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Mission-oriented R&D and growth

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ABSTRACT

We analyze the dynamic interaction of mission-oriented R&D expenditure stocks with domestic and foreign private and public R&D, total-factor-productivity (TFP), and gross domestic product (GDP) for seven EU countries. We use the vector-error-correction method. Permanent changes on mission-oriented R&D increase total-factor-productivity and GDP. On average across periods and countries, a 1% increase of mission-oriented R&D leads to an additional 0.485% public R&D, 0.705% private R&D, 0.485% for TFP, and 0.56% GDP. We also show years of positive gains, the sums of discounted net present values, and the average yearly gains/GDP ratio. Mission-oriented R&D has high internal rates of return.

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1. Introduction

1.1. Public knowledge, human capital, and private R&D driving TFP, GDP, and wages

Ever since the growth model by Solow (1956) had shown that exogenous technical change may be the driving force for the growth of labour demand, wages, and GDP per capita, there has been a keen interest in getting to know how technical change is generated through the interaction between firms, governments and households. Nelson (1959) suggested that basic scientific research is a public good, leading to a strong role of the government, and that high-level human capital production reduces the uncertainty in research, leading to a strong role of education. Schultz (1961, 1964) emphasized that households are the producers of the human capital and therefore its supplier, using basic education and scientific research as a public good, leading to a strong role of governments and households. Public knowledge and education suggest an important role for public investment.

Arrow (1962) stressed that private R&D is related to all sorts of market imperfections that economic theory considers: uncertainty with lack of insurance against failure in R&D; monopoly for the invention and the information included in the new product or process in case of research success; externalities in the form of knowledge spillovers, leaking out or in, to and from competitors. All three market imperfections provide an

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incentive for less than efficient investment of resources in R&D, leading to a correcting supportive role of governments.¹ It has been taken for granted since the early 1960s, that this will lead to more R&D by private business if government activity in this area is well designed. In short, efficient government policies, including public R&D, interacting with private R&D, are crucial in growth policy.

Even stronger, Schultz (1964) emphasized that technical change was too weak in countries where private business did too much of what could better be done by governments. Making the right or wrong choices here may have an impact on countries' history of catching up as in Japan and the Asian Tigers or falling behind like Argentina (Reynolds, 1985).

In short, factor productivity drives labor demand, wages, and GDP, if there is growth in public knowledge, human capital, and R&D. Households, firms, and governments have all an important role in the making of productivity.

1.2. The need for public investment and public R&D, and its relation to mission-oriented R&D expenditures

A major issue in defining public R&D is the agreement on the definition of the related public goods, externalities, social objectives, or natural monopolies. In areas like defense, environment, energy, health, and space called "missions" there is a too low activity of the market, and governments must decide what and how much they want to add and how to limit prices set by natural monopolies (see online appendix "the basic economics of mission oriented R&D"). The related R&D is called mission-oriented R&D (see OECD MSTI). The crucial criterion of governments is the definition of a need that is insufficiently satisfied by the market under the existing regulations. To each mission there may be a corresponding R&D activity for which the role of the government has to be defined. Although there are some earlier papers on mission-oriented R&D (see Mazzucato (2018) and online appendix), the empirical effects of mission R&D on domestic and foreign public R&D, TFP, and foreign private R&D have not been considered in a macroeconomic growth context.

In this paper we try to link mission-oriented R&D at the macro-level, via domestic and foreign privately and publicly performed R&D to TFP and GDP. Where R&D activities are building on each other, mission-oriented R&D may stimulate other public or private R&D and have an impact on productivity. The basic presumption in economics is that this knowledge complementarity enhances productivity and growth. But, of course, one R&D activity may compete with the other in the factor market for good researchers turning private and public R&D into substitutes on the input level (David & Hall, 2000). Moreover, defense and health expenditure may enhance current welfare, but they are partly government consumption activities, which may reduce long-run growth and future welfare. In contrast, the corresponding R&D for defense and health may improve future welfare. It is then an empirical question what the net effect on productivity and growth is. Therefore, empirical research for this question is required.

The optimum performance of public knowledge itself can in principle be determined based on endogenous growth models (Antonelli, 2020; Shell, 1967; Ziesemer, 1990). If,

¹For a broad introduction see European Commission (2017).

however, distributional conflicts destroy the possibility of defining such criteria, especially in the presence of non-rivalrous rather than publicly provided private goods, less rigorous and more intuitive criteria must be used (Zieseemer, 1990). A second approach to a theoretical basis could be partial, static oligopoly models. No model so far can capture all constellations of complements and substitutes with too little or too much private and public R&D, and the models have not been tested with respect to their assumptions regarding public and private factors, which impose complementarity or substitutability of public and private R&D (Zieseemer, 2021). Therefore, we keep the theory brief, here and below. A theoretical paper that employs the almost the same variables is Zieseemer (2020), which does not include mission-oriented R&D though.

Summing up, in areas like defense, transport, health, space, energy, and environment the logic of market systems with natural monopolies and some externality corrections through taxes and subsidies needs to be complemented by public investment in capital as well as public and mission-oriented R&D. The question of this paper is how mission-oriented R&D affects TFP and GDP via private and public R&D or perhaps even directly. In a post-COVID perspective, mission-oriented R&D may help in the short-run through its expenditure effect on the business cycle established by Deleidi and Mazzucato (2021), and in the long run through its effect on factor productivity and GDP as shown in this paper; the EU programs emphasizing sustainability try to bridge both (Biggeri & Ferrannini, 2020). For the above-mentioned mission areas, it is imperative that they are carried out with a good increase in productivity in order to avoid crowding out of other areas as under Baumol's disease. Mission-oriented R&D may have the potential to help doing this.

