Working Paper Series

#2019-047

The impact of mission-oriented R&D on domestic and foreign private and public R&D, total factor productivity and GDP

Thomas H.W. Ziesemer

Maastricht Economic and social Research institute on Innovation and Technology (UNU-MERIT)
email: **info@merit.unu.edu** | website: **http://www.merit.unu.edu**

Boschstraat 24, 6211 AX Maastricht, The Netherlands
Tel: (31) (43) 388 44 00

UNU-MERIT Working Papers
ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology
UNU-MERIT

The impact of mission-oriented R&D on domestic and foreign private and public R&D, total factor productivity and GDP

Thomas H.W. Ziesemer

Maastricht University, Department of Economics, School of Governance, and UNU-MERIT[1]

P.O. Box 616, 6200MD Maastricht, The Netherlands. E-mail: T.Ziesemer@maastrichtuniversity.nl.

ORCID 0000-0002-5571-2238

November 2019

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, for which we have sufficiently long time-series of mission-oriented R&D data. We use the vector-error-correction (VECM) method. Permanent shocks on mission-oriented R&D increase total-factor-productivity and GDP, mostly because for the UK private R&D is increased or, for Belgium and Italy, public R&D is increased or, for Denmark, France, Germany and the Netherlands, both are increased. France has an initial phase where mission-oriented R&D has to be reduced first and expanded later to get good policy results. On average across periods and countries, a 1 percent 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 calculated from comparison of baseline and shock scenario comparison using VECM simulations until 2040. Heterogeneity limits the possibility to find a common model of long-term relations. For most countries we find that in steady states mission R&D reacts to foreign and domestic public R&D and increases TFP. TFP, foreign public and domestic private R&D have two-way causality relations.

Keywords: Total factor productivity, R&D, growth, cointegrating VAR, permanent policy shocks.

JEL codes: O11, O38, O47, O52.

[1]This paper stems from work for European Commission, Expert Group Support of R&I performance and policy analysis under contract number CT-EX2017D315103-101. Useful comments from the contract partner's expert and participants at meetings of DG RI A4 and A2 (ESIR) are gratefully acknowledged. I am grateful to Bart Verspagen for providing the data and useful comments.

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 GDP per capita and wages, 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 suppliers of the human capital and therefore its producer, with 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 success; externalities in the form of knowledge spillovers, leaking out or in, to and from competitors. All three market imperfections provide an incentive for less than efficient investment of resources in R&D, leading to a correcting supportive role of governments.[2] 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.[3] 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 labour 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 or natural monopolies. One of the classical examples of public goods is defense; the classical definition of value here is the sum of marginal utility of all citizens. Although soldiers can be hired privately on a national or world market, this is limited and not necessarily desirable. Countries may have the need to defend themselves, but citizens may have an incentive to try to free ride on the public service instead of contributing to the cost (Musgrave and Musgrave 1973). The same then holds for the related R&D. The consequence then is that governments organize this in terms of budgeting and perhaps also carrying out the related tasks. There may be spillovers to private R&D. The classical examples are contributions to computer technology related to the research on militarily oriented rockets and atomic bombs where the computer industry has received spillovers, which are complementary; on the other hand, once private and public R&D exist, they may compete for the best specialists

[2] For a broad introduction see European Commission (2017).

[3] As a correction of spillovers, R&D subsidies or tax deductions were seen as adequate. For the high uncertainty, cooperation with universities' research and that of non-university institutions was seen as a way out. For the monopoly issue, appearing after the fact of invention, limiting the patent length to about 20 years appeared to be adequate to limit the static post-invention-monopoly inefficiency that would provide an additional dynamic incentive for both, the incumbent and its competitors, to come up with new products and processes before and after expiration of patents. For the information problem, the patent would protect not only against commercial use of products but would also provide information through publication.

and the relation may be competitive in the factor market and therefore public and private R&D may become substitutes (Goolsbee 1998; Wolff and Reinthaler 2008).

Another relatively clear set of issues where preferences and profit motives do not lead to market solutions is the one of environmental externalities, where the value is determined as costs of externalities, or as marginal costs or revenues from removing externalities. This works through the creation of markets only if the property rights are defined despite of the obvious conflict about their distribution; if only a small group of persons is affected there is the possibility that a private negotiation solves the problem provided that the conditions of the Coase theorem are fulfilled (Baumol and Oates 1988). Correspondingly, if property rights are not allocated and large groups are affected, there is no private incentive to do the related R&D unless the government is guaranteeing the demand for it through environmental policy specifications. Then governments may want to think of environmental R&D.

Similarly, health externalities through limited infrastructure and the subsequent epidemics have made health organization a public task in many countries some time ago. Public institutes and private firms develop medicines, but for private firms this is often mainly profitable because public insurance schemes ensure the required size of the market. Where the market size is too small, for example for rare diseases, public research and development of drugs may be a necessary activity, unless take-it-or-leave-it prices (in connection with higher than monopoly prices) are accepted.[4]

In space and energy activities there are complementary private and public actions undertaken and natural monopolies. Mostly they take the form of governments guaranteeing private firms exclusive rights to access of outer space and electricity network access, with control and regulation in some period of history. Public R&D then is often driven by the need of governments to do calculations for public planning procedures involving many private land owners – especially in the current energy transition towards renewables - whereas energy and network regulation technology is developed by private R&D.

In all these cases 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. The additional activities in areas like defense, environment, energy, health, and space are called 'missions' in the statistics and the related R&D is called mission-oriented R&D (see OECD MSTI).[5] The crucial criterion of governments is the definition of a need that is insufficiently satisfied by the market under the existing regulations.[6] To each mission there may be a corresponding R&D activity for which the role of the government has to be defined (Foray et al. 2012; Veugelers 2012; Mazzucato 2018). Foray et al. (2012) survey analyses of mission-oriented R&D programs. Veugelers (2012) finds that Flemish firms react with clean innovations to policy incentives. The impact analysis does not

[4] In the basic model of take-it-or-leave-it pricing the monopolist also claims the consumer surplus above the monopoly price.

[5] See Kattel and Mazzucato (2018) for a history of mission-oriented R&D.

[6] This goes beyond pure market fixing in the case of many types of public investment. First, there are high fixed infrastructure costs in the case of provision of infrastructure for water, waste water services, electricity, and transport (roads, railways, harbours, airports). As parallel systems are cost-inefficient we have natural monopolies here. Prices are efficiently regulated to the unit-costs level. This makes these areas unattractive for profit-seekers. Therefore, these activities were mostly started as state monopoly. Only later, in a phases of business routine with principal-agent problems they were privatized. However, when large reforms are needed, government planning is inevitable again, as in the case of private highways, or planning energy transitions. In all these cases it is a political question how much of the services is offered, in particular in other areas than the large cities. For education, health, and communication, compared to the above-mentioned purposes of public investment, the non-rivalry of knowledge is much more important than fixed costs, and therefore both, private and public institutions were always active in these areas. Adding public investment in order to get the needed level in the spirit of correcting market failure is typical here. A major issue as formulated in the MDGs and SDGs (millennium and sustainable development goals) is that there is insufficient government activity here especially in developing countries. Government failure leads to too little tax revenues invested in these goals, reflecting that they have not become missions in all countries. Moreover, space and defense R&D are not only opportunities but also carry the risk of diverting means away from SDGs (Robinson and Mazzucato 2018).

cover the macroeconomic level though. Mazzucato and Semieniuk (2017) discuss issues of financing mission-oriented R&D, but not its effects on privately and publicly performed R&D. Several papers consider the pro-cyclical character of GBAORD (Makkonen 2013; Cruz-Castro and Sanz-Menéndez 2016), but not the opposite causality direction of the effect of GBAORD or mission-oriented R&D on growth. Deleidi and Mazzucato (2018) provide a theoretical model of the macroeconomic goods market, in which they call one of two government expenditure items mission-oriented R&D. Deleidi and Mazzucato (2019) provide a structural VAR for the USA in defense R&D, other government expenditure, private R&D, and GDP, and show (among other things related to short-term macroeconomics) that a permanent shock to defense R&D has a statistically significant effect on private R&D, and an effect on GDP becoming insignificant after 4 quarters of a year. The authors do not include TFP. 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.[7]

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. 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 (Shell 1967; Ziesemer 1991; Antonelli 2019). If, 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.[8] 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. Therefore, we keep the theory brief, here and below.

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. An additional question of this paper is how this affects TFP and GDP via private and public R&D or perhaps even directly.

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 a corresponding new way from Soete et al. (2019) 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. Section 6 briefly summarizes the main line of the argument, states the policy conclusion and admits the limitations of the research.

[7] An exception is a companion paper on Japan, using a GBAORD stock variable instead of mission-oriented R&D as described above. Recent microeconomic issues are discussed by Cantner and Vannuccini (2018). A special issue of *Industrial and Corporate Change* in 2018 contains several papers discussing institutional issues.

[8] See Ziesemer 1990 and 1995 for cases without and with dynamic optimization.

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 et al. 2010; Luintel et al. 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 observation per country. This makes time-series analysis possible. For each country then there is a distance weighted average of foreign public and private R&D stocks. Domestic and foreign private and public R&D stocks are calculated in the same way as indicated in Soete et al. (2019) using the data from the UNU-MERIT data base. 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 et al. 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' ratio is always falling. That of Germany is mostly falling with a short growth period after 1977.

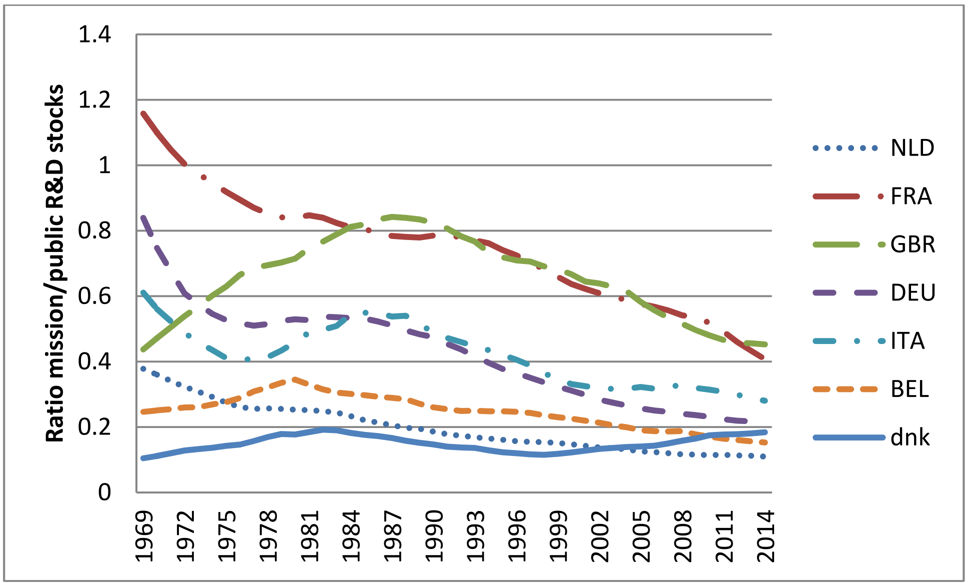


Figure 1 R&D stocks for five mission-oriented categories divided by public R&D for seven EU countries 1969-2014.

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 and Fuertes 2016) the R&D literature uses mainly homogeneous panels finding one regression coefficient for all countries or firms (van Elk et al. 2019). 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: Tests for deterministic and stochastic trends, lag length, number of cointegrating equations, normal distribution of residuals, heteroscedasticity, serial correlation, and stability. Relations among levels are long-term equations in homogenous form, which are valid with two-way causality. Adding control variables later is not an option, but rather variables of interest must be included right from the beginning of the analysis. If the levels of, in the simplest case, any two endogenous variables have a long-term relation, a third endogenous variable that also has a long-term relation with one of the others should not be added to the first equation but rather put into a second equation for pairs of the three equations. If a long-term relation does not exist for pairs but only for triples of endogenous variables in levels, a fourth endogenous variable, that is correlated with some of the three variables mentioned first, should not be added into the first equation, but it should enter a second equation with one or two of the first mentioned variables (Juselius 2006; Lütkepohl 2005, 2007).

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.[9] 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 Appendix A.

The VECM approach has been used before 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 researchers and patents. None of these papers uses disaggregation into public and mission-oriented R&D. Soete et al. (2019) use domestic and foreign private and public R&D but not mission-oriented R&D, which is the main issue of this paper.

There are of course some limitations of the method. First, only countries with sufficiently long data series can be included in a time-series analysis. For other countries more laborious methods must be used. Second, our version of the method does not make immediate effects in the policy year explicit, but rather all effects show up for the first time only after one or two years; extensions to show the impact effects are possible, but, again, rather laborious and technical and might capture pure expenditure effects which are not of interest in this paper. Third, the method is one that gives priority to 'let the data speak' and therefore leaves causality to background intuition, as given in section 3.3 below. Fourth, our macro approach confirms highly productive mission-oriented R&D of the past but asks for good future project selection through micro methods; in other words, we cannot simply extrapolate results because structural breaks may come in through new policies like energy transition, Stoltenberg initiative and others. What we want to show though, is that mission-oriented R&D has supported and not diminished economic growth in the recent past.

[9] We 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 multiplied by the GDP of the corresponding year; the returns 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 of 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 discounted present value to zero. This method using the exact time resolution from a VECM has first been developed and used in Soete et al. (2019). 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 dis-advantages of discounting by looking at the yearly gains as a share of GDP also shown below.

3.3 Suggestions for intuitive interpretation

In this sub-section we explain the major concepts used in the interpretation of what we find in the data: (i) Decreasing marginal products and dynamic complementarity; (ii) downward sloping isoquants and static substitutability; (iii) cost-minimization in cooperation between firms and governments; (iv) wage increases counteracting the effects of additional hiring of researchers; (v) differences in time horizons, discount rates and payback periods of firms and governments. As the VAR approach is not theory based but rather lets the data speak, causal interpretation is not necessarily straightforward. Therefore, some suggestions may be helpful.

We use the log-log approach which has strong similarity with the Cobb-Douglas production function and we mainly deviate in adding lags (see Appendix B) and combining differenced and level versions of variables in the VECM. For the relation between mission-oriented, public and private R&D it is part of our models that they produce TFP and receive spillovers or competition from foreign TFP. With positive regression coefficients below (above) unity we then have *decreasing (increasing) marginal effects*. The effect of each variable on TFP is larger when the other variables are larger as well; if mission-oriented, public and private R&D all grow in a balanced way because this may avoid running into decreasing marginal effects. This is, briefly speaking, an idea of *dynamic complementarity* mentioned above.

Cobb-Douglas functions have normal, *downward sloping isoquants*, meaning that for a given output, for example TFP, there is a negative relation between any two input variables, allowing to use one of them less if there is more of the other. If there is a change in the relative unit costs of the two inputs, it is cost reducing to shift towards using the cheaper one more intensively. This is an idea of *static substitutability*. However, stock variables can change only slowly over time.

A second idea of substitutability stems from the observation that *firm and government institutions often cooperate*; then they must decide which part of a research project is done in the firm and which part in the government institution. One may observe a proportional expansion, which looks like complementarity, if this is shared in constant proportion, if not equally. But it may also be shifted over time more and more, from project to project, into the organization of one of these two partners. As an extreme example of a limiting case one can think of a university lab being the R&D organization of one or more firms who pay for the costs of the lab. Such a process may be driven by cost considerations like the one along the isoquants of a macro-economic TFP production function. Activities may then be shifted to the place with lower costs. A less cooperative version of this is simply market competition for the relevant production factors, for example the best scientists.

The time paths of R&D capital variables, as they appear in our simulations below, can always be interpreted as a combination of the dynamic complementarity and the two substitution processes.

