Internal rates of return for public R&D from VECM estimates for 17 OECD countries

Working Paper Series

#2023-026

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Published 19 July 2023

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UNU-MERIT Working Papers
ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology
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Internal Rates of Return for Public R&D from VECM Estimates for 17 OECD Countries

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Abstract In this paper we evaluate vector-error-correction model **(**VECM) estimations and simulations of a companion paper to show (i) internal rates of return to public R&D shocks of 17 OECD countries, (ii) the related payback periods, gain/GDP ratios, and discounted (at 4%) net present values, (iii) the underlying effects of public R&D shocks on domestic and foreign private and public R&D stocks. 14 countries show high internal rates of return from positive public R&D shocks if projects are stopped when gains get negative. Three countries show crowding out effects and require (initial) reductions of public R&D before showing positive results through crowding in of private R&D. Keywords: R&D; growth; returns. JEL codes: H43; H54; O32; O47.

1. Introduction

Soete et al. (2022) report results from the analysis of shocks on publicly performed R&D from VECM estimations with six variables – GDP, TFP, domestic and foreign private and public R&D stocks - for 17 OECD countries during the period 1975-2014. They do not report the internal rates of return or related measures for public R&D that can be derived from these shock simulations going out of sample either until 2040 or until effects get negative. In this companion paper to Soete et al. (2022) we report the corresponding results for internal rates of returns for public R&D and closely related results. The methodology has been developed by Soete et al. (2020) and is restated in section 2. Aspects of this paper, which are not explained here, are explained in these two companion papers.

Some high rates of return for public R&D shown below in this paper are as high as those for basic research (see OECD 2017, Box 6), and those for total private and social rates of return to R&D in McMorrow and Röger (2009) going up to 147% for social rates of return of private R&D, and Coe and Helpman (1995), which are 123% and 155% respectively for domestic aggregate R&D, or the 251% in Ogawa et al. (2016) for R&D-intensive countries. The latter are based on steady state calculations and the former are based on derivations from elasticity estimates, whereas ours exploit the exact period-by-period solution of the model simulations and its multiplier effect. For most countries we find higher rates of return for public R&D than the early literature discussed in OECD (2017) but in line with recent literature just mentioned here. Moreover, for closely related five types of mission-oriented R&D, which is between 20 and 120 percent of publicly performed R&D, internal rates of return from shocks to VECM estimates are reported to be between 44 and 305 percent for seven EU countries in Ziesemer (2021a). Similarly, Fieldhouse and Mertens (2023) report rates of return for publicly funded non-defense R&D of five major US institutions (covering

[1] This paper is an extension of parts of work for European Commission, Expert Group Support of R&I performance and policy analysis, under contract number CT-EX2017D315103-101. Useful comments from Luc Soete, Bart Verspagen, and the contract partner's expert and participants at meetings of DG RI A4 and A2 (ESIR) are gratefully acknowledged. Responsibility is entirely mine.

about 90% of publicly funded R&D) as high as 150 to 300 percent from impulse response analysis of a dynamic single-equation regression for TFP. All of these rates of return from dynamic methods are much larger than those derived from estimates of an elasticity of production of R&D capital in a Cobb-Douglas production function (see Hall et al. 2010; OECD 2017).

Section 2 introduces the methodology of a new way to find internal rates of return and related measures of performance from the time resolution of the VECM. Section 3 presents the results on a country-by-country basis summarized in some tables and answers three research questions based on the evaluations of estimations and simulations in Soete et al. (2022):

1) Does publicly performed R&D affect business R&D?

2) Do the two aforementioned together affect total factor productivity (TFP), GDP and foreign R&D?

3) Do the returns, which are positive if the above effects are positive, outweigh the costs?