Section 2 presents the data for the crucial variables mentioned so far, GDP, TFP, domestic and foreign private and public R&D, and domestic mission-oriented R&D; the data situation has an impact on the choice of the empirical model and therefore is described first. Section 3 introduces the dynamic empirical models and econometrics of cointegrated VAR or vector-error-correction models (VECMs) and uses a corresponding new way from Soete, Verspagen, and Zieseemer (2020a) to find internal rates of return and related measures of performance from the time resolution of the policy simulations using the VECMs. Section 4 compares the estimated country-specific models and explores the possibilities and limits for a common long-run model. Section 5 presents the results from permanent policy shocks on a country-by-country basis summarized in some tables. Our paper is the first to analyze the role of mission-oriented R&D on domestic and foreign public R&D, foreign private R&D and TFP in dynamic econometric models and to provide internal rates of return for mission-oriented R&D and therefore we relate it to some selected literature in section 6. Section 7 briefly summarizes the main line of the argument, states the policy conclusion, and admits the limitations of the research.

2. Data

This section briefly discusses basic aspects of the data used: GDP, TFP, domestic and foreign private, public, and mission-oriented R&D. We take the total flows of GERD and BERD over all sub-items in \$2005, PPP, from OECD MSTI. The difference between GERD and BERD is defined as public R&D flow. From these,

and their foreign counterparts with distance weighted aggregation, we have stock values using the perpetual inventory method with a standard rate of depreciation of 15% (Hall, Mairesse, & Mohnen, 2010; Luintel, Khan, & Theodoridis, 2014). Data are then available at a maximum for 1970–2014 with some missing values mainly either in the beginning or in the end of the period. This results in a maximum of 45 observations per country making time-series analysis possible. For each country then there is a distance weighted average of foreign public and private R&D stocks. GDP data are taken from World Development Indicators and are transformed into 2005 PPP dollars. TFP data until 2014 are taken from PWT9. They do not include human capital (Feenstra, Inklaar, & Timmer, 2015). Mission-oriented R&D is financed by governments and the expenditures go to R&D partly performed privately and partly performed publicly and therefore leading to overlap with money in our variables for BERD stock and public R&D stock, thereby possibly causing some collinearity in regressions.

By assumption, mission-oriented R&D includes only categories which are currently in the public debate or in announced policies: (1) Environment, (2) Exploration and exploitation of space, (3) Energy, (4) Health, (5) Defense. We use mission-oriented-R&D-stock variables from these five categories. We do not include General University Funds (GUF) because they are also fully included in public R&D and would make collinearity more likely. The range of the mission/public R&D-stock ratio in Figure 1 goes from 0.1–1.2 down to 0.1–0.45. Before 1990 there are several increasing series, but after 1988 they are mostly falling. Only Denmark is always below the 0.2 line. France's ratio is always falling. That of Germany is mostly falling with a short growth period after 1977. In an online appendix we show the flow data. Defence as a share of GBARD is falling since 1990. Space as a share of civil GBARD is increasing from 1981–1995 and then falling until 2005 from which onward it is constant on the 1981 level. Health and environment as a share of civil GBARD is slightly increasing since 2005 for most countries,

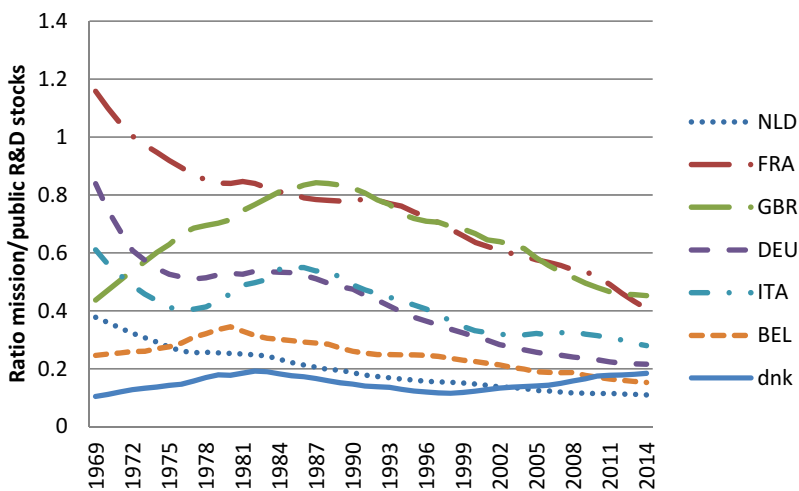


Figure 1. R&D stocks for five mission-oriented categories divided by public R&D for seven EU countries 1969–2014.

and more strongly so for the UK. Overall, the fall of defense R&D seems to be dominating.

3. Methodology

3.1. *The cointegrated VAR or VECM approach*

In this sub-section we explain the basic idea for the policy analysis. We consider a difference equation system in TFP, GDP and the five R&D variables that should be estimated and used for policy simulations. We use the regression approach for dynamic simultaneous equation estimation, the cointegrated vector-autoregressive (VAR) or vector-error-correction (VEC) approach. This approach generates a difference equation system in differences and levels of each of the variables mentioned above. Due to the presence of lagged dependent variables, we can calculate short and long-run effects. This method includes feedback effects among all variables and equations. Moreover, although panel heterogeneity is an aspect discussed in econometrics (see Smith & Fuertes, 2016) the R&D literature uses mainly homogeneous panels finding one regression coefficient for all countries or firms (Van Elk, ter Weel, van der Wiel, & Wouterse, 2019) and therefore supports on-size-fits-all policies. This ignores differences in the coefficients of single countries or firms; it can be avoided through country-by-country estimation if there are sufficiently many observations per country. We focus in the following on countries where this is the case. This yields a difference equation system with an equation for the first differences of each variable regressed on its own lag(s) and the lag(s) of all other variables in the form of both, levels and differences. A major strength of this type of model is its backing through many tests that help avoiding ad-hoc mis-specifications. Relations among levels are long-term equations, which are valid with two-way causality and can be related to the theory (Juselius, 2006; Ziesemer, 2020).