For the labour market for researchers there are two possible constellations (Goolsbee 1998; Jaumotte and Pain 2005, Wolff and Reinthaler 2008). If all scientists including those just entering the market are fully and efficiently employed, additional R&D expenditure cannot increase R&D activity but rather only the wages. More expensive researchers will lead to less hiring and lower profitability of technology adoption projects. There will be less R&D activity and TFP may suffer than. In contrast, if researchers are not fully and efficiently employed and young scientists entering the market are abundantly available, higher R&D expenditure can lead to more hiring of researchers and little wage increases. There will be effectively more R&D activity, and more technology adoption projects can be done. In this case more expenditure goes together with more hiring.

For the relation of private domestic and foreign R&D we suggest the following two lines of thought. The above-mentioned production functions may have spillover externalities, which enhance the marginal productivities, suggesting a positive relation between domestic and foreign R&D independent of the details of the market structure. However, R&D is done by only about ten percent of all firms even in rich countries. Once they have made several innovations, they may have a strong market position and not be price takers anymore, even if they originate from countries, which are small in terms of land and population. For example, in the basic Cournot model with R&D, there are not only negatively sloped reaction functions for output but also for R&D expenditure flows (D'Aspremont and Jacquemin 1988): if one firm spends more on R&D the other spends less. This suggests a negative relation between R&D expenditures of foreign and domestic firms stemming from the Cournot-conduct or strategic-substitute assumption.

The observed or simulated relation between private domestic and foreign R&D can be imagined to be the combination of both, positive knowledge externalities and competition effects through negative R&D investment reactions (Luintel and Khan 2004). They can go one way for a certain period and another for a different period if the dominant aspects are changing quantitatively over time.

Finally, policies may be designed differently for each country. Governments may be active in R&D decisions. For example, in some countries the main policy instrument is a tax credit system. Firms decide on the R&D and then put the cost into their tax declaration. In contrast, other countries support private R&D with subsidies for projects, where the government has a strong impact on the definition of the projects. If the government has a longer or shorter time horizon than the firms, this implies lower or higher discount rates in the calculations. Higher (lower) discount rates lead to shorter (longer) payback periods. 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.

4. Estimation results: Heterogeneity limits for a common model

This section tries to find elements of a common model and its limitations. It is encouraged by the first impression that the UK, Italy, Denmark and the Netherlands seem to 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 for France, and 7-6 = 1 for Germany). For Belgium we find $r = K$, more than 6 long-term relations, and estimate a VAR in (log-) levels.

There are several types of heterogeneity: different numbers of long-term relations (7 for Belgium,[10] 4 for France and 6 for Germany, 5 for the other four countries); different variables in long-term relations; different slope

[10] As the hypothesis 'at most 6 cointegrating equations' is rejected, there are no unit roots and therefore there is no cointegration problem and, by implication, no cointegrating equations. However, estimation in levels

coefficients in similar long-term relations. 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 an appendix). It should be kept in mind that these may work also via other long-term relations through reversed causality. Also, transitional effects may go the opposite way.

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, 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 has a unit coefficient although the Johansen tests suggest that there is no unit root in the system. Again, we see strong slope heterogeneity as in all other equations.

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	-	0.00134t + 16.4
Italy	1	2.55	-0.196	-	0.0142t + 15.7
Netherlands	1	1.92	-0.257	-	0.0083t + 15.2
Germany [(e)]	1	1.78	**-**	**-**	0.0046t + 14.64
France [(b)]	-	-	-	-	-
Denmark	1	1.567	-	-0.21FPUBST	0.0097t + 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) + 0.55**A**(-1) + 13.175 + 0.055D + 0.03t			
2. equation	***TFP***	***BERDST***	***FPUBST***	***Other variables***	***Trend & intercept***
UK	1	0.295	0.95	-	-0.02t - 15.3
Italy	1	0.187	1.61	-	-0.048t - 21.36
Netherlands	1	1.03	-	-0.3FBERDST	-0.038t - 5.2
Germany	1	0.17	-	-	0.00159t - 2.25
France	1	0.22	0.45	-	-0.0137t - 8.1
Denmark	1	0.06	2.38	-	-0.058t - 29.997
Belgium	1	-0.16P(-2) + 0.2**M(-2)** + 0.33**FP**(-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	-	0.068t+15.9
Italy	1	12.2	-4.5	-	0.16t+53.4
Netherlands	1	0.45	0.65	-	0.033t+2.7
Germany [(e)]	1	-	2.94	-	-0.044t-19.89
France	1	-7.2	2.3	-	0.02t-15.5
Denmark	1	3.94	-2.53	-	0.117t+27.3
Belgium	1	1.649B(-1) - 0.948B(-2) - 0.19M(-1) + 0.13M(-2) + 0.22FB(-1) – 0.24FB(-2) - 0.26Y(-1) + 0.295**A**(-1) + 6.48 + 0.00897Dt - 0.1496D +			

using a VAR then has seven equations for the short and the long run, where residuals should be zero in equilibrium.

		0.0155t			
4. equation	***FPUBST***	***TFP***	***FBERDST***	***Other variables***	***Trend & intercept***
UK	1	4.87	-1.127	-	0.017t + 28.7
Italy	1	1.99	-1.74	-	0.084t +33.998
Netherlands	1	-	0.158	-	0.01134t+10.5
Germany	-0.0764	-	1	-	0.034t + 13.39
France (b)	1	5.05	-2.3	-	0.0795+42
Denmark	1	0.32	0.0297	-	0.023t+12
Belgium	1	-0.122P(-1) + 0.13P(-2) - 0.115B(-1) - 0.05B(-2) + 0.038M(-1) + 1.366FP(-1) - 1.048FP(-2) - 0.124**FB**(-1) + 0.33**FB**(-2) - 0.027Y(-1) + 0.124**A**(-1) + 0.038**A**(-2) + 7.139 + 0.0032Dt - 0.058D + 0.0175t			
5. equation	***Mission R&D***	***FPUBST***	***PUBST***	***Other variables***	***Trend & intercept***
UK	1	1.33	0.48	-	-0.051t-10.486
Italy	1	-	0.80	0.89BERDST	-0.032t-7.286
Netherlands	1	0.72	0.45	-	-0.0097t-5.356
Germany	-0.0052	-	-	1FBERDST	0.032t+12.4
France	1	-1.43	1.6	-	0.0029t+11.4
Denmark	1	9.4	-9.6	-	0.13t - 38.2
Belgium	1	-0.336B(-2) + 0.688M(-1) - 0.174M(-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 + 0.0259t			
6. equation	***PUBST***	***Mission R&D***			
Germany(c)	1	0.21MissionR&D		0.025t+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) + 0.007587t			
7. equation	***FBERDST***				
Belgium (d)	**1**	-0.274P(-1) + 0.26P(-2) - 0.225B(-2) - 0.085M(-1) + 0.095M(-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 + 0.028t			

(a) Constants and only statistically significant coefficients. All variables in natural logarithms. France has four long-term relations, Germany six, Belgium 7, 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 $K\text{-}r=1$ 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 = LM5, D = DUM6380.

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 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 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 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. 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 (Wooldridge 2013, chapter 10.5) 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 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 more in line with the shock results.
2. TFP reacts not only to domestic private but also mostly to foreign public or, for the Netherlands, foreign private R&D;
3. domestic private R&D reacts to TFP;
4. Foreign private and 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 perhaps indicate that they are neither substitutes nor complements in general. Moreover, they react positively to countries' TFP as a 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, 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 substitutes. The two negative effects suggest withdrawal of foreign private R&D when there is more public R&D, and consequently more German engagement in mission-oriented 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).[11]

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 as well as 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,

[11] Our companion paper for Japan also has this property

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

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 public R&D. Implicit adverse effects supposedly come from increases in wages of researchers, which may discourage innovative activities. 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 VECM (see Juselius 2006; Pesaran 2015), the baseline simulation, and the shock scenarios are presented in country-specific appendices. 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 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 1 or 2 of 7 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 fourty years; for Italy the effect on private R&D is positive for fourty years before it becomes negative (see country-specific appendices). These latter examples of effects changing over time point to the importance of discounting with results reported in Table 3.

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 six and eight percent of the baseline values.

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 appendices. (a) Model without GDP variable.

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 public R&D is five times as strong as that of 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 shock 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.

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. Labour 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 approximation[12] 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 percent increase of mission-oriented R&D leads to an additional 0.485% (0.43, 0.54) public R&D, 0.705% (0.65, 0.76) private R&D, 0.485% (0.33, 0.62) for TFP, 0.564% (0.445, 0.684) GDP. 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 labour demand and employment. When calculating the benefits below we consider only the impact on TFP and not those on labour 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 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 and therefore is endogenous as also shown by positive adjustment coefficients.

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 GDP gains for decennia, mostly short payback periods, high gains in terms of additional GDP - through TFP diminished by higher R&D costs-, 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. Immediately after the shock there are gains in four countries. In Denmark there is one and in the Netherlands four other periods of losses; Germany the period 1980-1999 has losses but these get low weight, due to the gains 1973-1979. In the UK the early gains are lower than the later gains and therefore the irr is 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. 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. 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 in the middle of the seven countries. These gains are

[12] This 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.

highest in Germany and Italy (followed closely 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.

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
Netherlds	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.

Some high internal rates of return shown in Table 3 are as high as or even higher than those for basic research (see NESTI 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 et al. (2016) for R&D-intensive countries among 32 OECD and EU countries, both based on steady state calculations. 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. For France, Italy and Germany we find even higher ones than in the literature. 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 then 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 take into account the additional costs for firms' capital and labour 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 labour 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. Summary, policy conclusion and limitations

The basic contours of traditional thinking about R&D and TFP driven growth appear in our country-specific models. We show that mission-oriented R&D has a negative impact on the long-term relation of TFP and GDP for three countries. 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 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, in the past, the effects of mission-oriented R&D were 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 et al. 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 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 analyse 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 focussed on the categories discussed most recently in the public domain. In the future, new projects will be defined and must proof that they support growth and welfare. 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 then 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.

References

Antonelli, Cristiano (2019). Knowledge exhaustibility public support to business R&D and the additionality constraint. The Journal of Technology Transfer.

Arrow, Kenneth J. (1962) Economic Welfare and the Allocation of Resources for Invention. The Journal of Law and Economics 12, 609-624.

Baumol, William J. and Wallace E. Oates (1988) The theory of environmental policy (with contr. by V.S. Bawa, David Bradford). Cambridge University Press, New York.

Bottazzi, L., and G. Peri (2007). The International Dynamics of R&D and Innovation in the Long Run and in the Short Run. The Economic Journal 117 (March): 486–511.

Cantner, Uwe and Simone Vannuccini (2018) Elements of a Schumpeterian catalytic research and innovation policy. Industrial and Corporate Change, Vol. 27, No. 5, 833–850.

Chakraborty, Shankha and Amartya Lahiri (2007). Costly intermediation and the poverty of nations. *International Economic Review*, Vol. 48, No. 1, February.

Coe, D. T., and E. Helpman (1995). International R&D Spillovers. European Economic Review 39 (5): 859–887.

Cruz-Castro, Laura, and Luis Sanz-Menéndez (2016) The effects of the economic crisis on public research: Spanish budgetary policies and research organizations. Technological Forecasting & Social Change 113 157–167.

D'Aspremont, C., & Jacquemin, A. (1988). Cooperative and noncooperative R&D in duopoly with spillovers. The American Economic Review, 78(5), 1133-1137.

Deleidi, M, Mazzucato, M, (2018). "Putting austerity to bed: Technical progress, aggregate demand and the supermultiplier." UCL Institute for Innovation and Public Purpose, Working Paper Series (IIPP WP 2018-01). https://www.ucl.ac.uk/bartlett/public-purpose/wp2018-01

Deleidi, Matteo, and Mariana Mazzucato (2019) MISSION-ORIENTED INNOVATION POLICIES: A THEORETICAL AND EMPIRICAL ASSESSMENT FOR THE US ECONOMY. Dipartimento di Economia Università degli studi Roma Tre Working Paper n° 248.

Elk, Roel van, Bas ter Weel, Karen van der Wiel, Bram Wouterse (2019. Estimating the Returns to Public R&D Investments: Evidence from Production Function Models. De Economist, March 2019, Volume 167, Issue 1, pp 45–87.

European Commission (2017) THE ECONOMIC RATIONALE FOR PUBLIC R&I FUNDING AND ITS IMPACT. Policy Brief Series March, Brussels.

Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2015), "The Next Generation of the Penn World Table" American Economic Review, 105(10), 3150-3182, available for download at www.ggdc.net/pwt.

Foray, D., D.C. Mowery, R.R. Nelson (2012) Public R&D and social challenges: What lessons from mission R&D programs? Research Policy 41 1697–1702.

Goolsbee, A. (1998) Does government R&D policy mainly benefit scientists and engineers? NBER WP 6532.

Gospodinov, N., A. M. Herrera, and E. Pesavento (2013): "Unit roots, cointegration and pre-testing in VAR models," Advances in Econometrics, 31, 81–115.

Hall, B., J. Mairesse and P. Mohnen, 2010, Measuring the Returns to R&D, In: Bronwyn H. Hall and Nathan Rosenberg, Editor(s), Handbook of the Economics of Innovation 2, 1033-1082.

Hecq, Alain, Franz C. Palm & Jean-Pierre Urbain (2002) Separation, Weak Exogeneity, And P-T Decomposition In Cointegrated Var Systems With Common Features, Econometric Reviews, 21:3, 273-307.

Helpman, E. and P.R. Krugman (1989), Trade Policy and Market Structure. MIT Press, Cambridge, MA, London.

Hjalmarsson, Erik and Pär Österholm (2010) Testing for cointegration using the Johansen methodology when variables are near-integrated: size distortions and partial remedies. Empirical Economics 39: 51–76.

Jaumotte, F. and Pain, N. (2005) 'Innovation in the Business Sector', OECD Economics Department Working Paper No. 459, OECD, Paris.

Juselius, Katarina (2006) The Cointegrated VAR Model: Methodology and Application. Oxford University Press. Oxford, New York.

Juselius, Katarina, Niels Framroze Møller and Finn Tarp (2014) The Long-Run Impact of Foreign Aid in 36 African Countries: Insights from Multivariate Time Series Analysis. Oxford Bulletin of Economics and Statistics, 76, 2, 153-184.

Kattel, Rainer and Mariana Mazzucato (2018) Mission-oriented innovation policy and dynamic capabilities in the public sector. Industrial and Corporate Change, Vol. 27, No. 5, 787–801.

Kilian, L., and Lütkepohl, H. (2017). Structural vector autoregressive analysis. Cambridge University Press, Cambridge, New York.

Luintel, K. B., and M. Khan (2004). Are International R&D Spillovers Costly for the United States? Review of Economics and Statistics 86 (4): 896–910.

Luintel, Kul B., Mosahid Khan, Konstantinos Theodoridis (2014) On the robustness of R&D. Journal of Productivity Analysis 42:137–155.

Lütkepohl, Helmut (2007) General-to-specific or specific-to-general modelling? An opinion on current econometric terminology. Journal of Econometrics 136 (2007) 319–324.

Maddala, G. S., and I.-M. Kim. (1998). Unit Roots, Cointegration and Structural Change. Cambridge University Press, New York.

Makkonen, Teemu (2013) Government science and technology budgets in times of crisis. Research Policy 42 (3), 817-822.

Mazzucato, Mariana (2018a) Mission-Oriented Innovation Policy: Challenges and Opportunities. In: European Commission (2018) Science, Research and Innovation Performance of the EU 2018. Strengthening the foundations for Europe's future. Brussels. Pages 396-427.

Mazzucato, Mariana and Gregor Semieniuk (2017) Public financing of innovation: new questions. Oxford Review of Economic Policy, Volume 33, Number 1, 2017, pp. 24–48.

Mowery, David C., Richard R. Nelson, Ben R. Martin (2010) Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won't work) Research Policy 39 1011–1023.

Musgrave, RA and PB Musgrave (1973) Public finance in theory and practice. McGraw-Hill, New York.

Nelson, Richard R. (1959) The Simple Economics of Basic Scientific Research. Journal of Political Economy, Vol. 67, No. 3 (June), pp. 297-306.

