Private	-0.038	(0.017)**	-0.001	(0.012)	-0.021	(0.014)	-0.032	(0.013)***
Manufact	0.019	(0.034)	-0.048	(0.029)*	-0.026	(0.032)		–
Agric	-0.088	(0.097)	-0.009	(0.076)	-0.005	(0.020)		–
Spill-agg	-0.030	(0.026)	-0.066	(0.029)**	-0.033	(0.020)		–
Spill-disag	-0.049	(0.030)	-0.020	(0.018)	-0.015	(0.018)		–
Reg-data	-0.174	(0.042)***	-0.152	(0.036)***	-0.166	(0.039)***	-0.173	(0.025)***
CRTS-all	0.004	(0.020)	-0.032	(0.010)***	-0.010	(0.019)		–
CRTS-priv	0.038	(0.047)	0.035	(0.022)*	0.043	(0.027)	0.052	(0.027)*
Cap-util	-0.004	(0.024)	0.003	(0.015)	-0.002	(0.016)		–
Pfrontier	-0.038	(0.084)	0.007	(0.091)	-0.004	(0.060)		–
Energy-p	-0.134	(0.046)***	-0.135	(0.054)**	-0.140	(0.045)***	-0.144	(0.046)***
Energy-q	-0.027	(0.031)	-0.056	(0.144)	-0.026	(0.036)		–
Education	0.010	(0.030)	0.022	(0.029)	0.031	(0.026)		–
Raw	0.056	(0.054)	0.039	(0.142)	0.057	(0.051)		–

Meta-regression results: main moderators (cont.)

	OLS	Fixed Effects	Random Effects	Restricted
Coint	-0.005 (0.037)	0.040 (0.039)	0.034 (0.032)	–
Long-diff	0.099 (0.031)***	0.098 (0.029)***	0.096 (0.025)***	–
Long-run	–	–	–	0.039 (0.015)***
Spurious-ts	0.090 (0.042)**	0.115 (0.043)***	0.101 (0.035)***	0.086 (0.025)***
Spurious-pd	0.026 (0.023)	0.067 (0.013)***	0.050 (0.021)**	0.030 (0.014)**
Endog	-0.062 (0.017)***	-0.040 (0.019)**	-0.052 (0.017)***	-0.046 (0.015)***
Fixed-eff	0.008 (0.016)	-0.004 (0.013)	-0.001 (0.014)	–
Time-eff	0.001 (0.020)	0.009 (0.015)	-0.018 (0.015)	–
Trend	0.021 (0.022)	-0.009 (0.015)	-0.019 (0.016)	–
Cross	0.008 (0.045)	0.050 (0.050)	0.014 (0.039)	–
Sample-med	-0.003 (0.002)*	-0.006 (0.001)***	-0.004 (0.001)***	-0.0039 (0.001)***
Date	0.006 (0.002)**	0.006 (0.002)***	0.004 (0.002)**	0.0029 (0.001)**
Published	-0.009 (0.017)	-0.015 (0.014)	-0.015 (0.013)	–
δ_p	1.290 (0.204)***	1.775 (0.137)***	1.571 (0.166)***	–
δ_n	-1.560 (0.221)***	-1.486 (0.188)***	-1.247 (0.201)***	–
$\delta_p = -\delta_n$	–	–	–	1.455 (0.100)***
$\bar{R}^2$	0.728	0.695	0.708	0.723
Q	–	–	1,484	1,572
$\hat{\sigma}_v^2$	–	–	0.005	0.006
F-test	–	–	–	1.101 [0.457]

Meta-regression results: country dummies

	Studies	Estimates	OLS	Fixed Effects	Random Effects	Restricted
Australia	4	27	0.096 (0.070)	-0.038 (0.059)	-0.001 (0.045)	–
Belgium	1	3	-0.148 (0.104)	-0.129 (0.248)	-0.124 (0.108)	–
Canada	3	25	0.231 (0.065)***	0.116 (0.051)**	0.190 (0.056)***	0.180 (0.048)***
Denmark	1	2	0.365 (0.347)	0.447 (0.312)	0.487 (0.299)	0.506 (0.299)*
Finland	1	2	0.088 (0.173)	0.089 (0.298)	0.105 (0.150)	–
France	5	19	0.246 (0.051)***	0.182 (0.047)***	0.221 (0.043)***	0.228 (0.036)***
Germany	4	11	0.295 (0.090)***	0.251 (0.068)***	0.304 (0.079)***	0.290 (0.062)***
Greece	1	2	0.205 (0.198)	-0.066 (0.323)	0.018 (0.189)	–
Ireland	2	3	0.106 (0.184)	0.003 (0.217)	-0.010 (0.186)	–
Italy	4	34	0.202 (0.068)***	0.241 (0.042)***	0.259 (0.064)***	0.238 (0.054)***
Japan	4	24	0.149 (0.060)***	0.091 (0.044)**	0.126 (0.047)***	0.144 (0.034)***
The Netherlands	2	11	0.398 (0.098)***	0.297 (0.105)***	0.346 (0.076)***	0.356 (0.062)***
New Zealand	1	2	-0.559 (0.134)***	-0.575 (0.359)	-0.547 (0.088)***	-0.504 (0.057)***
Norway	1	3	-0.188 (0.050)***	-0.275 (0.265)	-0.234 (0.052)***	-0.221 (0.040)***
Portugal	2	15	0.030 (0.055)	0.041 (0.068)	0.028 (0.044)	–
Spain	13	73	0.155 (0.053)***	0.095 (0.043)**	0.134 (0.044)***	0.114 (0.035)***
Sweden	2	3	0.373 (0.214)*	0.279 (0.239)	0.332 (0.177)*	0.336 (0.171)*
United Kingdom	1	2	-0.027 (0.116)	0.029 (0.348)	0.057 (0.060)	–
United States	31	278	0.200 (0.053)***	0.104 (0.038)***	0.142 (0.040)***	0.133 (0.027)***

Conditional output elasticities of public capital

Time period	All Public Capital		Core Public Capital	
	Regional	National	Regional	National
Short run	0.106	0.083	0.154	0.131
Long run	0.145	0.122	0.193	0.170

Average OEPCs in more recent studies (2009-2016)

Estimator	Estimate	95% CI
Simple Average	0.141	[0.122 – 0.159]
Fixed Effects	0.102	[0.093 – 0.112]
Random effects	0.140	[0.122 – 0.158]
PB correction	0.128	[0.102 – 0.155]

Based on 127 estimates of the OEPC

Take-Home Messages

Final Remarks

- The average output elasticity of public capital amounts to 0.102, after correcting for publication bias
- More recent studies find slightly higher estimates of 0.128, in average
- Substantial variation across estimates, which can be partly explained by:
  - true effect heterogeneity: larger for the core component, in the long run, and installed by regional/local governments
  - study design characteristics: spillover effects, CRTS, endogeneity, stationarity
  - publication bias
- Short-run output elasticity of 0.083, implying a rate of return of about 17%
- Long-run output elasticity of 0.122, implying a rate of return of about 25%