After estimation of a VECM, we test for parameter stability through dropping observations at the beginning and the end of the estimation period. In the second step, after estimation and testing of VECMs, we will carry out analysis of permanent shocks in the model, by way of increasing the intercept of the equation(s) for mission-oriented R&D and comparing the old and the new solutions over time.² If a shock enhances one variable there is not only a consideration of the partial impact effect but rather a feedback reaction between all variables. This can show whether additional mission-oriented R&D generates positive effects on business and public R&D, TFP and GDP, and its own future values. We get not only short-run effects but also *long-run and transitional effects*. We explain the technical details of the VECM methodology in an online appendix.

The VECM approach has been used before in the R&D literature by Coe and Helpman (1995) and Luintel and Khan (2004) both linking domestic to foreign R&D stocks. Bottazzi and Peri (2007) use a VECM for researcher and patent variables. None of these papers uses disaggregation into public and mission-oriented R&D. Soete et al. (2020a) use domestic and foreign private and public R&D for the Netherlands, but not mission-oriented R&D, which is the main issue of this paper.

²We deal with shocks to public R&D in a different paper because it relates to a different literature.

3.2. Net gains and internal rates of return

Here we explain the two major evaluation concepts for R&D policies applied here to mission-oriented R&D. The returns to shocks on mission-oriented R&D are the achieved difference of the GDP compared to baseline, as obtained by multiplying the percentage difference of the TFP to the GDP of the corresponding year; the returns considered are then only those coming from TFP changes, and not those from additional employment and capital inflows or reduced outflows. The additional costs are the yearly changes of private and public or mission investment. The method of using shocks in a dynamic model results in yearly numbers for the changes. Subtracting the yearly costs from the yearly returns defines the gains; discounting them at a standard rate of 4% makes adding up useful and allows seeing for which years they are positive. In addition, when the costs precede the benefits, one can calculate the internal rate of return (irr), which is the discount rate that brings the sum of discounted present values to zero. This method using the exact time resolution from a VECM has first been developed and used in Soete et al. (2020a). Earlier methods used to be of a static nature (Hall et al., 2010). The irr method may be problematic though for cases where gains go from negative to positive and then to negative and to positive again as we find it for the case of Germany. But we do not have encountered the case of a non-unique irr so far. One can avoid disadvantages of discounting by looking at the yearly gains as a share of GDP, also shown below.

4. Estimation results: Heterogeneity limits for a common model

This section tries to find elements of a common model and its limitations from the long-term relations. It is encouraged by the first impression that the UK, Italy, Denmark, and the Netherlands have somewhat similar equations. Therefore, it seems worthwhile to investigate the possibilities for a common model and the heterogeneity limitations in detail. An important point for understanding the results is that most countries have $K = 7$ (6 for France) variables and $r = 5$ (or 4 for France, 6 for Germany) long-term relations. As an econometric matter of identification in the VECM framework, each long-term relation can have only a maximum of $K - r = 7 - 5 = 2$ free coefficients (6 - 4 = 2 for France, and 7 - 6 = 1 for Germany).³ For Belgium we find $r = K$, more than six long-term relations, no unit eigenvalues, and estimate a VAR in (log-) levels. Country-specific test results for the lag length, the stability of the VAR and the VECM, the number of cointegrating equations, the estimation of the VECMs (see Jusélius, 2006; Pesaran, 2015), the baseline simulation, and the shock scenarios are presented in country-specific online appendices.

There are several types of heterogeneity: different numbers of long-term relations (7 for Belgium,⁴ 4 for France and 6 for Germany, 5 for the other four countries); different variables in long-term relations; different slope coefficients in similar long-term relations.

³When $dy(t) = \Pi y(t-1) \dots$ is written as $y(t) = \alpha \beta' y(t-1) \dots$ with α as (K,r) matrix of adjustment coefficients and β' as (r,K) matrix of long-term coefficients, the problem is that $\Pi = \alpha \beta' = \alpha l \beta' = \alpha Q Q^{-1} \beta'$, where l is the (r,r) identity matrix and Q is any invertible (r,r) matrix, unless Π has full rank, leading to a VAR estimation in levels. To have unique values of α and β we need r^2 constraints for Q (Pesaran, 2015, p.531). Therefore, β is often written as $\beta = [l_r, \beta_{r,K-r}]$ meaning that each row or column of β has only $K-r$ free coefficients (Boswijk, 1996). From there, re-normalization can be used to obtain economically meaningful and statistically significant relations.

⁴As the hypothesis "at most 6 cointegrating equations" is rejected, there are no unit roots ($K-r = 0$) and therefore there is no cointegration problem and, by implication, no cointegrating equations. However, estimation in levels using a VAR then has seven equations for the short and the long run, where residuals should be zero in equilibrium.

Additional or different variables in long-term relations may lead to different signs or size of coefficients. [Table 1](#) presents the results for the statistically significant regression coefficients of the long-term relations (short-run effects are provided in the online appendix). It should be kept in mind that these may work also indirectly via other long-term relations through reversed causality. Transitional and short-term effects may go the opposite way; long-term relations are in equilibrium only asymptotically after a shock.

The first part of [Table 1](#) shows the following partial steady-state effects for GDP. GDP depends positively on TFP with strong slope heterogeneity and negatively (positively) on mission R&D for UK, Italy, and the Netherlands (except for Belgium), which serves public or meritorious goods or political objectives instead. From a policy perspective this raises the question how important this asymptotic steady-state result is relative to short and medium run effects after discounting. For Denmark, foreign PUBST has an additional negative impact. For France GDP is not in the model, because all VAR models with GDP are unstable. For Belgium, besides TFP and a positive impact of mission R&D, there are several other effects in the GDP equation. The GDP of Germany is affected by mission R&D only indirectly via TFP, BERDST, and PUBST, or, for Denmark by foreign public R&D and TFP, explained next.