NESTI (Working Party of National Experts on Science and Technology Indicators) (2017) The Impact of R&D Investment on Economic Performance: a Review of the Econometric Evidence. OECD, Directorate for

Science, Technology and Innovation, Committee for Scientific and Technological Policy, document DSTI/STP/NESTI(2017)12.

Ogawa, Kazuo, Elmer Sterken, Ichiro Tokutsu (2016) International R&D Spillovers and Marginal Social Returns on R&D. CESIFO WORKING PAPER NO. 6255.

Patterson, K. 2000. An Introduction to Applied Econometrics: A Time-Series Approach, Houndmills and New York: Palgrave Macmillan.

Pesaran, M. Hashem (2015) *Time Series and Panel Data Econometrics*. Oxford University Press.

Reynolds, L.G. (1985). The Spread of Economic Growth to the Third World: 1850-1980. Journal of Economic Literature, Vol. XXI (September), 941-981.

Robinson, Douglas K.R. and Mariana Mazzucato (2019) The evolution of mission-oriented policies: Exploring changing market creating policies in the US and European space sector. Research Policy 48 (4), May, Pages 936-948.

Schultz, T.W. (1961) Investment and human capital. American Economic Review 51, 1-7.

Schultz, T.W. (1964) Transforming Traditional Agriculture. Yale University Press.

Shell, Karl (1967) A Model of Inventive Activity and Capital Accumulation. In Essays on the Theory of Optimal Economic Growth, edited by Karl Shell, 67-85. Cambridge, MA: The MIT Press.

Smith, Ron P. and Ana-Maria Fuertes (2016) Panel Time-Series. Mimeo, August.

Soete, Luc, Bart Verspagen and Thomas Ziesemer (2019) The productivity effect of public R&D in the Netherlands. Economics of Innovation and New Technology. Online.

Solow, Robert M. (1956) A Contribution to the Theory of Economic Growth, Quarterly Journal of Economics, LXX, 1, 65-94.

Veugelers, Reinhilde (2012) Which policy instruments to induce clean innovating? Research Policy 41, 1770 – 1778.

Wolff, G., Reinthaler, V., 2008. The effectiveness of subsidies revisited: accounting for wage and employment effects in business R&D. Research Policy 37, 1403–1412.

Wooldridge, Jeffrey M. (2013) Introductory Econometrics: A Modern Approach, Fifth Edition.

Ziesemer, T. (1990) Public Factors and Democracy in Poverty Analysis, Oxford Economic Papers, 1990, Special Issue on Public Economics, Vol.42, January, 268-280.

Ziesemer, T. (1991) Human Capital, Market Structure and Taxation in a Growth Model with Endogenous Technical Progress, Journal of Macroeconomics, Vol.13, 1991, No.1, Winter, 47-68.

Ziesemer, T. (1995) Endogenous Growth with Public Factors and Heterogeneous Human Capital Producers, Finanzarchiv, Neue Folge, Vol. 52, Issue 1, 1-20.

Appendix A: VECM methodology

The basis is a VAR model in differences for *K* variables, where *K* is 7 or 6 in our applications.

$$dy = A(CE) + B_1 dy(-1) + B_2 dy(-2) + Cx. \quad (1)$$

Here dy is the (K, 1)-vector (K rows, 1 column) of first differences of the variables discussed above. $r \leq K$ cointegrating equations, abbreviated as *CE*, provide information on long-term relations in addition to the VAR model in differences. If the term *A(CE)* were absent, we would simply have a system for the K variables regressed on the lags of all K variables, all in differences. Estimation in differences avoids problems from variables with unit roots, which means that they are dependent on their own lag with coefficient unity. B_p is the (K, K) matrix of coefficients of the (K, 1)-vector of differenced terms in each of the K equations with lag $p = 1, 2$ (and perhaps more or less as obtained from lag length tests). C is the (K, 2)-matrix of the coefficients of the vector of exogenous variables $x' = (c, t)$, in the first instance only constant and time trend. *CE* is the *(r, 1)*-vector of cointegrating or long-term equations. A is the *(K, r)*-matrix of adjustment coefficients. In principle, if adjustment coefficients for one or more of the variables turn out to be statistically insignificant and this variable is also insignificant in all short-term relations, we will have additional exogenous candidate variables x with coefficient matrix C extended and the number of K endogenous variables must be reduced to K-1 (Patterson 2000). However, this does not happen to occur in our analysis; all variables turn out to be endogenous. The difficulty here is to find the number r of long-term relations, which add valuable information to the model in differences. We use the trace test and the maximum-eigenvalue test. Pesaran (2015) refers to articles preferring the trace test. Kilian and Lütkepohl (2017) suggest that both tests are equally good. Hjalmarsson and Österholm (2010) show that the trace test suffers more in case of variables with near unit roots below unity to an extent around 0.04-0.2. Therefore, we look at both tests. They both have low power in the case of exact unit roots, meaning that we might accept the hypothesis under consideration too often. The hypotheses are of the type 'at most r cointegrating equations'; if we reject, r is enhanced by one for the next hypothesis test. We consider rejecting a null hypothesis of having a certain number of cointegrating equations only if both tests reject it as suggested by Hjalmarsson and Österholm (2010), because also near unit roots may lead to absence of cointegration. This leads to a conservative way of moving to higher numbers of cointegrating equations. It is in contrast though with the suggestion of Juselius (2006) and Juselius et al. (2014) to be aware of the low power of unit root tests and cointegration tests and be conservative against the hypothesis of having a unit root or 'at most r cointegrating equations'. Moreover, a too low number of cointegrating equations leads to inconsistent estimation results (Kilian and Lütkepohl 2017). Finding the number of cointegrating equations, r, and the number of unit roots K-r, may require balancing the two suggestions also using the results for univariate unit-root tests. For the latter we use the Perron-Vogelsang ADF test with breakpoints; we do not have sufficiently long data series to make sense of a higher number of breaks. If $r = 0$ we would estimate in differences, which means that the *A(CE)* term is dropped in (1). If all hypotheses suggesting $r < K$ are rejected, we have $r = K$ and estimate in levels without differenced terms. The estimation method is maximum likelihood. Both, the VAR and the preferred VECM should be stable (Patterson 2000, Pesaran 2015).

In practice, this method is used for small models, typically less than ten variables. Even this may lead to problems regarding the degrees of freedom in the estimations when several lags are used, which we will discuss in due course.

A variable is called weakly exogenous if all adjustment coefficients in its equation are statistically insignificant. We impose restrictions on the statistically highly insignificant adjustment coefficients. Consequently, we see that some adjustment coefficients become highly significant indicating that a variable is not weakly exogenous. In none of our models do we find weakly exogenous variables. This implies that even for small countries foreign R&D variables are endogenous. The reason may be that firms doing R&D have fixed costs making perfect competition impossible. Under imperfect competition there are no small countries defined as price takers. There is strategic interaction if they are not in Chamberlain monopolistic competition, and even in the latter they react to each other via price effects and changes in the number of firms (Helpman and Krugman 1989).

Finally, we want to point out that the VECM methodology is mostly explained in the literature for I(1) variables only, but I(0) variables can be included. "… the modelling procedure is robust to uncertainties surrounding the order of integration of particular variables. It is often difficult to establish the order of integration of particular variables using the techniques and samples of data which are available, and it would be problematic if the modelling procedure required all the variables in the model to be integrated of a particular order. However, the observations above indicate that, so long as the rx1 cointegrating relations, $\hat{\Xi}_t = \hat{\beta}' y_{t-1}$, are stationary, the conditional *VEC* model, estimated and interpreted in the usual manner, will be valid even if it turns out that some or all of the variables in y_{t-1} are *I(0)* and not *I(1)* after all." (Pesaran 2015, ch.22, Cointegration analysis, p.550). The critical issue here is whether cointegrating relations are stationary and have stable parameters. We include variables which are likely to be I(0). I(0) variables can be combined with each other, or with I(0) combinations of I(1) variables. However, equations consisting of I(0) variables or relations cannot be combined with single I(1) variables, because these combinations cannot be stationary. We follow therefore a two-step strategy. First, we assume that all variables are I(1) or have near unit roots, which should be treated as I(1) variables (see Juselius 2006). Then we test for parameter stability. We test for stable coefficients by re-running the final equation with successively one year less at the end and the beginning of the sample. Coefficients turn out to be much more stable if highly insignificant adjustment coefficients are constrained to zero as in Juselius (2006). If parameters are unstable, we would try to find which variables may be I(0), put them into the upper part of the cointegrating equation form ($I_{(r)}$, $\beta_{(K-r)}$) as suggested by Lütkepohl (2005). In the lower part, we then have the cointegrated I(1) variables. Depending on details, this can be a special form of separate cointegration (see Hecq et al. (2002). However, we can also add I(0) variables to cointegrated I(1) variables, which may be economically plausible if statistically significant. Having done so we test for parameter stability again. Hjalmarsson and Österholm (2010) discuss the issue in a more detailed manner. Finding a long-term relation with coefficients β = (1, 0, 0) would point to having an I(0) variable and no cointegration of two I(1) variables (Patterson 2000). Of course, this would also show that this is not an economically meaningful relation as coefficients are insignificant and set to zero. Finally, I(2) variables can either be treated with an I(2) model (see Maddala and Kim 1998; Juselius 2006) but they can also be treated with the I(1) model as shown by equation (16.5) in Juselius (2006). Given the uncertainty around some of the I(2), results we prefer to integrate them into the I(1) model explained above.

Opposition to this approach suggests that (i) unit roots do not exist or (ii) are not a problem for Bayesian statistics (see Maddala and Kim 1998) or (iii) the possibility of local-to-unity downward deviations from unit roots which may imply that estimation in levels is more robust to errors in the order of integration (Gospodinov et al. 2013). However, this debate is informed by a special macroeconomic literature. Moreover, it does neither include the literature discussing larger then unit roots nor I(2) variables, which are relevant in this paper. "The relevance of such simulation results for applied work, of course, depends on how closely the assumed underlying DGP matches the features of the actual DGP." (Kilian and Lütkepohl 2017). Based on this, we conclude that it is not admissible to carry insight from one area of economics mechanically to other areas.

Appendix B: Linking VAR and Cobb-Douglas functions

We extend the single equation approach of van Elk et al (2019) and other earlier literature to a multi-equation approach in the form of a vector error correction model (VECM) for each country in order to capture multi-way causality explicitly. Thereby we avoid slope homogeneity and the arbitrary assumption of having only one cointegrating equation.

We define *A* as total factor productivity, normalized to unity for 2011 in PWT9 (Feenstra et al. 2015). *P* is the domestic private R&D capital stock. *G* is the domestic public R&D capital stock. *G** is the foreign public R&D capital stock, *P** the foreign private R&D stock, *Y* is domestic GDP and *Y** is foreign GDP aggregated over other (OECD) countries, and *M* is mission-oriented R&D stock. We assume that *A*, *G, P*, *G**, *P*,* and *M* are produced by country-specific Cobb-Douglas functions with the following properties. (i) Each uses all the lagged values of the others and their own lagged value as R&D experience or spillover indicators. (ii) A share of the GDP for current costs is incurred to buy scientific and non-scientific personnel as well as capital for labs. (iii) Each CD functions has an exogenous technical progress term and a constant. (iv) Each log-linear version of the equations has a residual. (v) Each residual has an autoregressive process of order 1 or higher to be tested in the empirical part. We assume the following (with (-1) as indication of a one-period lag; equation *k=7* will be explained further below):

$$Log\ A = \alpha_{11} logA(-1) + \alpha_{12} \log\,(G(-1) + \alpha_{13} logP(-1) + \alpha_{14} logG^*(-1) + \alpha_{15} logP^* + \alpha_{16} log(h_1 Y) + \alpha_{17} logM(-1) + \alpha_{18} t + \alpha_{19} + u_1$$

$$Log\ G = \alpha_{21} logA(-1) + \alpha_{22} \log\,(G(-1) + \alpha_{23} logP(-1) + \alpha_{24} logG^*(-1) + \alpha_{25} logP^* + \alpha_{26} log(h_2 Y) + \alpha_{27} logM(-1) + \alpha_{28} t + \alpha_{29} + u_2$$

$$Log\ P = \alpha_{31} logA(-1) + \alpha_{32} \log\,(G(-1) + \alpha_{33} logP(-1) + \alpha_{34} logG^*(-1) + \alpha_{35} logP^* + \alpha_{36} log(h_3 Y) + \alpha_{37} logM(-1) + \alpha_{38} t + \alpha_{39} + u_3$$

$$Log\ G^* = \alpha_{41} logA^*(-1) + \alpha_{42} \log\,(G(-1) + \alpha_{43} logP(-1) + \alpha_{44} logG^*(-1) + \alpha_{45} logP^* + \alpha_{46} log(h_4 Y^*) + \alpha_{47} logM(-1) + \alpha_{48} t + \alpha_{49} + u_4$$

$$Log\ P^* = \alpha_{51} logA^*(-1) + \alpha_{52} \log\,(G(-1) + \alpha_{53} logP(-1) + \alpha_{54} logG^*(-1) + \alpha_{55} logP^* + \alpha_{56} log(h_5 Y^*) + \alpha_{57} logM(-1) + \alpha_{58} t + \alpha_{59} + u_5$$

$$Log\ M = \alpha_{61} logA(-1) + \alpha_{62} \log\,(G(-1) + \alpha_{63} logP(-1) + \alpha_{64} logG^*(-1) + \alpha_{65} logP^* + \alpha_{66} log(h_6 Y) + \alpha_{67} logM(-1) + \alpha_{68} t + \alpha_{69} + u_6$$

$$u_k = \sum_p \rho_{k,p} u_k(-p) + \epsilon_k,\ k = 1, \ldots, 7;\ p = 0, \ldots, P$$

Insertion of the residuals of the first six equations, u_k, and its lagged form into the latter autoregressive process of residuals yields a VAR with *P+1* lags. With *k* as the number of the variable and its equation, *j* as the number of the argument except for the constant and the time trend, and *p* as the number of the lagged years, shifting one period forward, this can be written more compactly in de-log form as

$$X_{t+1}(k) = \prod_k X(k)_t^{\alpha(k,j)}\ \alpha_{k,9} e^{\alpha(k,8)\times(t+1)+u_k},\ u_k = \sum_p \rho_{k,p} u_k(-p) + \epsilon_k,\ k = 1, \ldots, 7;\ j = 1, \ldots, 7$$

X corresponds to arguments *A, G, P, G*, P*, M* and either *Y or Y**. h_j are the shares of GDP going into the processes. ϵ_k are the residuals in the final VAR. Moreover, we imagine that domestic output is produced by a production function $Y = AK^{\alpha}$, and there are approximately perfect capital movements for the OECD countries leading to a given interest rate at world market level, *r*, and the marginal productivity condition $r+\delta = \alpha Y/K$ with δ as rate of capital depreciation. Solving the latter equation for *K* and inserting into the production function yields $Y = A^{1/_{1-\alpha}} \left(\frac{\alpha}{r+\delta}\right)^{\alpha/_{1-\alpha}}$. Depending on the value of *α*, which can be as large as 0.6 if public capital is included (Chakraborty and Lahiri 2007), the percentage change of GDP can be larger than that of TFP by a factor as high as 2.5 through attraction of foreign capital in proportion with output keeping the interest rate constant at the world level. If two-way causality is included in the empirical estimation this effect can be even higher. Taking natural logs and inserting the first equation above for *logA* provides the seventh equation. We will estimate the system without the implied constraints though as we do not know whether the production functions are exactly of the Cobb-Douglas type. For foreign GDP, *Y**, we assume that its level goes into the trend of the long-term relations and its growth rate goes into a constant of the VECMs outside the long-term relations.