2. Methodology

The returns to shocks on public R&D equations in the VECMs are the achieved yearly difference of the GDP compared to baseline, as obtained by multiplying the percentage difference of the TFP multiplied by the GDP of the corresponding year. If effects on GDP are larger than those on TFP this will come from additional employment and capital inflows through higher TFP. The additional costs are the yearly changes of private and public R&D investment. The method of using shocks in a dynamic model, here mainly VECMs, results in exact numbers of yearly changes over time. Subtracting the yearly costs from the yearly returns defines the gains; discounting them at a standard rate of, for example, 4% allows adding them up and seeing whether or not they are positive. In addition, when the costs precede the benefits one can calculate the internal rate of return (irr), which is by definition the discount rate that brings the discounted present value to zero. The results depend strongly on the number of periods with losses preceding the years with gains; therefore, they are not directly comparable to other rate-of-return estimates (see Hall et al. 2010). One can avoid the disadvantages of discounting by looking at the yearly gains as a share of GDP. Moreover, as emphasized by Fieldhouse and Mertens (2022), the results also depend strongly on the period of evaluation. In the first step we evaluate the effects until 2040. In a second step we let the evaluation go until effects get negative.

Our results show that internal rates of return are inversely related to the number of periods with losses (payback periods); internal rates of return are at normal levels when payback periods are normal (say, more than five years), and they are very high when periods of losses are five years or less and gains last long. If governments mainly have an impact on projects with long term relevance, the impact of public R&D may lead to long payback periods and low internal rates of return. If firms focus on projects with short run profitability even with government R&D support, the payback periods may be short and the internal rates of return high.

We also show the years of positive gains, the sum of discounted net present value, and the average yearly gains/GDP ratio over the years, and the sum of discounted (at 4%) net present value (DPV) in billion dollars. Results contradict the view that innovation effects from public R&D are modest (low additionality): business R&D, TFP, and GDP are strongly enhanced (high additionality) with some exceptions though. For these calculations we assume that the projects are stopped when we get only subsequent periods of losses; this implies setting gains and costs to zero for phases of losses if no positive net gains follow later.

3. Results from permanent public R&D changes of VECM estimations

In this section we show that the effects from additional public R&D in the VECM estimates in Soete et al. (2022) are additional private and foreign R&D, additional TFP, and additional GDP with a small number of exceptions showing crowding out of private through public R&D. Country-specific test results for the lag length, the stability of the underlying VAR, the number of cointegrating equations, the estimation of the VECM, the baseline simulation, and the shock scenarios are presented in country-specific appendices in the companion paper of Soete et al. (2022). We present the effects of policy shocks and their consequences for all the variables. Shocks are modelled as increase of the intercept of the growth rate equations for public R&D by a half percentage point, 0.005, or -0.005 on public R&D variables for the countries with crowding out;[2] changing public R&D in the first period affects domestic and foreign private and public R&D as well as TFP and GDP in all following periods until 2040. These results are shown in Table 1.

Moreover, we present periods of positive gains defined above, average gain/GDP ratio over the years, sum of discounted (at 4%) net present value (DPV) in billion dollars, and internal rates of return from the policy shocks, which are infinity in case of financing through reduction of crowding out. For these calculations we assume that the projects are stopped when we get only subsequent periods of losses; this implies setting gains and costs to zero for phases of losses if no positive net gains follow later. Country specific aspects are noted in the column ‘remarks’ in Table 2 presenting the results.

3.1 Policy shocks of public R&D: Effects on TFP, GDP, and R&D variables

In this sub-section we show that the effects from additional domestic public R&D expenditures in terms of additional TFP are mostly an increase in TFP, GDP and private and foreign private and public R&D in the VECMs of Soete et al. (2022). Positive effects stem from hiring more researchers and spillovers including competition reduction effects. Adverse effects come from increases in wages of researchers, which may discourage innovative activities, and from stronger competition.

In Table 1 a shock of a half percent of public R&D stock in the initial period as shown in the last column of Table 1 leads to percentage change of public R&D compared to baseline, both averaged over about all years until 2040 (first shock year listed in Table 2) and a concomitant

[2] Soete et al. (2022) use only positive shocks for the purpose of special comparisons.

expected percentage change of the private R&D stock compared to baseline shown in the first two columns.