The second part of [Table 1](#) shows that for most countries TFP is driven by positive effects of domestic private R&D and foreign public R&D, the latter indicating knowledge spillovers, not for Germany though. For the Netherlands, TFP is driven by domestic and foreign private R&D, with a negative effect from the latter indicating competition effects. In Belgium, surprisingly, TFP is driven by lagged mission R&D and foreign public R&D, whereas domestic public R&D has a negative partial effect. Lagged TFP (denoted as A (-1)) has a unit coefficient although the Johansen tests suggest that there is no unit eigenvalue in the system. Again, we see strong slope heterogeneity as in all other equations.

Equation 3 of [Table 1](#) shows that for three countries (Germany, Netherlands, France) public R&D has a positive partial effect on private R&D indicating complementarity, whereas on three others (UK, Italy, Denmark) it has a negative one suggesting substitutability, and in Belgium no effect. Moreover, BERDST is encouraged by TFP or, for the UK and France, by its weakness.

In equation 4 of [Table 1](#), foreign public R&D reacts to TFP of all countries except for Germany and the Netherlands. Foreign public R&D is probably a policy reaction to countries' TFP: it reacts negatively to Germany's TFP, not at all to the Dutch TFP, but positively to five other countries' TFP, with lower elasticities for smaller countries like Belgium and Denmark when compared to the larger countries, UK and Italy. Foreign private R&D is a long-run substitute in France, the UK and Italy but a complement in the four other countries. Again, these are only partial results whereas the complete result is found by shock analyses below.

In equation 5 of [Table 1](#), mission R&D is driven mainly by domestic and foreign public R&D, mostly with non-negative signs. For Belgium only other arguments are relevant. Among the other six countries, three of the twelve coefficients of domestic and foreign public R&D are zero, and two are negative, leaving seven positive coefficients in this fifth equation.

As only Germany and Belgium have six and seven long-term relations, the lowest part of [Table 1](#) has only one or two equations. In equation 6, public R&D is stimulated by

Table 1. Long-term relations: heterogeneity limits for a common model (a).

1. equation	GDP	TFP	Mission R&D	Other variables	Trend & intercept
UK	1	2.12	-0.17	-	0.00134 t + 16.4
Italy	1	2.55	-0.196	-	0.0142 t + 15.7
Netherlands	1	1.92	-0.257	-	0.0083 t + 15.2
Germany	1	1.78	-	-	0.0046 t + 14.64
France ^(b)	-	-	-	-	-
Denmark	1	1.567	-	-0.21FPUBST	0.0097 t + 14.5
Belgium	1	-0.119P(-1) - 0.33B(-1) + 0.268 M(-2) - 0.4FP(-2) + 0.27FB(-2) + 0.4Y(-1) - 0.189Y(-2) + 0.55A(-1) + 13.175 + 0.055D + 0.03 t			
2. equation	TFP	BERDST	FPUBST	Other variables	Trend & intercept
UK	1	0.295	0.95	-	-0.02 t - 15.3
Italy	1	0.187	1.61	-	-0.048 t - 21.36
Netherlands	1	1.03	-	-0.3FBERDST	-0.038 t - 5.2
Germany	1	0.17	-	-	0.00159 t - 2.25
France	1	0.22	0.45	-	-0.0137 t - 8.1
Denmark	1	0.06	2.38	-	-0.058 t - 29.997
Belgium	1	-0.16P(-2) + 0.2 M(-2) + 0.33FP(-1) - 0.339Y(-1) + 1.015A(-1) - 0.008Dt - 0.163(1-D)			
3. equation	BERDST	TFP	PUBST	Other variables	Trend & intercept
UK	1	-4.23	-0.66	-	0.068 t + 15.9
Italy	1	12.2	-4.5	-	0.16 t + 53.4
Netherlands	1	0.45	0.65	-	0.033 t + 2.7
Germany	1	-	2.94	-	-0.044 t-19.89
France	1	-7.2	2.3	-	0.02 t-15.5
Denmark	1	3.94	-2.53	-	0.117 t + 27.3
Belgium	1	1.649B(-1) - 0.948B(-2) - 0.19 M(-1) + 0.13 M(-2) + 0.22FB(-1) - 0.24FB(-2) - 0.26Y(-1) + 0.295A(-1) + 6.48 + 0.00897Dt - 0.1496D + 0.0155 t			
4. equation	FPUBST	TFP	FBERDST	Other variables	Trend & intercept
UK	1	4.87	-1.127	-	0.017 t + 28.7
Italy	1	1.99	-1.74	-	0.084 t + 33.998
Netherlands	1	-	0.158	-	0.01134 t + 10.5
Germany	-0.0764	-	1	-	0.034 t + 13.39
France ^(b)	1	5.05	-2.3	-	0.0795 + 42
Denmark	1	0.32	0.0297	-	0.023 t + 12
Belgium	1	-0.122P(-1) + 0.13P(-2) - 0.115B(-1) - 0.05B(-2) + 0.038 M(-1) + 1.366FP(-1) - 1.048FP(-2) - 0.124FB(-1) + 0.33FB(-2) - 0.027Y(-1) + 0.124A(-1) + 0.038A(-2) + 7.139 + 0.0032Dt - 0.058D + 0.0175 t			
5. equation	Mission R&D	FPUBST	PUBST	Other variables	Trend & intercept
UK	1	1.33	0.48	-	-0.051 t-10.486
Italy	1	-	0.80	0.89BERDST	-0.032 t-7.286
Netherlands	1	0.72	0.45	-	-0.0097 t-5.356
Germany	-0.0052	-	-	1FBERDST	0.032 t + 12.4
France	1	-1.43	1.6	-	0.0029 t + 11.4
Denmark	1	9.4	-9.6	-	0.13 t - 38.2
Belgium	1	-0.336B(-2) + 0.688 M(-1) - 0.174 M(-2) + 0.84FB(-1) - 1.05FB(-2) - 0.79Y(-1) + 0.554Y(-2) + 0.9997A(-1) - 0.557A(-2) + 12.067 + 0.0236Dt - 0.3476D + 0.0259 t			
6. equation	PUBST	Mission R&D			Trend & intercept
Germany ^(c)	1	0.21MissionR&D			0.025 t + 8.39
Belgium	1	1.327P(-1) - 0.56P(-2) - 0.1B(-1) + 0.099 M(-1) + 0.446FB(-1) - 0.41FB(-2) + 0.13Y(-2) - 0.23A(-2) - 0.004Dt - 0.0699(1-D) + 0.007587 t			
7. equation	FBERDST				
Belgium ^(d)	1	-0.274P(-1) + 0.26P(-2) - 0.225B(-2) - 0.085 M(-1) + 0.095 M(-2) + 0.377FP(-1) - 0.85FP(-2) + 1.3FB(-1) - 0.38FB(-2) - 0.31Y(-2) + 0.15A(-1) + 0.297A(-2) + 12.5 + 0.0055Dt - 0.1D + 0.028 t			