APPENDIX: COUNTRY-SPECIFIC RESULTS

In the figures below, the labelling indicates that they show actuals data, baseline simulation, scenario simulation and deviations of scenario from baseline. In addition, the reader can see lines, which are the confidence intervals of the scenario using +- 2 standard deviations. Deviations from baseline are measured on the left axis through the lower curve, in all graphs with shifts of confidence intervals of equal size and therefore invisible; the high and the low scenario differ only at digits 11 to 16 from the medium deviation as indicated on the computer but not in six-digit print format. By implication the deviation of scenarios from baseline are highly significant. The policy scenario with its confidence intervals and the baseline calculation are measured on the right axis through the higher set of curves.

Graphs with a horizontal line indicate the equation to which the shock has been imposed at value of one standard deviation of the residuals of the mission equation with left-hand variable *dlm5*.

Cointegrating equations are written in the form $y(i) - Y(j)\beta = 0, j \neq I,$ all with lag (-1). Standard interpretation therefore requires using the opposite sign of the one written here except where the coefficient is set to unity.

In the regression output below, variable definitions are as follows. The first three letters indicate the country, e.g. *BEL*; then an *L* indicates the natural logarithm of a variable like BERD, in the end *ST* may indicate that we look at stock variables:

BELLPUBST is Belgium's log of public R&D stock; BELLBERDST is Belgium's log of private R&D stock; BELLM5 is Belgium's log of mission R&D stock from five flow elements defined in the introduction; BELLFPUBST is Belgium's log of foreign public R&D stock; BELLFBERDST is Belgium's log of foreign private R&D stock; BELLGDP is Belgium's log of GDP; BELLTFP is Belgium's log of TFP.

In order to provide the reader with as much information as possible we paste the regression output below.

In the constraint notation, B(4, 2) is the coefficient of the 4th cointegration equation and column for its second variable from above. A(4, 3) =0 is a zero constraint in the 4th equation of the VECM on the 3rd adjustment coefficient. This serves to exclude the possibility of weak exogeneity. Weak exogeneity is never found; we run the simulations with constraints on the most highly insignificant adjustment coefficients. Without constraints we would have too much noise and with many constraints we run the risk of cutting off relevant channels. We try to find a good way in between.

After all, we have never found a coefficient combination of the type β = (1, 0, 0), which would be expected if I(0) and I(1) variable are correlated. Thus, we can conclude that we have not correlated I(0) and I(1) variables. Variables that appear to be I(0) in unit root tests may actually have near unit roots.

We have tested for parameter stability by way of successively dropping one two or three years of observations at the end or at the beginning of the sample (not shown). Typically, parameters start getting unstable or policy shock results get strongly different if the sample starts with the oil crisis year 1974 or ends with 2011 or 2012, two years in the 2007-2013 crisis. In doubt about the interpretation we decide according to the fact that the policy result is still present or has vanished or the model becomes unstable for the period in question. For Italy, starting or ending with crisis periods makes the model unstable. The model for Denmark gets unstable when 1974, 1975 are the starting periods. For Belgium the policy effect vanishes when the period ends 2011 or 2012. For France, Germany, the Netherlands, and the UK the policy result is present for all seven regressions although slightly weaker when starting or ending with the crisis years. Clearly, in years where crises dominate the data, TFP is dominated by capacity utilization problems and R&D has at least a reduced impact which weakens the result based on other periods.

References to this appendix

Boswijk, H. Peter (1996) Testing Identifiability of Cointegrating Vectors. Journal of Business & Economic Statistics, Vol. 14, No. 2, pp. 153-160.

Hjalmarsson, Erik and Pär Österholm (2010) Testing for cointegration using the Johansen methodology when variables are near-integrated: size distortions and partial remedies. Empirical Economics 39: 51–76.

Appendix Belgium

Unit root tests give the results in the following table. They vary strongly with the lag length.

Order of integration from ADF with breakpoint test for innovational and additive outlier [(a)]

Lag fixed\variables	LGDP	LTFP	LBERDST	LPUBST	LM5	LFPUBST	LFBERDST
0 (VECM(0); or VAR(1)	I(1)	I(1), ao	I(2) ao,	I(1)	I(1)	I(0)	I(2)
1 (VECM(1); or VAR(2)	I(1)	I(1), ao	I(0)	I(0)	I(2)	I(1)	I(0)
2 (VECM(2); or VAR(3)	I(1)	I(1)	I(2)	I(0) ao 0.1188	I(1)	I(2)	I(1)

(a) with constant, trend and their breaks, all only if statistically significant. 'ao' indicates additional outlier, 'io' innovational outlier.

For Belgium there was a data revision after 1980. We add a dummy for the period 1969-1980 to the constant and also interact it with a time trend in addition to the linear time trend of the VARs. A VAR is stable with one or two lags. The lag length criteria prefer two lags unanimously. The cointegration tests suggest seven cointegrating equations far below the 5% level of significance. This would suggest that there are no unit roots. This result is in contrast with those from uni-variate tests in the table above. Juselius (2006) suggests not to rely on the uni-variate tests, but rather use those implied by the cointegration rank, here $K = r$ implying $K\text{-}r = 0$ unit roots. Residuals have a multi-variate normal distribution with p = 0.126, some serial correlation in the first lag, and no heteroscedasticity with p = 0.21. The VAR with two lags with variables having a p-value of less 0.1 (not shown because mostly zero) then is as follows (t-values in parentheses).

LPUBST = 1.327LPUBST(-1) - 0.56LPUBST(-2) - 0.1LBERDST(-1) + 0.099LM5(-1) + 0.446LFBERDST(-1) –
(17.5) (-8.26) (-3.4) (2.9) (4.93)

0.41LFBERDST(-2) + 0.13LGDP(-2) - 0.23LTFP(-2) - 0.004DUM6380t - 0.0699(1-DUM6380) + 0.007587t
(-4.76) (4.58) (-8.89) (-2.06) (-2.21) (10.4)

LBERDST = 1.649LBERDST(-1) - 0.948*LBERDST(-2) - 0.19LM5(-1) + 0.13LM5(-2) + 0.22LFBERDST(-1) –
(22.26) (-12.4) (-3.42) (3.18) (2.11)

0.24LFBERDST(-2) - 0.26LGDP(-1) + 0.295LTFP(-1) + 6.48 + 0.00897DUM6380t - 0.1496DUM6380 + 0.0155t
(-2.44) (-4.54) (4.65) (6.72) (4.77) (-4.66) (7.59)

LM5 = -0.336LBERDST(-2) + 0.688LM5(-1) - 0.174LM5(-2) + 0.84LFBERDST(-1) - 1.05LFBERDST(-2) –
(-3.97) (6.77) (-2.04) (3.39) (-4.75)

0.79LGDP(-1) + 0.554LGDP(-2) + 0.9997LTFP(-1) - 0.557LTFP(-2) + 12.067 + 0.0236DUM6380t –
(-3.22) (2.22) (3.39) (-1.95) (6.36) (6.54)

0.3476DUM6380 + 0.0259t
(-5.75) (6.74)

LFPUBST = -0.122LPUBST(-1) + 0.13LPUBST(-2) - 0.115LBERDST(-1) - 0.05LBERDST(-2) + 0.038LM5(-1) +
(-4.5) (5.26) (-4.49) (-1.8) (3.39)

1.3655LFPUBST(-1) - 1.048LFPUBST(-2) - 0.1239LFBERDST(-1) + 0.33LFBERDST(-2) - 0.027LGDP(-1) +
(16.9) (-14.3) (-2.95) (5.56) (-1.72)

0.1244LTFP(-1) + 0.038LTFP(-2) + 7.139 + 0.0032DUM6380t - 0.058DUM6380 + 0.0175t
(5.44) (3.17) (8.86) (3.66) (-3.84) (9.30)

LFBERDST = -0.274LPUBST(-1) + 0.257LPUBST(-2) - 0.225LBERDST(-2) - 0.085LM5(-1) + 0.095LM5(-2) +
(-4.95) (5.13) (-5.56) (-3.69) (3.75)

0.377LFPUBST(-1) - 0.85LFPUBST(-2) + 1.3LFBERDST(-1) - 0.38LFBERDST(-2) - 0.31LGDP(-2) +0.15LTFP(-1)
(3.60) (-6.49) (13.5) (-2.95) (-9.45) (5.67)

+ 0.297LTFP(-2) + 12.5 + 0.0055DUM6380*t - 0.1DUM6380 + 0.028t
(6.63) (7.64) (3.01) (-3.26) (7.47)

LGDP = -0.119LPUBST(-1) - 0.33LBERDST(-1) + 0.268LM5(-2) - 0.4LFPUBST(-2) + 0.27LFBERDST(-2) +
(-2.89) (-4.89) (5.04) (-3.59) (4.35)

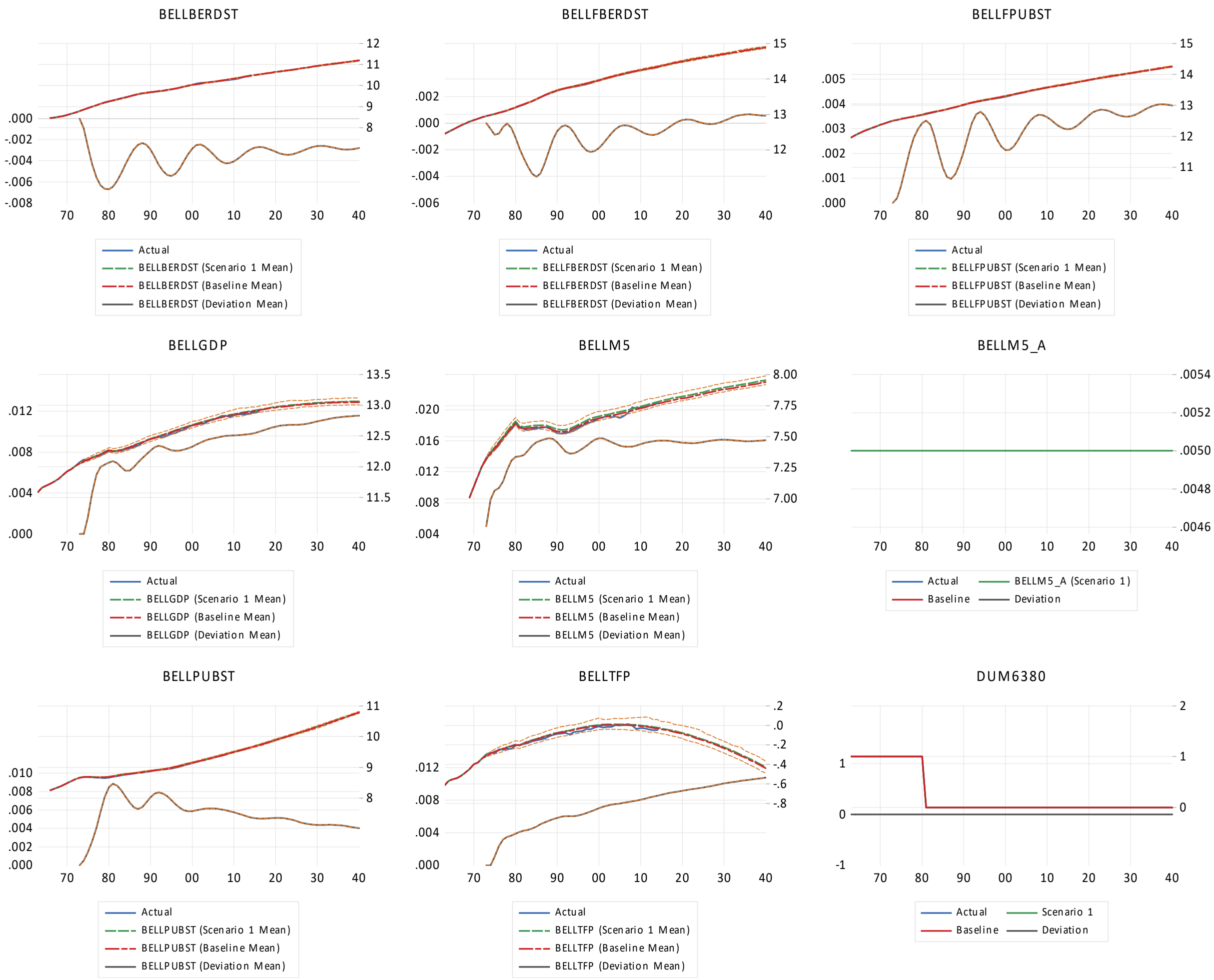
0.4LGDP(-1) - 0.189LGDP(-2) + 0.55LTFP(-1) + 13.175 + 0.055DUM6380 + 0.029776t
(3.20) (-3.36) (4.37) (6.26) (4.90) (6.06)

LTFP = -0.16LPUBST(-2) + 0.2LM5(-2) + 0.33LFPUBST(-1) - 0.339LGDP(-1) + 1.01479LTFP(-1) –
(-4.92) (3.81) (5.05) (-4.89) (19.6)

0.008DUM6380t - 0.163(1-DUM6380)
(-2.97) (-3.34)

Observations (1970-2014): 45, 44, 44, 45, 44, 44, 44. Adjusted R-squared: 0.999, 0.999, 0.994, 0.999, 0.999, 0.996, 0.987.

A shock of one standard deviation of 0.005 on the intercept of the mission equation, *dlm5*, using the bootstrap method because of the low p-value for the multi-variate normal distribution, yields the following policy and baseline scenarios and their differences from 1000 repetitions.



Mission R&D, *Lm5*, increases for roughly 15 year and then keeps a constant percentage distance from baseline. Domestic and foreign public R&D also increase from baseline for 7 or 8 years. Domestic and foreign private R&D are mostly slightly below baseline. Effects on TFP and GDP are still positive for all years indicating that increases in public R&D have stronger effects than decreases in private R&D. Further evaluation of the effects is reported in Tables 2 and 3 of the main text.

Appendix Denmark

Most lag length criteria prefer three lags, but then the VAR is unstable. SIC prefers two lags and then the VAR is stable. The corresponding VECM then has two lags. There is no serial correlation up to lag 4 considered separately, and not up to 2 lags jointly with *na* for higher lags. Heteroscedasticity can be rejected at p = 0.31. The cointegration tests suggest 7 or 3 cointegrating equations at the five percent level. TFP and foreign public R&D in logs have a high likelihood of having a unit root. As the mission variable has no unit root it is plausible to have 5 cointegrating equations, as K - r = 7 - 5 = 2 is number of (near) unit roots in the system. Residuals are normally distributed with p = 0.79. The estimated VECM in the renormalized form is as follows.