Table 1 Percentage difference to baseline for R&D variables from additional public R&D (yearly average from shock to 2040)

Country	Domestic		Foreign		Domestic		
	Public R&D	private R&D	public R&D	Private R&D	TFP	GDP	Shock size
Austria	0.37	0.00456	0.098	0.27	0.1374	0.1366	0.005
Belgium	0.06	0.0058	0.012	-0.0143	0.0776	0.012	0.005
Canada	-0.037	0.143	0.011	0.0226	0.0334	0.0267	-0.005
Denmark	0.137	0.275	0.084	0.157	0.064	0.14	0.005
Finland	0.1035	0.138	-0.003	-0.0274	0.119	0.096	0.005
France	0.273	0.285	-0.02	0.14	0.315	0.65	-0.005
Germany	0.425	0.326	-0.15	-0.017	0.18	0.27	0.005
Ireland	-0.19	0.133	-0.149	-0.168	0.21	- (a)	-0.005
Italy	0.17	0.21	0.036	0.076	0.088	0.144	0.005
Japan	0.654	0.67	0.024	0.138	0.26	0.37	0.005
Netherlands	0.32	0.028	0.023	0.246	0.118	0.259	0.005
Norway	0.835	0.387	0.17	0.145	0.35	0.37	0.005
Portugal	1.21	0.09	0.145	0.207	0.21	0.566	0.005
Spain	-0.079	-0.176	-0.016	-0.088	-0.08	0.064	0.005
Sweden	0.07	-1.03	0.006	0.0238	-0.0757	-0.046	0.005
UK	0.44	-0.016	0.083	-0.105	-0.064 (b)	0.025 (c)	0.005
USA	0.138	0.436	0.305	1.354	0.155	- (a)	0.005

Notes: The shock is a half percentage point, 0.005 (-0.005 for Canada, France, Ireland), on the intercept of the equation for stocks of public R&D (see Appendix 'Figures' in Soete et al. (2022)). For ups and downs before 2040 see country-specific appendices in Soete et al. (2022). Values are averages until 2040 even if policies run into losses. (a) Model without GDP (see appendices Ireland, USA in Soete et al. (2022)). (b) TFP is above baseline only for the period 1966-1980 (see Appendix UK in Soete et al. (2022)). (c) GDP is above baseline for all periods (see Appendix UK in Soete et al. (2022)).

The results suggest distinguishing five country groups with different effects of public on private R&D.

1. The strongest results are found for Japan, USA, and Norway, all above 35 percent increase of business R&D.

2. A second strong group with increases in BERD stock above 20 percent are Germany, Denmark, Italy, 13.8 for Finland, and 9 percent for Portugal.

3. A third group with small positive effects is Belgium, Netherlands , and Austria.

4. Negative effects are found for Spain, Sweden, and UK, but for the UK only because long periods of late losses are included in the averaging over roughly 70 years.

5. Finally, we have the crowding out countries Canada and Ireland, who encourage private R&D through reduction of public R&D, and France through an initial reduction followed by an increase later.

The answer to the *first research question* is that in 12 of 17 countries there is a positive impact of public on private R&D, 8 of which are sizable, and in 5 of 17 there is a negative impact (for Spain, Sweden, UK, and the crowding out countries Canada and Ireland), which we have for France only in the initial period. For Spain, Sweden, and the UK a negative shock would also help avoiding reduction of private R&D. For the crowding-out countries a negative effect on private R&D can be avoided by a reduction of public R&D, which is needed for France only in an early phase.