(a) Constants and only statistically significant coefficients. All variables in natural logarithms. France has four long-term relations, Germany six, Belgium seven, and all other countries have five long-term relations. Signs as on the right-hand side of an equation, except first column.

(b) France, with only four long-term equations, does not appear in one of the equation sets. The model has no GDP variable. The model for France has only $K = 6$ variables and $r = 4$ long-term relations.

(c) The model for Germany has $K = 7$ variables and $r = 6$ long-term relations, implying a maximum of $K-r = 1$ free coefficients for endogenous variables in each long-term relation. It requires adding a sixth equation to the scheme.

(d) The model for Belgium has $K = 7$ variables and $r = 7$ long-term relations and therefore is estimated in log levels. It requires adding a seventh equation to the scheme. Abbreviations for Belgium used only in this table: Y = LGDP, A = LTFP, B = BERDST, FB = FBERDST, P = LPUBST, FP = LFPUBST, M = LMS, D = DUM6380.

Table 2. Percentage difference to baseline for R&D variables from additional mission-oriented R&D (average from shock to 2040).

Country	Domestic mission R&D	Domestic public R&D	Domestic private R&D	Foreign public R&D	Foreign private R&D	TFP	GDP
Belgium	0.015	0.0055	-0.0035	0.0029	-0.0007	0.0073	0.0088
Denmark	0.068	0.024	0.134	0.009	-0.0063	0.04	0.053
France	0.0965	0.0685	0.073	-0.0046	0.0366	0.157	_(a)
Germany	0.807	0.163	0.45	-0.078	-0.05	0.049	0.123
Italy	0.185	0.23	-0.003	0.47	0.071	0.091	0.177
Netherlands	0.085	0.073	0.189	-0.043	0.01365	0.082	0.1285
UK	0.041	-0.0041	0.0016	0.0094	0.0132	0.0057	0.0048
Average	0.185	0.08	0.12	0.052	0.011	0.06	0.08

Notes: The shock is a half percentage point (0.005) on the intercept of the equation for mission stocks. For ups and downs in sub-periods see country-specific online appendices. (a) Model without GDP variable.

mission R&D in both countries. In equation 7 Belgium's foreign private R&D is stimulated by all variables with one or other lag; only its own lags and those of TFP are both positive (when adding up the effects of both lags for each variable). Domestic BERDST and GDP have negative effects.

Time trends are reported in the last column but will not be discussed because they may serve the mere purpose of detrending and not only represent elements of exogenous growth in addition to effects of the endogenous variables.

Summing up, the results confirm the main line of traditional argumentation for the long-term relations: GDP is driven by TFP, TFP by domestic private R&D, and private R&D by public R&D, and the latter either as complements or substitutes. In addition, we find that (keeping in mind the two-way causality among any other two variables of long-term relations)

- (1) Mission R&D seemingly reduces the TFP-GDP relation as a partial effect in the long run in [Table 1](#), which is dominated by all other effects from shocks according to [Table 2](#) though; for given GDP, TFP goes up if mission R&D goes up in equation 1, which is an interpretation more in line with the shock results.
- (2) TFP reacts not only to domestic private but also mostly to foreign public R&D or, for the Netherlands, foreign private R&D.
- (3) Domestic private R&D reacts positively to TFP or its weakness.
- (4) Foreign private and foreign public R&D react to each other. However, signs are different indicating that the country in question, which is taken out of the aggregate, can change the sign of the relation, and indicate that they are neither substitutes nor complements in general. Moreover, foreign public R&D reacts positively to countries' TFP as a foreign policy reaction function would suggest.
- (5) Mission-oriented R&D reacts often to domestic and foreign public R&D.

A common model is not available though, because slope heterogeneity implies different signs and size of coefficients, often in the spirit of substitutes versus complements, defending higher TFP more strongly or reacting to its sluggishness, and small and large countries reacting and responded to differently. Moreover, differences in the number of long-term relations imply multiple two-way relations with signs hard to compare across countries.

The purest and simplest story can be told for the long run of Germany: GDP is determined only by TFP; TFP only by private R&D; private R&D only by public R&D; public R&D only by mission-oriented R&D; mission R&D negatively by foreign private R&D; and foreign private R&D negatively by foreign public R&D, suggesting strategic substitutes. The latter two negative effects taken together suggest withdrawal of foreign private R&D when there is more foreign public R&D, and consequently more German engagement in mission-oriented R&D. Conversely, more mission-oriented R&D, perhaps internationally coordinated, leads to less foreign private R&D and more foreign public R&D.