Vector Error Correction Estimates

Sample (adjusted): 1972 2014
Included observations: 43 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:
A(2,4)=0,A(7,5)=0, A(4,1)=0, A(5,3)=0,A(7,1)=0,A(7,4)=0, A(1,2)=0,B(1,1)=1, B(1,3)=0, B(1,7)=0, B(1,5)=0,

B(1,6)=0, B(2,6)=0, B(2,3)=1, B(2,2)=0, B(2,1)=0,B(2,5)=0, B(3,4)=0,B(3,2)=1, B(3,3)=0, B(3,5)=0, B(3,6)=0, B(4,2)=0, B(4,3)=0, B(4,4)=1,B(4,5)=0, B(4,7)=0,B(5,2)=0, B(5,3)=0, B(5,6)=0,B(5,5)=1, B(5,7)=0,
Convergence achieved after 1123 iterations.
Restrictions identify all cointegrating vectors
LR test for binding restrictions (rank = 5):

Chi-square(7)	1.337651
Probability	0.987405

Cointegrating Eq:	CointEq1	CointEq2	CointEq3	CointEq4	CointEq5
DNKLTFP(-1)	1.000000	0.000000	-3.937505	-0.322380	-1.567425
			(0.14697)	(0.00533)	(0.03937)
			[-26.7914]	[-60.4738]	[-39.8093]
DNKLBERDST(-1)	-0.063438	0.000000	1.000000	0.000000	0.000000
	(0.00571)				
	[-11.1153]				
DNKLM5(-1)	0.000000	1.000000	0.000000	0.000000	0.000000
DNKLFPUBST(-1)	-2.379083	-9.413523	0.000000	1.000000	0.207532
	(0.02751)	(0.76307)			(0.06940)
	[-86.4668]	[-12.3365]			[2.99049]
DNKLGDP(-1)	0.000000	0.000000	0.000000	0.000000	1.000000
DNKLFBERDST(-1)	0.000000	0.000000	0.000000	-0.029672	0.000000
				(0.00394)	
				[-7.52169]	
DNKLPUBST(-1)	0.000000	9.611491	2.526989	0.000000	0.000000
		(0.84145)	(0.31520)		
		[11.4226]	[8.01705]		
@TREND(63)	0.058361	-0.127985	-0.116807	-0.022749	-0.009676
	(0.00111)	(0.03356)	(0.01212)	(0.00034)	(0.00200)
	[52.6861]	[-3.81381]	[-9.63569]	[-66.8143]	[-4.83721]
C	29.99670	38.20351	-27.34275	-12.00917	-14.48541

Error Correction:	D(LTFP)	D(LBERDST)	D(DNKLM5)	D(LFPUBST)	D(LGDP)	D(LFBERDST)	D(LPUBST)
CointEq1	-4.736081	-0.316696	13.48832	0.000000	-5.037153	2.407474	0.000000
	(2.08986)	(0.12427)	(3.90723)	(0.00000)	(2.95760)	(0.70774)	(0.00000)
	[-2.26622]	[-2.54841]	[3.45215]	[NA]	[-1.70312]	[3.40165]	[NA]
CointEq2	0.000000	0.021434	-0.389790	-0.018184	-0.051500	-0.029615	-0.049542
	(0.00000)	(0.01899)	(0.07165)	(0.00581)	(0.02078)	(0.01325)	(0.01004)
	[NA]	[1.12855]	[-5.43984]	[-3.13161]	[-2.47825]	[-2.23512]	[-4.93472]
CointEq3	-0.093071	-0.054167	1.334221	0.045597	0.000000	0.073981	0.024708
	(0.04144)	(0.04938)	(0.21676)	(0.01489)	(0.00000)	(0.03420)	(0.01000)
	[-2.24565]	[-1.09700]	[6.15533]	[3.06196]	[NA]	[2.16340]	[2.47089]
CointEq4	-11.52507	0.000000	27.57144	-0.356174	-11.65972	5.267644	0.000000
	(5.02783)	(0.00000)	(9.04471)	(0.09623)	(7.19879)	(1.68902)	(0.00000)
	[-2.29226]	[NA]	[3.04835]	[-3.70145]	[-1.61968]	[3.11876]	[NA]
CointEq5	-0.624026	-0.481171	0.795308	0.088235	-1.501931	0.405231	0.000000
	(0.50850)	(0.17584)	(0.67391)	(0.05884)	(0.74829)	(0.15723)	(0.00000)

	[-1.22718]	[-2.73635]	[1.18014]	[1.49947]	[-2.00716]	[2.57732]	[NA]
D(DNKLTFP(-1))	-0.282089	-0.531889	1.030229	0.041596	-1.317264	0.255046	-0.174717
	(0.55876)	(0.21943)	(0.69019)	(0.09499)	(0.79634)	(0.16711)	(0.29228)
	[-0.50484]	[-2.42392]	[1.49268]	[0.43788]	[-1.65414]	[1.52622]	[-0.59777]
D(DNKLTFP(-2))	0.783029	-0.078549	0.770641	0.096499	0.874237	0.372038	0.161672
	(0.52830)	(0.20747)	(0.65257)	(0.08981)	(0.75293)	(0.15800)	(0.27635)
	[1.48215]	[-0.37860]	[1.18094]	[1.07442]	[1.16111]	[2.35466]	[0.58502]
D(DNKLBERDST(-1))	-0.024560	0.911945	-0.303326	0.088453	-1.128766	-0.117480	-0.086597
	(0.45844)	(0.18003)	(0.56627)	(0.07794)	(0.65336)	(0.13711)	(0.23980)
	[-0.05357]	[5.06538]	[-0.53566]	[1.13492]	[-1.72763]	[-0.85685]	[-0.36111]
D(DNKLBERDST(-2))	0.083870	-0.178527	-0.528879	0.001845	0.854350	0.129572	0.304662
	(0.42147)	(0.16552)	(0.52060)	(0.07165)	(0.60067)	(0.12605)	(0.22047)
	[0.19899]	[-1.07860]	[-1.01589]	[0.02575]	[1.42232]	[1.02794]	[1.38189]
D(DNKLM5(-1))	0.021926	0.123843	0.302223	0.012578	0.069300	-0.056892	0.024249
	(0.11117)	(0.04366)	(0.13732)	(0.01890)	(0.15844)	(0.03325)	(0.05815)
	[0.19723]	[2.83668]	[2.20090]	[0.66549]	[0.43739]	[-1.71115]	[0.41699]
D(DNKLM5(-2))	-0.063235	-0.122385	-0.339285	-0.021393	0.009252	-0.040385	0.132961
	(0.13783)	(0.05413)	(0.17025)	(0.02343)	(0.19644)	(0.04122)	(0.07210)
	[-0.45878]	[-2.26099]	[-1.99282]	[-0.91294]	[0.04710]	[-0.97969]	[1.84413]
D(DNKLFPUBST(-1))	0.800729	0.064124	1.186227	0.507100	0.201975	0.863510	-1.749147
	(1.79082)	(0.70328)	(2.21203)	(0.30445)	(2.55225)	(0.53558)	(0.93676)
	[0.44713]	[0.09118]	[0.53626]	[1.66563]	[0.07914]	[1.61228]	[-1.86723]
D(DNKLFPUBST(-2))	-2.414671	-0.760078	-1.488780	0.016440	-4.664783	-0.764958	0.250634
	(1.28193)	(0.50343)	(1.58345)	(0.21793)	(1.82698)	(0.38339)	(0.67056)
	[-1.88363]	[-1.50980]	[-0.94021]	[0.07544]	[-2.55327]	[-1.99526]	[0.37377]
D(DNKLGDP(-1))	0.038772	0.310662	-0.218627	0.021812	1.075221	-0.249968	0.160117
	(0.49931)	(0.19608)	(0.61675)	(0.08489)	(0.71161)	(0.14933)	(0.26118)
	[0.07765]	[1.58433]	[-0.35448]	[0.25696]	[1.51098]	[-1.67395]	[0.61305]
D(DNKLGDP(-2))	-0.772131	-0.041419	-0.145815	-0.030030	-0.859416	-0.323571	-0.176499
	(0.43317)	(0.17011)	(0.53506)	(0.07364)	(0.61735)	(0.12955)	(0.22659)
	[-1.78250]	[-0.24348]	[-0.27252]	[-0.40779]	[-1.39210]	[-2.49766]	[-0.77894]
D(LFBERDST(-1))	-0.201414	0.995626	-0.815537	-0.030040	0.652478	0.429039	0.294196
	(0.93416)	(0.36686)	(1.15388)	(0.15881)	(1.33135)	(0.27938)	(0.48865)
	[-0.21561]	[2.71395]	[-0.70678]	[-0.18915]	[0.49009]	[1.53568]	[0.60206]
D(LFBERDST(-2))	-0.529869	-0.250229	2.335750	-0.027062	0.453676	-0.106684	0.210834
	(1.03709)	(0.40728)	(1.28102)	(0.17631)	(1.47804)	(0.31016)	(0.54249)
	[-0.51092]	[-0.61439]	[1.82336]	[-0.15349]	[0.30694]	[-0.34396]	[0.38864]
D(DNKLPUBST(-1))	0.002515	0.046475	0.518859	0.011440	-0.293578	0.039878	0.361639
	(0.33655)	(0.13217)	(0.41571)	(0.05722)	(0.47965)	(0.10065)	(0.17605)
	[0.00747]	[0.35163]	[1.24812]	[0.19994]	[-0.61207]	[0.39619]	[2.05422]
D(DNKLPUBST(-2))	0.019067	-0.152857	-0.218256	-0.058707	0.316146	0.148007	0.360043
	(0.32731)	(0.12854)	(0.40429)	(0.05564)	(0.46647)	(0.09789)	(0.17121)
	[0.05825]	[-1.18920]	[-0.53985]	[-1.05504]	[0.67774]	[1.51200]	[2.10293]
C	0.089522	0.014128	0.046287	0.011320	0.124986	0.023934	0.014622
	(0.03445)	(0.01353)	(0.04255)	(0.00586)	(0.04909)	(0.01030)	(0.01802)

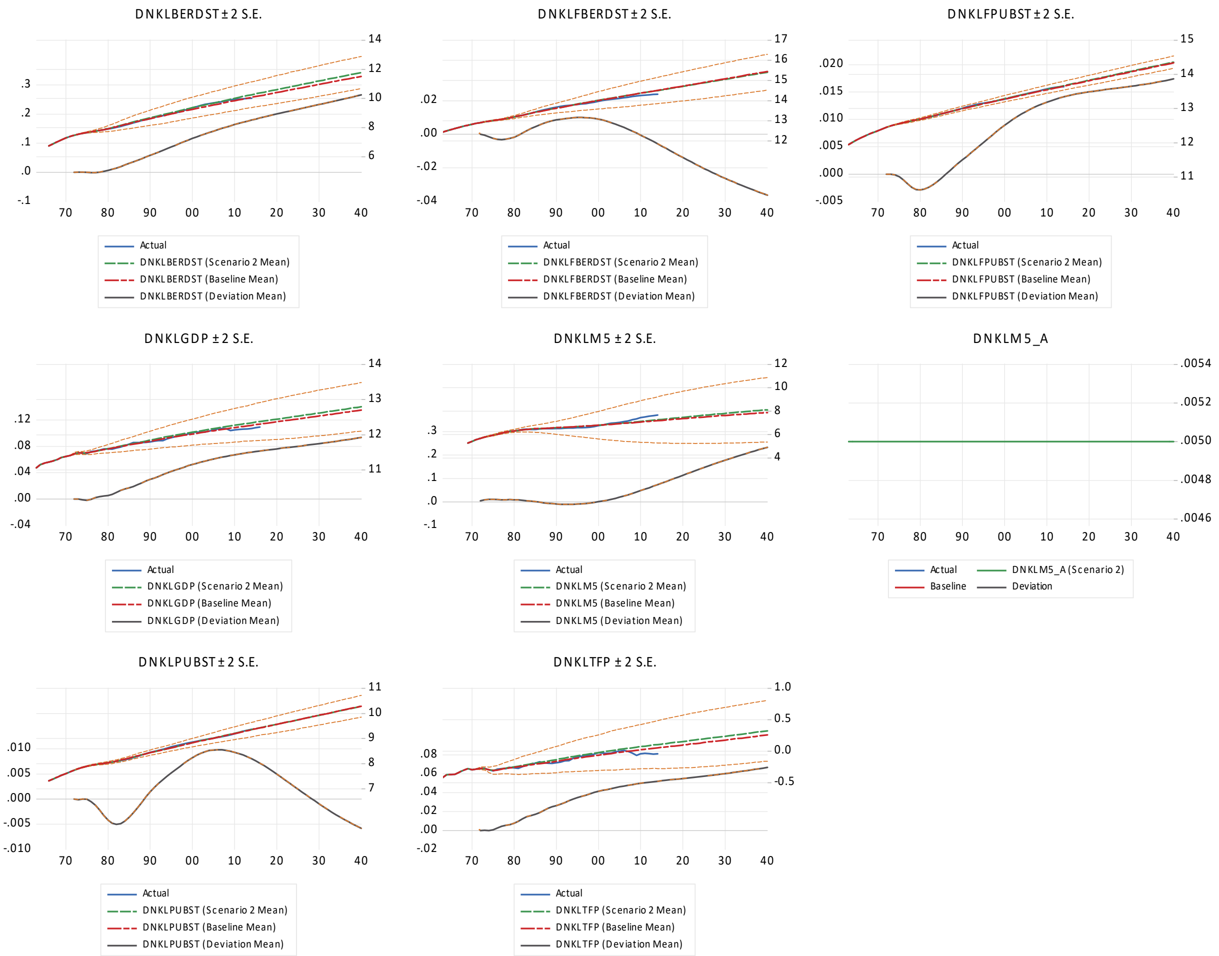
	[2.59883]	[1.04438]	[1.08786]	[1.93297]	[2.54590]	[2.32323]	[0.81150]
R-squared	0.748900	0.972335	0.918277	0.955520	0.690410	0.952919	0.847687
Adj. R-squared	0.541470	0.949480	0.850767	0.918775	0.434662	0.914025	0.721864
Sum sq. resids	0.002738	0.000422	0.004177	7.91E-05	0.005561	0.000245	0.000749
S.E. equation	0.010910	0.004285	0.013477	0.001855	0.015549	0.003263	0.005707
F-statistic	3.610374	42.54536	13.60203	26.00442	2.699573	24.50087	6.737106
Log likelihood	146.7141	186.9052	137.6308	222.9068	131.4791	198.6182	174.5782
Akaike AIC	-5.893680	-7.763034	-5.471202	-9.437526	-5.185075	-8.307824	-7.189683
Schwarz SC	-5.074518	-6.943871	-4.652039	-8.618363	-4.365912	-7.488662	-6.370520
Mean dependent	0.005663	0.061107	0.049204	0.028798	0.017945	0.033940	0.039262
S.D. dependent	0.016112	0.019063	0.034886	0.006508	0.020680	0.011128	0.010821

Determinant resid covariance (dof adj.)	6.11E-34
Determinant resid covariance	7.65E-36
Log likelihood	1310.836
Akaike information criterion	-52.59704
Schwarz criterion	-45.22458
Number of coefficients	180

The unit root variables have statistically significant coefficients and there is no need to renormalize.[13]

A shock to the mission variable *lm5* by 0.005, leads to the following baseline and shock results and their differences from 1000 repetitions using the multi-variate normal distribution assumption for the residuals.

[13] Coefficients of unit root variables may go to zero in case of parameter stability. Normalization to unity if the true value is zero means approximately division of other coefficients by zero, which could lead to very high coefficients. In this case other coefficients should be normalized to zero (Boswijk 1996).



The upper part, measured on the right axes, is the baseline scenario with the actual data and the shock scenario with confidence interval. The lower part, measured on the left axis, is the difference between baseline and shock scenario with shifts of the confidence interval of equal size as the baseline-shock shift so that they are invisibly lying on the deviation line as they differ only at digit 13. TFP and GDP, and the costs in terms of additional public and private R&D both increase above baseline for most periods. Numerical evaluation using as cost for the first period the shock size multiplied by the value of the mission variable for 1972, is shown in Table 2 and 3.

Appendix France

Unit roots are likely to be present in LGDP (p = 0.44), LFPUBST (p = 0.24), LTFP (p = 0.23), LM5 (p = 0.44). A VAR with all seven variables is not stable for any of the cases with lags 1 to 4. Taking out public R&D or GDP yields a stable VAR if there is only one lag. The model without PUBST has a much higher probability for normally distributed residuals and the model without GDP performs better on absence of heteroscedasticity. We have serial correlation in both implying from all these aspects, that caution is in order more than usually. Cointegration tests would suggest five cointegrating equations for the model without PUBST and four without GDP. In simulations of shock scenarios, models are almost identical. The model without GDP keeps public R&D as a cost and therefore we use it here.