This result from all our model simulations is in line with the literature survey in Ziesemer (2021b): Overall there is a positive effect of public R&D on private R&D as the literature finds it for publicly performed R&D, but in the literature review there are also exceptions. We find exceptions in terms of values with negative signs in Table 1 for the UK, Canada, Ireland, Spain, and Sweden, with opposite sign for public and private R&D, except for Spain. These may come about through factor substitution, market competition for researchers, or foreign competition. In particular, if public R&D expenditure is expanded, there will be more hiring in the governmental research institutions; this hiring can come from the private business sector or from students finishing university studies (Jaumotte and Pain 2005, p.8). If demand increases more strongly than supply, part of the additional money goes into wage increases (Goolsbee 1998; David and Hall 2000; Wolff and Reinthaler 2008). Private R&D may then become less profitable and may be reduced in terms of hiring. If hiring is reduced more (less) strongly than wages increase, private R&D expenditures fall (increase). Conversely, if labour supply of the relevant level of knowledge increases more quickly than demand, wages will fall or grow less quickly, and public and private R&D can have more researchers, making private R&D more profitable. If wages fall less (more) quickly than private hiring grows, private R&D expands (shrinks) in terms of expenditures.[3] In both cases, excess demand and excess supply, the intuition that falling private R&D is a bad thing is valid because it goes together with relatively weak hiring activity in R&D. Jaumotte and Pain (2005) find an average demand elasticity of 0.6-0.7. If researchers' wages increase, private demand for researchers will be reduced at a lower percentage and private R&D expenditure will increase on average. For every average result, however, there must be countries below and above the average; in Table 1, UK, Sweden, and Spain (ignoring crowding-out countries Canada, France, Ireland) are the countries where a negative impact on private R&D expenditure would suggest that the percentage reduction of researchers would be stronger than the increase in wages.

[3] As wages are roughly half of business R&D expenditures (Jaumotte and Pain 2005, p.14), similar considerations for other R&D expenditures could complement this line of reasoning.

Domestic and foreign private R&D go into the same direction except for Belgium, Germany, and Ireland. This suggests that for these countries the R&D competition argument is more relevant whereas for all other countries the expansion of private R&D in response to that of public R&D leads to more knowledge spillovers than competition and a positive incentive to do more R&D.

Table 1 also allows us to answer partly the *second research question*: How do public and private R&D together affect total factor productivity (TFP) and GDP? 14 of 17 countries have positive effects, of which 3 from a negative shock; 3 of 17 countries have negative effects. Negative effects exist, as for private R&D, for Sweden, Spain, and the UK. For Canada, France, and Ireland a negative shock to R&D is needed to get a positive effect on TFP. For the other countries, high effects for TFP (10-37%) are there for 8 countries: Japan, Finland, Norway, Portugal, Germany, USA, Netherlands, and Austria. Positive effects below 10 percent are there for Belgium, Denmark, Italy, in spite of strong effects on private R&D for the latter two. Again, all results in Table 1 hold for an average over 70 years under the assumption that projects are not stopped when yielding negative TFP effects.

In the UK the effect on the GDP is positive but on TFP it is negative unless only a short period is considered (see Table 1, note (a-c), and Table 2). R&D expenditure in the UK seems to increase researchers wages and thereby the GDP. Wage increases for researchers also make changes of TFP more expensive and therefore TFP changes are limited. This indicates that in the UK researchers are almost fully employed and much of the additional expenditure and the corresponding increase in demand for researchers increase their wages, and this makes adoption of technology for productivity purposes unprofitable. Spain again is similar to the UK having a negative TFP effect over the whole period and a positive one only for the first eleven periods. The negative impact on TFP in the UK and Spain may again stem from wage increases when supply of researchers grows too slowly.

For GDP we find strongly positive effects (above 8%) for Austria, Denmark, Finland, Italy, Norway, Portugal, Germany, Japan, Netherlands, all in line with positive effects of TFP from private R&D. Below 8% are Belgium, Canada, Spain, and UK, and negative effects only for Sweden.

Averaging over the rows of Table 1 per column (without the crowding out countries Canada, France, Ireland, which need different special policies, and also Sweden, the latter because of extreme ratios), and then dividing by the value for the first column, or, conversely, first doing the division by the public R&D difference by country and then averaging, we get a very rough approximation[4] as to what public R&D achieves (in parentheses the values for the two procedures followed by their average behind the parentheses):

Compared to baseline a one percent increase in public R&D leads to additional (0.50, 0.96) 0.73% of private R&D, (0.34, 0.58) 0.46% of TFP, and (0.555, 0.43) 0.49% of GDP.

[4] This averaging procedure does not consider that causes and effects may come in very different periods but rather averages over all periods for which results are available.

Of course, these procedures ignore the differences in the size of countries and some of the delays of the effects. The more sophisticated country-specific analysis is as follows in Table 2.