For other countries there is no similar clear-cut story. One reason is that the uniform sign in the equations for GDP and TFP are accompanied by heterogeneity in the signs of equations 3–5. A second reason is that only for Germany do we have the ideal case of pairwise cointegrated variables, which lends itself to a straightforward interpretation Lütkepohl (2007).

5. Results from policy shocks in VECMs and VARs

In this section we show that the effects from additional mission-oriented R&D are additional TFP and GDP, intermediated either by additional private or public R&D or both and modified by repercussions from foreign R&D. We present the effects of policy shocks and its consequences for all the variables. Shocks are modelled as increase of the intercept of the growth rate equations for mission-oriented R&D by a half percentage point, 0.005, affecting all R&D variables as well as TFP and GDP for the period until 2040. Changing mission-oriented R&D in the first period affects domestic and foreign private and public R&D increasing TFP and GDP in the following periods. These results are shown in Table 2.

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 in Table 3. 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. If, in contrast with our assumptions, projects were not stopped, the net losses are costs of policy inertia, not of R&D per se. Tables 2 and 3 present the results. Country-specific aspects are noted in the column “remarks” in Table 3.

5.1. Policy shocks of mission-oriented R&D: Effects on TFP, GDP and R&D variables

In this sub-section we show that the effects from additional national mission-oriented R&D expenditures in terms of additional TFP are mostly an increase in TFP, GDP, and private and/or public R&D. Implicit adverse effects supposedly come from increases in wages of researchers, which may discourage innovative activities (David & Hall, 2000; Goolsbee, 1998; Wolff & Reinthaler, 2008). In Table 2 we report results from shock scenarios from having enhanced the intercept of the growth rate equation for mission-oriented R&D by a half percentage point, 0.005. For France we have added a negative value because a positive shock leads to strongly negative results whereas a negative

Table 3. Timing, Net gains, DPV and internal rates of return to additional mission-oriented R&D.

Country	shock year	years of gains	Payback period ^(d) , (years of losses)	average gain/GDP ^(a)	Sum DPV (4%) ^(c)	Internal rate of return	remarks
Belgium	1973	1974–2040	1973 (1)	0.007	41.7	174%	dum1969-80 for data rev.
Denmark	1972	1973, 1975– 2040	1972, 1974 (2)	0.035	99.9	177%	-
France	1970	1970–2016	1970 (0)	0.0115	298	infinity	^(b)
Germany	1972	1973–79, 1996– 2040	2004 (17)	0.11	1101.4	303.6%	only initial losses; (e)
Italy	1971	1972–2040	1972 (1)	0.089	1909.7	335%	only initial losses
Netherlands	1972	1977–2040	1977 (5)	0.079	748.9	46.4%	-
UK	1970	1971–2040	1971 (1)	0.0057	169	77%	higher gains later

(a) Initial cost of mission-oriented R&D added in shock period; cost as change of public and private R&D stocks after the shock period.

(b) Negative shock implies having no period of losses. No GDP in the model. Analysis until 2016 only.

(c) In bill. \$ PPP 2005.

(d) First year where sum of gains discounted at 4% remains positive.

(e) Germany has two phases of losses and two phases of gains. It has almost a second internal rate of return.

shock is phased out soon and turned into positive changes of mission-oriented R&D stocks. This indicates that mission-oriented R&D stocks are too high in France, perhaps above their optimal value, and once they are reduced back to their optimal value they can grow again. In the UK, increasing mission-oriented R&D leads to a fall in public R&D and an increase in private R&D. In Denmark, France, Germany, and the Netherlands, public and private R&D expand both in the positive direction, at least in the long-run. In short, additional mission-oriented R&D leads to more business R&D except for Belgium, and to more public R&D except for the Italy and the UK; for both, there are one or two of seven countries forming an exception where the fall of one variable leads to an increase of the other R&D variable. However, on average both effects are positive suggesting an interpretation of complementarity effect being stronger than substitutability effects. For Denmark, the effect on public R&D is slightly negative for twenty years and then strongly positive for forty years; for Italy the effect on private R&D is positive for forty years before it becomes negative (see country-specific online appendices). These latter examples of effects changing over time point to the importance of discounting in the evaluation of results reported in Table 3. These results can be interpreted from the perspective of a Cournot model for several firms and one public research institute (Cabon-Dhersin & Gibert, 2020). Public and private R&D show positively (negatively) sloped reaction functions if public R&D has positive (negative) spillovers. In Denmark, France, Germany, and the Netherlands we then have positive spillovers from public to private R&D, whereas in Belgium, Italy, and the UK they are negative.

TFP and GDP are increasing in all countries because the exceptions of R&D reductions are mostly smaller than the increases. On average these effects are 6 and 8% of the baseline values.

Effects on foreign private and public R&D are positive for Italy and the UK, and negative for Germany, suggesting strategic complements for both foreign variables

whereas other countries have mixed impacts, suggesting strategic substitutes. On average both effects are positive, but the reaction of foreign public R&D is five times as strong as that of foreign private R&D. Foreign public R&D is a strong response to the growth of the countries as in equation 4 in [Table 1](#).

Regarding the relation between domestic and foreign private R&D, positive knowledge spillovers or complementary strategic reactions dominate slightly over negative R&D competition effects for four countries, but for Denmark, Germany, and Italy the substitution assumption is supported as one can see from the signs in [Table 2](#). Effects of mission-oriented R&D shocks on domestic and foreign private R&D are far from uniform. However, on average the effect on domestic private R&D is ten times as strong as that of foreign private R&D, implying that there is at best a weak foreign private reaction, whereas the foreign public reaction is not negligible. This could indicate that there is neither a clear complementarity nor a clear substitution relation between domestic and foreign private R&D. Static Cournot and Bertrand duopoly models have positively sloped R&D reaction functions, where in case of Cournot models strong spillovers are needed; in racing models with “winner-takes-all” property, reaction functions are upward sloping if the competition threat is stronger than the profit incentive (see Ziesemer, 2021 for a summary of these models). Whenever we observe opposite reactions of domestic and foreign private R&D, we might tentatively conclude that we have a dominant Cournot conduct with weak spillovers, or a racing model with strong profit incentive relative to the competitive threat.