Vector Error Correction Estimates

Sample (adjusted): 1970 2014
Included observations: 45 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:
A(2,2)=0, A(1,4)=0, A(1,1)=0,A(6,2)=0, B(1,1)=1, B(2,2)=1, B(3,3)=1, B(4,4)=1, B(1,3)=0,B(1,5)=0, B(1,6)=0, B(2,3)=0, B(2,4)=0, B(2,5)=0, B(3,1)=0, B(3,2)=0, B(3,5)=0, B(4,2)=0, B(4,3)=0, B(4,6)=0

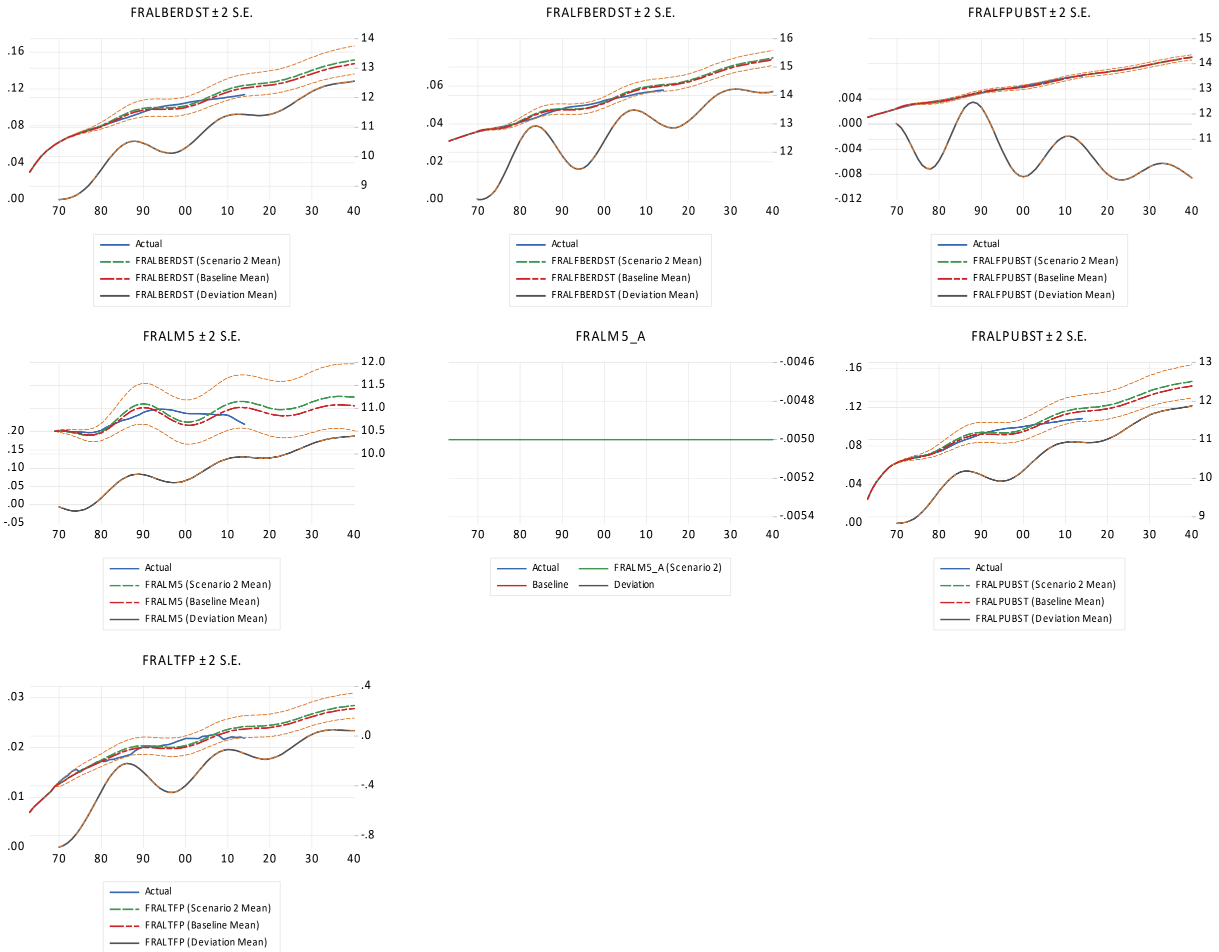
Convergence achieved after 77 iterations.
Restrictions identify all cointegrating vectors
LR test for binding restrictions (rank = 4):
Chi-square(4) 0.379620
Probability 0.984111

Cointegrating Eq:	CointEq1	CointEq2	CointEq3	CointEq4		
FRALTFP(-1)	1.000000	7.208503	0.000000	-5.050532		
		(0.42064)		(0.21719)		
		[17.1370]		[-23.2540]		
FRALBERDST(-1)	-0.220746	1.000000	0.000000	0.000000		
	(0.01293)					
	[-17.0697]					
FRALM5(-1)	0.000000	0.000000	1.000000	0.000000		
FRALFPUBST(-1)	-0.452419	0.000000	1.433633	1.000000		
	(0.04602)		(0.37849)			
	[-9.83109]		[3.78776]			
FRALFBERDST(-1)	0.000000	0.000000	0.000000	2.294895		
				(0.11198)		
				[20.4938]		
FRALPUBST(-1)	0.000000	-2.299376	-1.599775	0.000000		
		(0.14774)	(0.07384)			
		[-15.5639]	[-21.6642]			
@TREND(63)	0.013680	-0.020599	-0.002878	-0.079529		
	(0.00144)	(0.00400)	(0.01169)	(0.00408)		
	[9.47967]	[-5.14760]	[-0.24613]	[-19.5038]		
C	8.072872	15.49548	-11.40847	-42.12539		
Error Correction:	D(FRALTFP)	D(FRALBERDST)	D(FRALM5)	D(FRALFPUBST)	D(FRALFBERDST)	D(FRALPUBST)
CointEq1	0.000000	0.404842	0.442536	0.482989	0.478524	0.346774
	(0.00000)	(0.05654)	(0.21171)	(0.04466)	(0.08398)	(0.12672)
	[NA]	[7.15965]	[2.09028]	[10.8137]	[5.69776]	[2.73664]
CointEq2	-0.021780	0.000000	0.157621	0.013126	-0.055534	0.000000
	(0.00662)	(0.00000)	(0.01737)	(0.00668)	(0.01174)	(0.00000)
	[-3.28857]	[NA]	[9.07376]	[1.96480]	[-4.73150]	[NA]
CointEq3	-0.035997	-0.054780	-0.142289	0.055466	-0.098902	-0.076431
	(0.02079)	(0.00983)	(0.03596)	(0.00757)	(0.01457)	(0.02189)
	[-1.73158]	[-5.57320]	[-3.95712]	[7.32825]	[-6.79036]	[-3.49201]
CointEq4	0.000000	0.096276	0.228020	0.086300	-0.061497	0.043063
	(0.00000)	(0.00647)	(0.03215)	(0.00961)	(0.01715)	(0.01448)
	[NA]	[14.8690]	[7.09160]	[8.98423]	[-3.58665]	[2.97387]
C	0.008645	0.037678	0.003386	0.030043	0.033468	0.026584
	(0.00158)	(0.00061)	(0.00220)	(0.00046)	(0.00090)	(0.00136)
	[5.47495]	[61.6530]	[1.53604]	[65.3456]	[37.2532]	[19.5890]
R-squared	0.383354	0.953304	0.716002	0.844707	0.721680	0.622564
Adj. R-squared	0.321690	0.948634	0.687602	0.829178	0.693848	0.584820
Sum sq. resids	0.004488	0.000672	0.008747	0.000380	0.001453	0.003315

S.E. equation	0.010592	0.004100	0.014788	0.003084	0.006027	0.009104
F-statistic	6.216770	204.1510	25.21154	54.39436	25.92982	16.49454
Log likelihood	143.4422	186.1574	128.4265	198.9647	168.8187	150.2569
Akaike AIC	-6.152988	-8.051441	-5.485622	-8.620655	-7.280830	-6.455863
Schwarz SC	-5.952248	-7.850701	-5.284882	-8.419915	-7.080089	-6.255123
Mean dependent	0.008645	0.037678	0.003386	0.030043	0.033468	0.026584
S.D. dependent	0.012861	0.018088	0.026457	0.007462	0.010892	0.014128

Determinant resid covariance (dof adj.)	1.11E-27
Determinant resid covariance	5.49E-28
Log likelihood	1029.112
Akaike information criterion	-43.16052
Schwarz criterion	-40.83193
Number of coefficients	58

The model has some serial correlation and heteroscedasticity is absent with p = 0.11. The probability for normal residuals is only 0.01. Therefore, we use the bootstrap mechanism in simulations. A positive shock on mission R&D, *lm5*, let all variables fall, where *lm5* itself gets negative only after 10 years indicating that mission R&D is above its optimum. Therefore, we impose a *negative* shock of one standard deviation of the growth rate of lm5, -0.005. Mission R&D then is first going down, but after 10 years all domestic variables are increasing with some ups and downs. This is shown in the following graph. Perhaps this can be seen as a policy that finances itself through expenditure cuts on mission R&D in the beginning and increasing mission R&D later, perhaps in other mission areas. This is most plausible if mission R&D is higher than optimal and therefore should be reduced.



R&D costs and TFP are both increasing. The more detailed evaluation can be found in Table 2 and 3.

Appendix Germany

A VAR with three lags is unstable, but with two lags it is stable. With one lag, cointegration tests indicate six (seven) or 4 cointegrating equations at the five (six) percent significance levels in the trace and max-eigenvalue tests. We also pre-test using the ADF test with break point test. Univariate unit root tests yields result strongly dependent on the number of lags. Therefore, we re-run all unit root tests with one and two lags again, where one lag is used when following the SIC of the VAR showing two lags.

With only one lag, LGDP and LPUBST are stationary for additive and innovational outliers at the five percent level. I(1): LTFP; I(2): LFBERDST, LFPUBST, LM5, LBERDST. The I(1) model can also be used for I(2) variables (Juselius 2006, equation 16.5). The estimated VECM is as follows.

Vector Error Correction Estimates
Date: 10/17/19 Time: 15:33
Sample: 1972 2014
Included observations: 43
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:
A(2,3)=0, A(3,6)=0, A(3,1)=0, A(6,2)=0, A(7,3)=0, A(5,1)=0, A(2,1)=0, A(7,5)=0, A(5,6)=0, B(1,1)=1,B(1,3)=0, B(1,4)=0, B(1,5)=0, B(1,6)=0, B(1,7)=0, B(2,1)=0, B(2,2)=1, B(2,4)=0, B(2,5)=0, B(2,6)=0, B(2,7)=0, B(3,1)=0, B(3,2)=0, B(3,3)=1, B(3,5)=0, B(3,6)=0, B(3,7)=0, B(4,1)=0, B(4,2)=0, B(4,3)=0, B(4,4)=1, B(4,6)=0, B(4,7)=0, B(5,1)=0, B(5,2)=0, B(5,3)=0, B(5,7)=1, B(5,6)=0, B(5,4)=0, B(6,1)=0, B(6,2)=0, B(6,3)=0, B(6,4)=0, B(6,5)=0, B(6,7)=1,
Convergence achieved after 100 iterations.
Restrictions identify all cointegrating vectors
LR test for binding restrictions (rank = 6):

Chi-square(9)	3.159147
Probability	0.957649

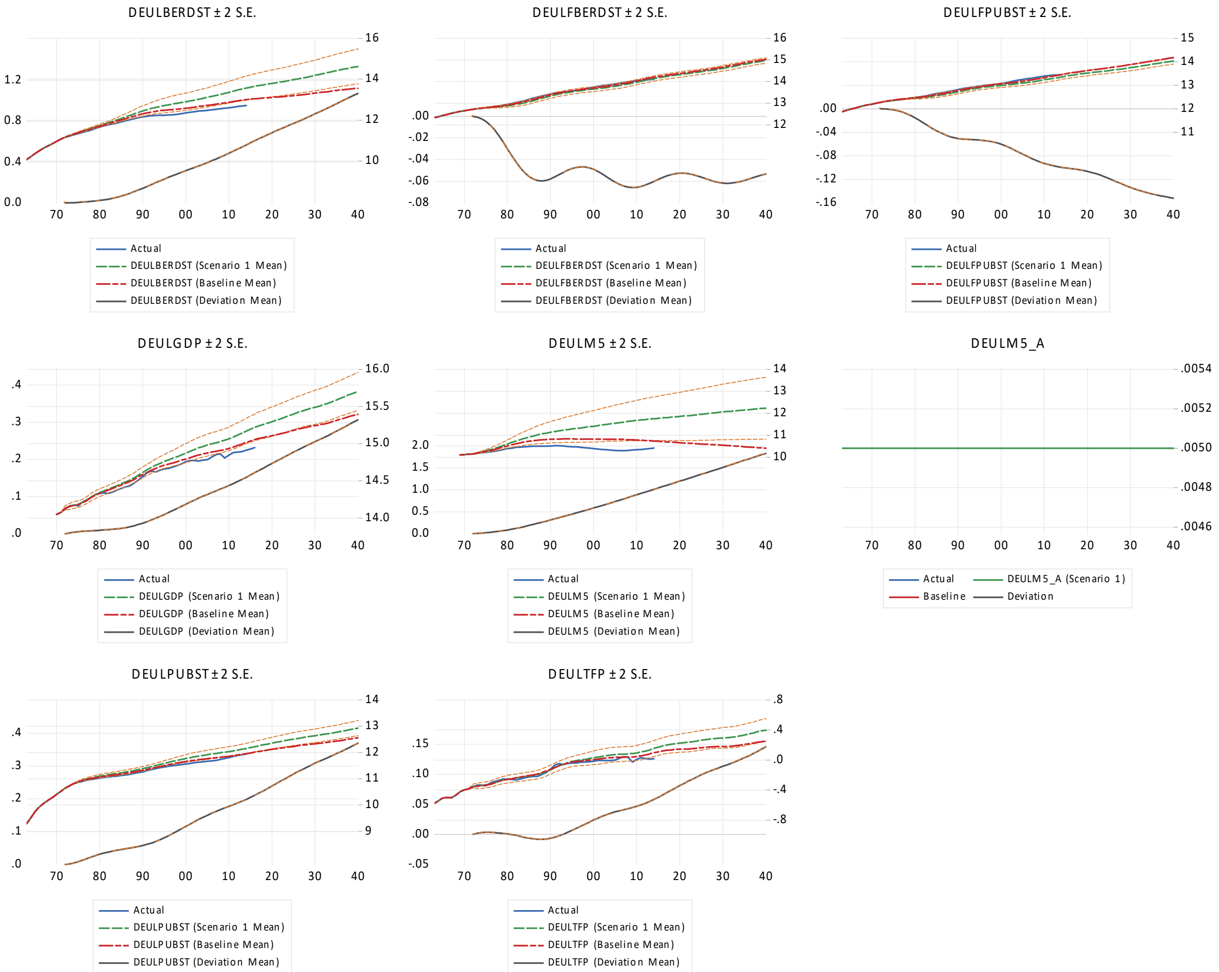
Cointegrating Eq:	CointEq1	CointEq2	CointEq3	CointEq4	CointEq5	CointEq6
DEULGDP(-1)	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000
DEULTFP(-1)	-1.783009	1.000000	0.000000	0.000000	0.000000	0.000000
	(0.01725)					
	[-103.347]					
DEULBERDST(-1)	0.000000	-0.172140	1.000000	0.000000	0.000000	0.000000
		(0.01334)				
		[-12.9072]				
DEULPUBST(-1)	0.000000	0.000000	-2.938550	1.000000	0.000000	0.000000
			(0.05990)			
			[-49.0590]			
DEULM5(-1)	0.000000	0.000000	0.000000	-0.209956	-0.005196	0.000000
				(0.00909)	(0.00104)	
				[-23.0922]	[-5.01656]	
DEULFPUBST(-1)	0.000000	0.000000	0.000000	0.000000	0.000000	0.076411
						(0.00490)
						[15.5860]
DEULFBERDST(-1)	0.000000	0.000000	0.000000	0.000000	1.000000	1.000000
@TREND(63)	-0.004629	-0.001590	0.044164	-0.025099	-0.031966	-0.034028
	(0.00062)	(0.00081)	(0.00210)	(0.00051)	(0.00055)	(0.00059)
	[-7.42253]	[-1.97521]	[21.0245]	[-49.2229]	[-58.4671]	[-57.5226]
C	-14.64058	2.251450	19.89050	-8.391066	-12.41564	-13.39040