3.2 Policy shocks of public R&D: Payback periods, net gains, and rates of return

In this sub-section we show that the effects from additional domestic public R&D expenditure in the VECMs of Soete et al. (2022) in terms of additional TFP generate mostly short payback periods, high gains in terms of additional GDP through TFP changes, and high internal rates of return if policies are stopped when net gains get negative. Table 2 allows us to answer partly the *third* research *question: Do the returns to public R&D outweigh the costs?*

Table 2 Net gains, DPV, and internal rates of return (IRR) to additional public R&D

Country	shock year	years of gains, average gain/GDP ratio (a)	Sum DPV (4%) bill $ PPP (a)	irr (%)	Remarks (b)
Austria	1969	1974-2040, 0.133	426	44.8	-
Belgium	1968	1969-2040, 0.144	333	225	(f)
Canada	1971	1971-2040, 0.02	360	∞	-
Denmark	1968	1974-2040, 0.053	120	33.4	-
Finland	1975	1976-2040, 0.123	304.5	325	-
France	1964	1964-2040, 0.057	1342	∞	-
Germany	1973	1975-2040, 0.164	6297	124	-
Ireland	1971	1971-2040 0.16	264	∞	-
Italy	1966	1967-2040, 0.084	1424	321	-
Japan	1965	1966-2040, 0.187	10324	330	-
Netherlands	1971	1972-2040, 0.24	2039	151	(e)
Norway	1971	1972-2040, 0.34	955.7	267	-
Portugal	1965	1966-2040, 0.2033	395	265	-
Spain	1967	1968-1979, 0.00158	7.93	258	-
Sweden	1969	1970-1971, 0.0007	0.3	237	(d)
UK	1966	1967-1979, 0.01	998.6	162	(g)
USA	1966	1967-1972, 0.0464 1989-2016	6347	287	(c)

(a) Taken over periods of initial losses and subsequent positive gains only. Gains are divided by the baseline GDP. PPP 2005 dollars.
(b) Shock normally is 0.005; for Canada, France, Ireland (-0.005).
(c) No GDP in model; analysis ends 2016.
(d) Only short and low gains in the beginning.
(e) Effects on private R&D turn downwards after 2005 (see Appendix Netherlands in Soete et al. (2022)).
(f) BERDST reduced 1974-86 in the simulation relative to baseline.
(g) Evaluation stops 1980.

In all but the three crowding-out cases there is first a period of at least one year of losses and then a period of positive gains. Countries differ in having or not having another period with years of losses, either or not followed by periods of gains. Internal rates of return are high even for the UK with its negative average (until 2040) effect on TFP, because there are first positive and only late negative effects; the net gains as calculated via TFP change are positive until 1979. For the numbers of Table 2 we stop the evaluation of the UK for 1980 meaning that we set losses to zero when no periods of gains follow.

High gain/GDP ratios (above 10%) are found for Belgium, Germany, Japan, Netherlands, Austria, Finland, Norway, and Portugal. Positive ratios, but below 10% are found for USA, Sweden, Spain, Denmark, Italy, UK. The lowest gain/GDP ratio is obtained in Sweden.

Relatively low internal rates of return are found for Austria and Denmark because of 4 or 5 years of losses. Finland, Japan, and Italy have the highest rates of return above 300%, behind the infinite values for Canada, France, and Ireland, which start with cost reductions of a negative shock. All other countries are between 120 and 290 percent: Belgium, Germany, Netherlands, Norway, Portugal, Spain, Sweden, UK, USA. If periods of losses are short and early effects are large, we get high rates of return whereas otherwise discounting makes late gains small in terms of internal rates of return. In other words, high rates of return are not miracles but merely the result of firms, jointly with governments, selecting mainly projects with a nearby payback period. The importance of the length of periods with losses essentially limits comparability of internal rates of return with atemporal rates of return from earlier analyses.