The occasionally negative or weak effects on private and public R&D and TFP may stem from wage increases with limited hiring of researchers, whereas the strong effects are likely to come from more hiring with no or little wage increases (David & Hall, 2000). Labor market heterogeneity seems to affect public and private R&D differently in different countries. We show next that overall, upon averaging, the positive values are larger than the negative ones. Averaging over the rows of [Table 2](#) per column and dividing by the value for the first column, or, conversely, first doing the division by the value in the first column by country and then averaging, we get a very rough approximation⁵ as to what mission-oriented R&D achieves (in parentheses the values for the two procedures preceded by their average behind the parentheses): Compared to baseline, a 1% increase of mission-oriented R&D leads to an additional 0.485% (0.43, 0.54) of public R&D, 0.705% (0.65, 0.76) of private R&D, 0.485% (0.33, 0.62) for TFP, 0.564% (0.445, 0.684) for GDP. The effect on public R&D is only slightly lower than that on private R&D. In this sense it is mitigating the trend away from public and towards more private R&D described by Archibugi and Filippetti (2018). Effects on GDP are higher than those on TFP. The reason most likely is that higher TFP attracts foreign capital, and both together lead to higher labor demand and employment. When calculating the benefits below we consider only the impact on TFP and not those on labor and capital.

The negative direct impact of mission-oriented R&D in the long-term relation between TFP and GDP in equation 1 of [Table 1](#) is outweighed by indirect effects of other variables on TFP and feedback effects from other variables on mission-oriented

⁵This averaging procedure does not consider that causes and effects may come in very different periods, but it rather averages over all periods for which results are available.

R&D. In [Table 2](#) these three variables are positively affected by the shock on mission-oriented R&D. For all countries, mission-oriented R&D deviates from baseline by more than the initial shock of a half percent because it is endogenous and gets predominantly positive feedback effects from the other variables.

5.2. Policy shocks on mission-oriented R&D: Payback periods, net gains and rates of return

In this sub-section we show that the effects from additional national mission-oriented R&D expenditure are often high GDP gains for decennia through TFP diminished by higher R&D costs, mostly short payback periods, and high internal rates of return. [Table 3](#) shows results for the consequences of permanent shocks on mission-oriented R&D in greater detail. The first column shows the year of the shock at the beginning of the period of data availability followed by the years of gains in column 2, and the number of years of losses and the payback period in column 3. France has no initial costs because we impose an initial cost reduction on missions, which is a gain itself and finances the start of the subsequent expansion. With no phase of losses, the rate of return is infinity for France. One year after the shock there are gains in five countries. In the Netherlands there are four additional periods of losses. For Germany, the period 1980–1999 has losses but these get low weight through discounting, and the gains 1973–1979 lead to a high internal rate of return. In the UK, the early gains are lower than the later gains and therefore the internal rate of return is relatively low in column 6. In the countries with early high gains, including Denmark, the rates of return are correspondingly high. In the Netherlands, the rate of return is lower because of five years of losses.

Columns 4 and 5 show the gains as a share of GDP and the NPV using a discount rate of 4%. Regarding gain/GDP and discounted present value, France ranges fifths and fourths of the seven countries. These gains are highest in Germany and Italy (followed by the Netherlands), where the rates of return are highest in column 6. For Belgium and Denmark, the internal rate of return is high because the gains come early (Belgium) or because they are high and a bit later (Denmark). For the Netherlands, the gains are also high, but they arrive relatively late. The UK has the lowest gain/GDP ratio, the second lowest rate of return, and the third lowest discounted net present value, suggesting that researchers are employed efficiently and opportunity costs for additional mission-oriented R&D are high. High internal rates of return shown in [Table 3](#) for Belgium and Denmark are in the range of the literature for basic research (see NESTI (Working Party of National Experts on Science and Technology Indicators), 2017, Box 6), based on derivations from elasticity estimates, and those for total private and social rates of return to R&D in Coe and Helpman (1995), which are 123% and 155% respectively, or the 251% for marginal social returns in Ogawa, Sterken, and Tokutsu (2016) for R&D-intensive countries among 32 OECD and EU countries, both based on steady state calculations. For the UK and the Netherlands they are still high but lower than this range. For France, Italy, and Germany we find even higher returns than in the literature. Our results exploit the exact period-by-period solution of the model and its discounted multiplier effect. For the internal rates of return the early years matter much and the steady state very little. High rates of return are not miracles but merely the result of firms, jointly with governments, selecting mainly mission-oriented R&D projects with a nearby payback period.

They are ultimately also not a property of the method, because it is handled in the same way for all countries.

There are several reasons for the high internal rates. These are also reasons behind the closely related and most clearly visible short periods of losses, where periods of gains are long, and returns come early. First, we do not consider the additional costs for firms' capital and labor in production of the higher GDP because they generate also income for households; it is exactly the purpose of growth policies to attract international capital and increase employment and wages, and therefore we include these income creating indirect effects only in the GDP variable in [Table 2](#), but not in the returns, where we use only TFPs effect on GDP. However, if the growth rates of TFP are larger (smaller) than those of GDP in the early phases, the rates of return are often higher (lower) than when counting the whole GDP effect as return. In short, effects of capital and labor are kept outside the costs and the returns. 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, positively on average and in the cases of Italy and the UK, but negatively for Germany, which generates spillover and competition repercussions to the economy under consideration, which are included in the simulation results; however, these can also be negative in case of competition effects. Fifth, we do not only estimate a partial effect or elasticity but rather the long-term multiplier effects of VECMs are included; when R&D variables increase TFP and GDP, there may be more means available for R&D in the next periods, which lead again to higher TFP and GDP. Finally, high internal rates of return go together with short payback periods, which suggest that high discounts of firms and governments and a short time horizon are implicit in the data.