Error Correction:	D(DEULGDP)	D(DEULTFP)	D(DEULBERDST)	D(DEULPUBST)	D(DEULM5)	D(DEULFPUBST)	D(DEULFBERDST)
CointEq1	-0.957463	0.000000	0.000000	0.616992	0.000000	-0.026394	-0.132110

	(0.13516)	(0.00000)	(0.00000)	(0.14110)	(0.00000)	(0.01812)	(0.08034)
	[-7.08380]	[NA]	[NA]	[4.37288]	[NA]	[-1.45704]	[-1.64432]
CointEq2	-1.352557	-0.483347	-0.078569	0.576747	-0.078159	0.000000	-0.116903
	(0.18015)	(0.12170)	(0.04942)	(0.12878)	(0.06336)	(0.00000)	(0.07205)
	[-7.50787]	[-3.97151]	[-1.58984]	[4.47860]	[-1.23365]	[NA]	[-1.62244]
CointEq3	-0.053804	0.000000	-0.201252	-0.235134	0.337647	0.071096	0.000000
	(0.04377)	(0.00000)	(0.07520)	(0.04470)	(0.09650)	(0.02927)	(0.00000)
	[-1.22927]	[NA]	[-2.67615]	[-5.25970]	[3.49904]	[2.42923]	[NA]
CointEq4	-0.278287	-0.223098	-0.524410	-0.901790	1.052191	0.195073	-0.046886
	(0.19547)	(0.13736)	(0.21174)	(0.12905)	(0.27168)	(0.07999)	(0.03386)
	[-1.42366]	[-1.62420]	[-2.47664]	[-6.98801]	[3.87289]	[2.43876]	[-1.38467]
CointEq5	18.31446	13.07124	0.112789	-7.850356	-0.401413	2.970773	0.000000
	(5.08237)	(4.54311)	(0.08979)	(1.78137)	(0.11517)	(0.73377)	(0.00000)
	[3.60353]	[2.87716]	[1.25608]	[-4.40693]	[-3.48525]	[4.04866]	[NA]
CointEq6	-17.40557	-12.27869	0.000000	7.933063	0.000000	-2.940821	-0.104171
	(4.86727)	(4.34067)	(0.00000)	(1.73997)	(0.00000)	(0.71801)	(0.02618)
	[-3.57604]	[-2.82876]	[NA]	[4.55932]	[NA]	[-4.09577]	[-3.97843]
D(DEULGDP(-1))	1.192140	0.323689	0.427497	-0.094703	0.621086	0.065673	0.277751
	(0.77581)	(0.70229)	(0.29174)	(0.16997)	(0.37645)	(0.09662)	(0.15367)
	[1.53664]	[0.46091]	[1.46536]	[-0.55719]	[1.64983]	[0.67968]	[1.80747]
D(DEULTFP(-1))	-0.765389	0.044144	-0.325673	0.138986	-0.540772	-0.094476	-0.238539
	(0.77148)	(0.69837)	(0.29011)	(0.16902)	(0.37435)	(0.09608)	(0.15281)
	[-0.99210]	[0.06321]	[-1.12259]	[0.82232]	[-1.44455]	[-0.98327]	[-1.56101]
D(DEULBERDST(-1))	0.051721	-0.175393	0.576951	0.149731	0.010266	-0.050464	-0.026419
	(0.46454)	(0.42051)	(0.17468)	(0.10177)	(0.22541)	(0.05786)	(0.09201)
	[0.11134]	[-0.41709]	[3.30282]	[1.47125]	[0.04554]	[-0.87224]	[-0.28712]
D(DEULPUBST(-1))	-0.564881	-0.709791	-0.243551	0.008647	0.608269	0.062306	-0.143656
	(0.52525)	(0.47547)	(0.19752)	(0.11507)	(0.25487)	(0.06542)	(0.10404)
	[-1.07545]	[-1.49281]	[-1.23307]	[0.07515]	[2.38656]	[0.95245]	[-1.38080]
D(DEULM5(-1))	0.469071	0.450920	0.101782	0.143403	0.353641	0.016811	-0.150400
	(0.40115)	(0.36313)	(0.15085)	(0.08788)	(0.19465)	(0.04996)	(0.07946)
	[1.16932]	[1.24176]	[0.67473]	[1.63173]	[1.81678]	[0.33649]	[-1.89285]
D(DEULFPUBST(-1))	0.196507	0.232161	0.540262	0.212258	-0.065324	0.734195	0.213707
	(0.95947)	(0.86854)	(0.36080)	(0.21020)	(0.46557)	(0.11950)	(0.19005)
	[0.20481]	[0.26730]	[1.49740]	[1.00978]	[-0.14031]	[6.14406]	[1.12450]
D(DEULFBERDST(-1))	-2.052890	-2.051863	-0.013279	-0.378217	-0.049714	0.078052	0.757915
	(0.68521)	(0.62027)	(0.25767)	(0.15012)	(0.33249)	(0.08534)	(0.13572)
	[-2.99602]	[-3.30802]	[-0.05153]	[-2.51950]	[-0.14952]	[0.91462]	[5.58434]
C	0.081085	0.093663	0.002514	0.032868	-0.021119	0.003660	0.005412
	(0.04720)	(0.04273)	(0.01775)	(0.01034)	(0.02290)	(0.00588)	(0.00935)
	[1.71780]	[2.19202]	[0.14162]	[3.17835]	[-0.92203]	[0.62264]	[0.57889]
R-squared	0.545607	0.559814	0.934764	0.977321	0.878110	0.936047	0.937705
Adj. R-squared	0.341913	0.362489	0.905520	0.967154	0.823470	0.907378	0.909780
Sum sq. resids	0.007829	0.006415	0.001107	0.000376	0.001843	0.000121	0.000307
S.E. equation	0.016430	0.014873	0.006178	0.003600	0.007973	0.002046	0.003254
F-statistic	2.678565	2.837014	31.96460	96.13108	16.07072	32.65056	33.57927
Log likelihood	124.1261	128.4074	166.1826	189.4135	155.2199	213.6991	193.7481
Akaike AIC	-5.122142	-5.321273	-7.078260	-8.158767	-6.568368	-9.288332	-8.360375

Schwarz SC	-4.548728	-4.747859	-6.504846	-7.585353	-5.994954	-8.714918	-7.786961
Mean dependent	0.019416	0.009361	0.038191	0.033032	0.006502	0.028096	0.033038
S.D. dependent	0.020253	0.018628	0.020100	0.019861	0.018975	0.006724	0.010835
Determinant resid covariance (dof adj.)		3.82E-34					
Determinant resid covariance		2.42E-35					
Log likelihood		1285.172					
Akaike information criterion		-52.98475					
Schwarz criterion		-47.00486					
Number of coefficients		146					

Heteroscedasticity is absent with p = 0.11 and there is some serial correlation. Residuals are normal only with p = 0.01 and therefore we use the bootstrap mechanism in the simulation of a shock on lm5 with size 0.005.



In the period under consideration, 70 years, mission R&D increases by a factor 1.8 through a shock of 0.5 percent, which is a bit less than one standard deviation of the growth rate of mission R&D. Public R&D increases beyond baseline by almost 36%. Private R&D increases by almost 105% from baseline. TFP increases by 14% and GDP by 30% from baseline. Foreign private and public R&D are both reduced. Numerical evaluation is shown in Table 2 and 3.

Appendix Italy

The log of mission R&D has no unit root. We have two more (near) unit root variables, for log(GDP) and log(TFP). A VAR of all seven variables is stable only with two lags. The cointegration tests suggest 6 or 5 cointegrating equations at the 7% level. Five matches with the number of two unit-root variables and the advice of Hjalmarsson and Österholm (2010) to use the lower number of the two standard tests. The VECM with five cointegrating equations is as follows.

Vector Error Correction Estimates

Sample (adjusted): 1971 2014
Included observations: 44 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:
A(6,5)=0, A(6,1)=0, B(1,1)=1, B(1,3)=0, B(1,7)=0, B(1,5)=0, B(1,6)=0, B(2,6)=0, B(2,3)=1, B(2,4)=0, B(2,1)=0, B(2,5)=0, B(3,4)=0,B(3,2)=1, B(3,3)=0, B(3,5)=0, B(3,6)=0,B(4,2)=0, B(4,3)=0, B(4,4)=1,B(4,5)=0, B(4,7)=0, B(5,2)=0, B(5,7)=0, B(5,4)=0,B(5,5)=1, B(5,6)=0,
Convergence achieved after 487 iterations.
Restrictions identify all cointegrating vectors
LR test for binding restrictions (rank = 5):
Chi-square(2) 0.365669
Probability 0.832906

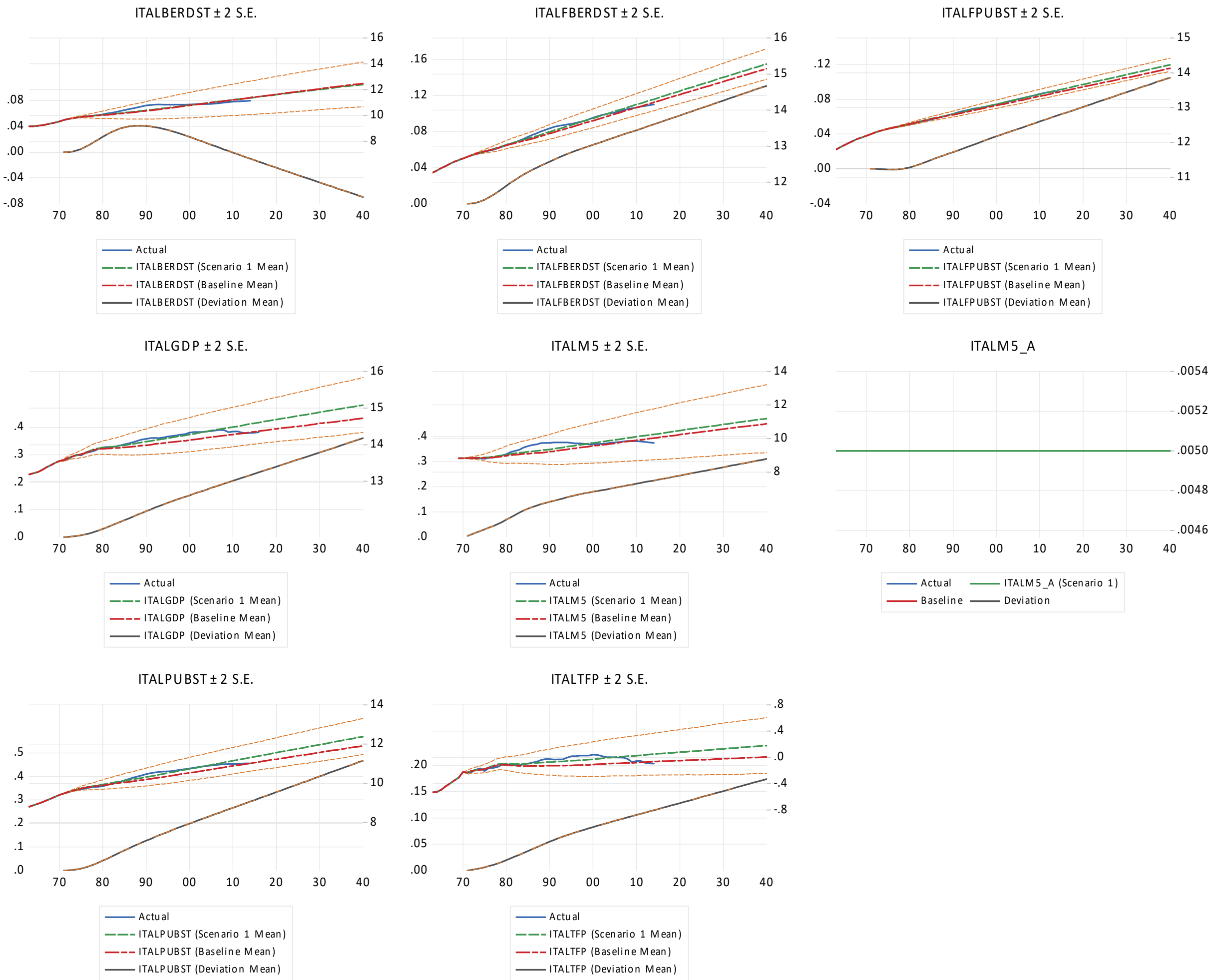
Cointegrating Eq:	CointEq1	CointEq2	CointEq3	CointEq4	CointEq5
ITALTFP(-1)	1.000000	0.000000	-12.22296	-1.989945	-2.550176
			(0.83351)	(0.09776)	(0.09380)
			[-14.6645]	[-20.3560]	[-27.1883]
ITALBERDST(-1)	-0.187399	-0.895326	1.000000	0.000000	0.000000
	(0.02646)	(0.11586)			
	[-7.08289]	[-7.72778]			
ITALM5(-1)	0.000000	1.000000	0.000000	0.000000	0.196205
					(0.01776)
					[11.0454]
ITALFPUBST(-1)	-1.612869	0.000000	0.000000	1.000000	0.000000
	(0.25947)				
	[-6.21594]				
ITALGDP(-1)	0.000000	0.000000	0.000000	0.000000	1.000000
ITALFBERDST(-1)	0.000000	0.000000	0.000000	1.743970	0.000000
				(0.08146)	
				[21.4088]	
ITALPUBST(-1)	0.000000	-0.798548	4.520198	0.000000	0.000000
		(0.22177)	(0.30420)		
		[-3.60073]	[14.8595]		
@TREND(63)	0.048085	0.032383	-0.163953	-0.083841	-0.014189
	(0.00677)	(0.00564)	(0.01121)	(0.00285)	(0.00066)
	[7.10303]	[5.74471]	[-14.6319]	[-29.3854]	[-21.3907]
C	21.35756	7.286139	-53.43182	-33.99818	-15.71265

Error Correction:	D(ITALTFP)	D(LBERDST)	D(LM5)	D(LFPUBST)	D(LGDP)	D(LFBERDST)	D(ITALPUBST)
CointEq1	0.314584	0.285546	1.436424	0.092361	0.490828	0.000000	0.303904