Rates of return are much lower in Austria and Denmark where payback periods are 5 or 6 years. In this interpretation, high or low rates of return are not an implication of the VECM methodology, because this is equal for countries with high or low rates of return. It is ultimately also not a property of the data, because they are made in the same way for all countries (except for some periods preceding data revisions, which are made for purposes of harmonization). Our interpretation prefers to emphasize heterogeneity between countries in the organization of R&D: some policies lead to longer payback periods than others, lower discount rates applied to the projects, and by implication to lower internal rates of return, ultimately based on a longer horizon. However, extending our explanation to all countries would be a large project analyzing the institutions of R&D and linking them to our estimation-plus-shock results.

In Table 2 we see for Portugal only one year of losses and positive gains until 2040, and therefore high rates of return. Austria has five periods of losses and therefore lower rates of return. Denmark has 6 years of losses and therefore there is a rate of return of 'only' 34 or 44% for these countries. As Canada, France, and Ireland have a negative shock as growth enhancing policy, there is no period of losses and therefore an infinite rate of return. For the USA we see changes from losses to gains twice, with gains dominating by far in all measures of Table 2. Spain has only eleven years of positive gains; in Table 1 above, all variables are averaged over the whole period to 2040 and are therefore negative; the only exception among the variables for Spain is the GDP. The strategy to push public R&D probably increases skilled wages and takes researchers from private to public R&D and therefore has a small and vanishing effect on TFP. Growth of human capital at the R&D level might enhance such effects. Sweden has the shortest period of additional gains, probably because it has extended R&D strongly in the past. For UK, Spain, and Sweden there are signs not only of additional hiring of researchers but also of wage increases mitigating the effects in terms of some of the evaluation measures of Table 1 and 2.

In sum, w*hen assuming that projects are stopped when gains get negative,* the effect of a positive change of public R&D on TFP and GDP is positive in all countries except for Canada, France, and Ireland; for public R&D the positive effect lasts 3 years for Sweden, 11 or 13 years in Spain and the UK, and longer in all other countries. The average (first per country over time, then across countries) gain/GDP ratio is 0.12. For Canada, France, and Ireland this can be achieved through a negative shock on public R&D.

Internal rates of return for public R&D are positive throughout and at normal levels when payback periods are normal, and they are very high when periods of losses are short and gains last long. For Canada, France, and Ireland positive effects require a negative shock to public R&D crowding in private R&D.

There are several reasons for the high internal rates, which are partly similar to the atemporal ones in the literature. These are also then reasons behind the closely related and most clearly visible short periods of losses with returns coming early, followed by long periods of gains. These reasons are as follows.

First, we do not take into account the additional costs for and income of capital and labour in production of the higher GDP; it is exactly the purpose of growth policies to increase employment and wages and attract international capital, and therefore we include these income creating indirect effects only implicitly in the GDP variable; however, if the growth rates of TFP are larger than those of GDP in the earlier phases, the rates of return would often be even higher.

Second, the analysis is done ex-post, whereas decisions are taken under uncertainty and risk; risk premia may be high here.

Third, a log-log specification as used here has decreasing marginal products in case of positive coefficients; by implication, rates of return may be higher if less has been done in terms of inputs.

Fourth, policies affect international R&D, which generates oligopolistic reactions to the economy under consideration (Ziesemer 2022) and spillover repercussions; these can be positive when externalities dominate, or negative if oligopolistic competition effects of increasing foreign R&D dominate; the overall results then depend also on the domestic reaction to foreign reactions.

Fifth, we do not only estimate a partial effect or elasticity but rather the long-term multiplier effects of VECMs are included. Finally, high internal rates of return go together with short payback periods, which suggest high discounting of firms and a short time horizon.

4. Policy conclusions

In dynamic policy evaluations it is crucial to make good decisions on the period of evaluation, because gains and costs change over time. In our analysis, public R&D has strongly positive effects in terms of internal rates of return, average gain/GDP ratios, discounted net present values. This assumes that policies are stopped when net gains get negative. It seems safe to say that the policy recommendation is that public R&D should be expanded except for Canada, France, and Ireland. For these three countries a policy of first reducing and then increase public R&D is leading to positive TFP effects. For France, the initial reduction is small and short, for Canada the 70-year average effect is only 5% of the baseline value.[5] Of course, exploration of country-specific circumstances can figure out in greater detail which parts of public R&D are most productive.

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