6. Discussion

In this section we briefly indicate the contribution of this paper to the literature in a broader perspective. It is now twenty years ago that Salter and Martin (2001) concluded that “no simple model of the economic benefits from basic research is possible”. The reason for this statement regarding public and basic R&D was the heterogeneity observed across scientific fields, technologies, and sectors. However, as usual in macroeconomics, heterogeneity at some lower level of aggregation does not preclude clear results on the macro level. Our VECMs for seven countries, though perhaps not simple, show what they have in common and where the countries differ. Heterogeneity implies that there is not one simple model but several slightly different models of R&D and TFP.

The VECM approach extends the macroeconomic approach with lagged dependent variables by Guellec and Van Pottelsberghe De La Potterie (2003) to several equations and the possibility of more lags. The advantage of a VECM is that shock analysis per country gives additional insights. Having found that three countries have a positive and another three countries a negative effect of public on private R&D in equation 3 of [Table 1](#), it is not surprising that single equation regressions under panel-slope-homogeneity assumptions come to the result that publicly performed R&D has no impact on private R&D. Soete, Verspagen, and Ziesemer (2020b) evaluate 17 country-specific VECMs and

find, in their Figure 5, a positive relation between public and private R&D from shocks on public R&D. Similarly, Guellec and Van Pottelsberghe De La Potterie (2003) found that defense R&D crowds out private R&D. For mission-oriented R&D, in our definition including defense R&D, the result of crowding out is small for Belgium and Italy, and there is a positive effect of mission-oriented on private R&D for the other five countries and on average, and the effect on TFP is positive for all countries. The fact that these results are not visible from the long-term relations alone suggests that the feedback effects of all seven equations are crucial in getting these results.

Mission-oriented R&D is often carried out in the form of research programs. Their academic discussion yields interesting insights in terms of industrial and public economics, but the evaluation remains qualitative in terms of classical criteria (Foray, Mowery, & Nelson, 2012). In our macroeconomic approach the opposite is the case: the industrial and public economics properties vanish through the aggregation, but we can calculate internal rates of return from effects on TFP or GDP, which are very high for all countries.

Similarly, in a macroeconomic approach, the second-order incentive effects of intellectual property rights in an x -best environment, in particular patent laws (see Dosi & Stiglitz, 2014), are not visible. The ex-post underutilization of patented knowledge, which has the character of a non-rivalrous public goods, may change through mission-oriented policies but a macro model has no way of seeing whether the problem is getting better or worse. In contrast, the interaction of mission-oriented, public and private R&D with technical change in our VECM seems to be a good way to deal quantitatively with “. . . the fact that technological innovation is highly dependent on a variety of complementary institutions (e.g., public agencies, public policies, universities, professional communities and, of course, corporate organizations with their rich inner structure) . . .” (Dosi & Stiglitz, 2014, p. 14). At the same time, the cross-country heterogeneity of these institutions may be one of the reasons for the heterogeneity of the models we have obtained.

Whereas European Commission (2018) contains some nice qualitative reasoning in favour of mission-oriented R&D, it is missing a quantitative underpinning regarding the link with factor productivity and growth, which the VECM approach of this paper provides.

7. Summary, policy conclusion and limitations

The basic contours of traditional thinking about R&D and TFP driven growth appear in our country-specific models. There is a long-term relation of TFP and GDP; surprisingly, for three countries we show that mission-oriented R&D is also in this relation and has a negative partial impact. TFP depends positively on domestic private R&D and also positively on foreign public R&D for five countries, perhaps suggesting positive spillovers. In addition, we have shown several other elements related to mission, public and foreign R&D, the latter also split into public and private. Not only do they help generating TFP, but rather TFP triggers domestic and foreign public and private R&D often like a policy response. Mission-oriented R&D reacts often to domestic and foreign public R&D. A common model – and thereby one-size-fits-all policies – cannot be distilled from the long-term relations though, because the number of long-term relations differs among countries, the variables therein are not always the same, or at least the slope coefficients are very heterogeneous within and between the groups of small and large countries.

The analysis of permanent shocks shows that, overall, the transitional effects of mission-oriented R&D go against the negative partial long-term effect and are positive in terms of TFP, GDP, and the five R&D variables, internal rates of return and gain/GDP ratios.

The policy recommendation of this paper is that mission-oriented R&D has to be defined on the project level according to the criterion of current and future need and welfare effects, and in terms of suitable organization of research (Mowery, Nelson, & Martin, 2010) in order to make sure that it is as successful from a macro-policy perspective as it was in the past, as first shown in this paper.

Limitations of this paper are, first, mainly in the data availability; only for a few early EU member countries do we have the sufficiently long data series for mission-oriented R&D. Second, the results are difficult to interpret because the cointegrated VAR method lets the data speak as it does not impose any theory but rather imposes only an assumption as to what the relevant variables are. This requires using background knowledge for the interpretation of mainly the long-term relations in an intuitive manner. Third, there is overlap of mission with public and private R&D data, which can only be avoided by using mission and non-mission data; this would not allow us to analyze the shift from public to private R&D or vice versa. Fourth, the effects of mission-oriented R&D, in countries for which we have the data, may be different in the future because the related missions are also likely to be different although we have focused on the categories discussed most recently in the public domain. Fifth, whereas we find clearly positive effects from mission-oriented R&D this does not necessarily mean that mission-oriented R&D is better for growth than other forms of public or private R&D. This is a natural implication of the fact that welfare is more important than growth in the purpose of missions. A comparison of the growth effects from mission and non-mission R&D is a potential question for future research.

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