	(0.23042)	(0.10922)	(0.30432)	(0.03439)	(0.29530)	(0.00000)	(0.14660)
	[1.36525]	[2.61448]	[4.72018]	[2.68589]	[1.66215]	[NA]	[2.07303]
CointEq2	0.164308	0.064182	-0.155927	-0.020286	0.164661	0.042955	0.090400
	(0.06661)	(0.02783)	(0.08421)	(0.00847)	(0.08518)	(0.01186)	(0.03997)
	[2.46656]	[2.30648]	[-1.85170]	[-2.39489]	[1.93306]	[3.62126]	[2.26176]
CointEq3	0.178251	-0.019867	-0.079997	0.008697	0.213612	0.053217	-0.034938
	(0.05450)	(0.02213)	(0.06828)	(0.00668)	(0.06966)	(0.01059)	(0.03231)
	[3.27094]	[-0.89767]	[-1.17153]	[1.30287]	[3.06670]	[5.02591]	[-1.08142]
CointEq4	-0.321384	0.117477	0.694325	-0.068436	-0.482543	-0.344919	0.644434
	(0.38838)	(0.16350)	(0.49217)	(0.04989)	(0.49669)	(0.06726)	(0.23382)
	[-0.82750]	[0.71852]	[1.41074]	[-1.37177]	[-0.97152]	[-5.12844]	[2.75617]
CointEq5	-0.404077	0.261381	1.013027	0.060424	-0.468713	0.000000	-0.279640
	(0.20795)	(0.09857)	(0.27464)	(0.03103)	(0.26650)	(0.00000)	(0.13230)
	[-1.94310]	[2.65179]	[3.68853]	[1.94698]	[-1.75875]	[NA]	[-2.11360]
D(ITALTFP(-1))	-0.368931	-0.175372	-0.369943	0.085611	-0.614891	-0.095497	-0.282349
	(0.27076)	(0.10883)	(0.33821)	(0.03271)	(0.34603)	(0.05407)	(0.15983)
	[-1.36256]	[-1.61139]	[-1.09382]	[2.61711]	[-1.77697]	[-1.76604]	[-1.76652]
D(LBERDST(-1))	-0.199239	0.382841	-0.706180	0.032931	0.225004	0.073326	-0.049250
	(0.39160)	(0.15741)	(0.48916)	(0.04731)	(0.50047)	(0.07821)	(0.23117)
	[-0.50878]	[2.43220]	[-1.44367]	[0.69606]	[0.44959]	[0.93758]	[-0.21305]
D(ITALM5(-1))	0.165993	-0.096232	0.240818	-0.013074	0.145244	0.011389	0.100156
	(0.15528)	(0.06241)	(0.19396)	(0.01876)	(0.19844)	(0.03101)	(0.09166)
	[1.06901]	[-1.54185]	[1.24160]	[-0.69690]	[0.73191]	[0.36725]	[1.09267]
D(LFPUBST(-1))	-0.396364	-0.618506	-2.096088	0.983581	-0.344911	0.259332	-1.730569
	(1.08934)	(0.43786)	(1.36071)	(0.13161)	(1.39218)	(0.21755)	(0.64305)
	[-0.36386]	[-1.41256]	[-1.54044]	[7.47357]	[-0.24775]	[1.19203]	[-2.69119]
D(ITALGDP(-1))	0.287123	0.314964	0.563211	-0.100451	0.613348	0.104498	0.264936
	(0.27276)	(0.10964)	(0.34071)	(0.03295)	(0.34859)	(0.05447)	(0.16101)
	[1.05265]	[2.87279]	[1.65305]	[-3.04827]	[1.75951]	[1.91831]	[1.64542]
D(LFBERDST(-1))	0.564321	0.192746	-0.111995	0.107930	-0.016900	0.714850	0.323143
	(0.65421)	(0.26296)	(0.81718)	(0.07904)	(0.83608)	(0.13065)	(0.38619)
	[0.86260]	[0.73299]	[-0.13705]	[1.36554]	[-0.02021]	[5.47135]	[0.83675]
D(LPUBST(-1))	-0.527160	-0.136036	-0.413775	-0.022302	-0.536472	-0.029141	0.247676
	(0.35954)	(0.14452)	(0.44910)	(0.04344)	(0.45949)	(0.07180)	(0.21224)
	[-1.46622]	[-0.94133]	[-0.92135]	[-0.51343]	[-1.16755]	[-0.40584]	[1.16698]
C	0.016175	0.035979	0.116619	-0.002723	0.028953	-0.001927	0.063757
	(0.04639)	(0.01865)	(0.05794)	(0.00560)	(0.05928)	(0.00926)	(0.02738)
	[0.34869]	[1.92967]	[2.01266]	[-0.48586]	[0.48838]	[-0.20805]	[2.32836]
R-squared	0.509455	0.962559	0.831159	0.945392	0.501834	0.934635	0.865643
Adj. R-squared	0.319566	0.948065	0.765801	0.924253	0.308995	0.909332	0.813634
Sum sq. resids	0.007364	0.001190	0.011490	0.000107	0.012028	0.000294	0.002566
S.E. equation	0.015413	0.006195	0.019253	0.001862	0.019698	0.003078	0.009098
F-statistic	2.682913	66.41354	12.71706	44.72333	2.602352	36.93824	16.64409
Log likelihood	128.8630	168.9658	119.0761	221.8571	118.0700	199.7417	152.0558
Akaike AIC	-5.266498	-7.089355	-4.821639	-9.493506	-4.775908	-8.488261	-6.320716
Schwarz SC	-4.739351	-6.562208	-4.294492	-8.966359	-4.248761	-7.961114	-5.793569
Mean dependent	0.002944	0.036527	0.020916	0.029040	0.017405	0.033971	0.036682

S.D. dependent	0.018685	0.027185	0.039783	0.006766	0.023696	0.010223	0.021076
Determinant resid covariance (dof adj.)	1.52E-32						
Determinant resid covariance	1.31E-33						
Log likelihood	1228.545						
Akaike information criterion	-49.88842						
Schwarz criterion	-44.57640						
Number of coefficients	131						

Heteroscedasticity is absent with p = 0.31; serial correlation is absent at the five percent level. The percentage shock we impose on the mission variable is 0.005. For the simulations we use the bootstrap mechanism although we have multi-variate-normal residuals with p = 0.34, but there is some skewness. The result is as follows.



The mission R&D *lm5* moves upward, first strongly then more slowly, a change that is driven by the BERDST data. Public R&D also moves up. Private R&D goes up and away from baseline for 15 years, then back to baseline after 35 years and then falls below it. The increase of TFP is about 17% above baseline and that of GDP 14%. The more detailed numerical evaluation is found in Table 2 and 3.

Appendix Netherlands

The stock of mission-oriented R&D from five categories goes from 38% to 11% of public R&D stocks in the Netherlands in the period 1969-2014 (see Figure 1). A VAR with seven variables is stable with three lags but not with two lags. The probability for a normal distribution of the residuals is 0.85 percent. Serial correlation can be rejected at the 5 % level for all lags. The null for having no heteroscedasticity has a p-value of 28.6% and therefore is not rejected. Cointegration tests suggest seven long-term relations from the trace test and five from the maximum eigenvalue test. Hjalmarsson and Österholm (2010) suggest rejecting 'at most five' only if both tests reject it, which would lead to five CEs here, which is in line with having two (near) unit roots, in public domestic and foreign private R&D. The VECM with five cointegrating equations is as follows.

Vector Error Correction Estimates

Sample (adjusted): 1972 2014
Included observations: 43 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:
A(2,5)=0,A(5,4)=0, A(5,2)=0,A(1,4)=0,A(5,5)=0, A(2,2)=0,A(6,4)=0,A(7,2)=0, A(6,2)=0, A(1,1)=0,B(1,1)=1, B(1,3)=0, B(1,7)=0, B(1,5)=0, B(1,4)=0, B(2,6)=0, B(2,3)=1, B(2,2)=0, B(2,1)=0,B(2,5)=0, B(3,4)=0,B(3,2)=1, B(3,3)=0, B(3,5)=0, B(3,6)=0,B(4,2)=0, B(4,3)=0, B(4,4)=1,B(4,5)=0, B(4,1)=0, B(4,7)=0,B(5,2)=0, B(5,7)=0, B(5,4)=0,B(5,5)=1, B(5,6)=0,
Convergence achieved after 467 iterations.
Restrictions identify all cointegrating vectors
LR test for binding restrictions (rank = 5):
Chi-square(11) 2.076908
Probability 0.998207

Cointegrating Eq:	CointEq1	CointEq2	CointEq3	CointEq4	CointEq5
LTFP(-1)	1.000000	0.000000	-0.451851 (0.06110) [-7.39468]	0.000000	-1.917238 (0.05287) [-36.2604]
LBERDST(-1)	-1.032450 (0.02625) [-39.3251]	0.000000	1.000000	0.000000	0.000000
LM5(-1)	0.000000	1.000000	0.000000	0.000000	0.257146 (0.04111) [6.25508]
LFPUBST(-1)	0.000000	-0.722020 (0.13791) [-5.23553]	0.000000	1.000000	0.000000
LGDP(-1)	0.000000	0.000000	0.000000	0.000000	1.000000
LFBERDST(-1)	0.307147 (0.02274) [13.5094]	0.000000	0.000000	-0.158189 (0.01564) [-10.1163]	0.000000
LPUBST(-1)	0.000000	-0.449697 (0.06107) [-7.36370]	-0.649174 (0.04883) [-13.2958]	0.000000	0.000000
@TREND(63)	0.037935 (0.00499) [7.60655]	0.009687 (0.00610) [1.58690]	-0.032790 (0.00462) [-7.08995]	-0.011335 (0.00216) [-5.23594]	-0.008284 (0.00058) [-14.3234]

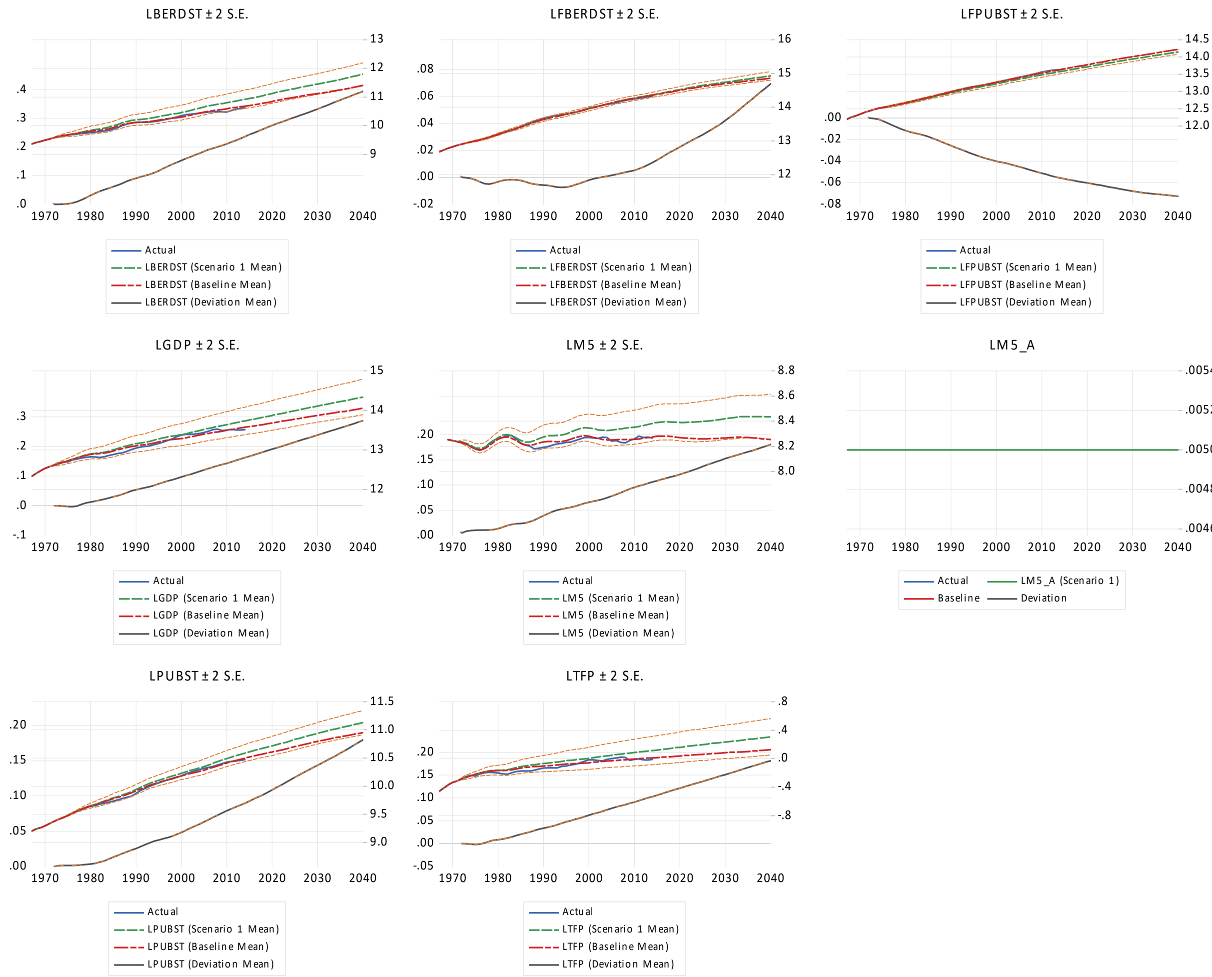
C	5.211217	5.356112	-2.708288	-10.53251	-15.19555		
Error Correction:	D(LTFP)	D(LBERDST)	D(LM5)	D(LFPUBST)	D(LGDP)	D(LFBERDST)	D(LPUBST)
CointEq1	0.000000	1.658419	-0.715173	-0.116808	0.191207	-0.186852	0.987613
	(0.00000)	(0.68882)	(0.70548)	(0.10327)	(0.19691)	(0.06580)	(0.30409)
	[NA]	[2.40762]	[-1.01374]	[-1.13105]	[0.97102]	[-2.83963]	[3.24780]
CointEq2	-0.083518	0.000000	-0.953010	-0.142188	0.000000	0.000000	0.000000
	(0.04419)	(0.00000)	(0.22142)	(0.01578)	(0.00000)	(0.00000)	(0.00000)
	[-1.88994]	[NA]	[-4.30417]	[-9.01316]	[NA]	[NA]	[NA]
CointEq3	0.118542	1.082927	-0.706915	-0.139124	0.239380	-0.198517	0.920391
	(0.04014)	(0.51325)	(0.55057)	(0.08048)	(0.21421)	(0.07348)	(0.23978)
	[2.95349]	[2.10992]	[-1.28398]	[-1.72869]	[1.11753]	[-2.70155]	[3.83854]
CointEq4	0.000000	-1.627664	-1.673091	-0.298226	0.000000	0.000000	-0.382017
	(0.00000)	(0.55583)	(0.74607)	(0.08801)	(0.00000)	(0.00000)	(0.22931)
	[NA]	[-2.92834]	[-2.24254]	[-3.38838]	[NA]	[NA]	[-1.66593]
CointEq5	0.326943	0.000000	0.336625	0.069905	0.000000	-0.145927	0.135775
	(0.06116)	(0.00000)	(0.21553)	(0.02336)	(0.00000)	(0.04460)	(0.07747)
	[5.34567]	[NA]	[1.56182]	[2.99211]	[NA]	[-3.27214]	[1.75254]
D(LTFP(-1))	0.283743	-0.804427	0.798118	0.175629	-0.211699	-0.134659	0.089235
	(0.69593)	(0.57913)	(0.56145)	(0.09088)	(0.98578)	(0.18020)	(0.23242)
	[0.40772]	[-1.38903]	[1.42153]	[1.93258]	[-0.21475]	[-0.74729]	[0.38395]
D(LTFP(-2))	0.512834	-0.672784	0.266014	0.219882	0.337655	-0.023222	-0.079447
	(0.71721)	(0.59684)	(0.57862)	(0.09366)	(1.01592)	(0.18571)	(0.23952)
	[0.71504]	[-1.12725]	[0.45974]	[2.34774]	[0.33236]	[-0.12505]	[-0.33169]
D(LBERDST(-1))	0.310032	1.014510	-0.348359	-0.046872	0.461198	0.093598	-0.112063
	(0.23280)	(0.19372)	(0.18781)	(0.03040)	(0.32975)	(0.06028)	(0.07775)
	[1.33178]	[5.23688]	[-1.85484]	[-1.54185]	[1.39863]	[1.55279]	[-1.44142]
D(LBERDST(-2))	-0.075743	0.192070	0.183278	-0.023643	0.068360	-0.023102	0.022901
	(0.34191)	(0.28453)	(0.27584)	(0.04465)	(0.48431)	(0.08853)	(0.11419)
	[-0.22153]	[0.67505]	[0.66443]	[-0.52953]	[0.14115]	[-0.26095]	[0.20055]
D(LM5(-1))	-0.084844	0.005879	0.552379	0.038354	-0.009260	-0.014921	0.148274
	(0.24206)	(0.20143)	(0.19528)	(0.03161)	(0.34287)	(0.06268)	(0.08084)
	[-0.35051]	[0.02919]	[2.82862]	[1.21340]	[-0.02701]	[-0.23807]	[1.83422]
D(LM5(-2))	-0.107856	0.063422	0.240933	0.030784	-0.064155	0.081604	-0.053712
	(0.22333)	(0.18584)	(0.18017)	(0.02916)	(0.31634)	(0.05783)	(0.07458)
	[-0.48295]	[0.34127]	[1.33725]	[1.05558]	[-0.20281]	[1.41122]	[-0.72017]
D(LFPUBST(-1))	1.494794	-0.013023	-0.733569	0.640380	2.525926	1.065467	-0.105121
	(1.57608)	(1.31156)	(1.27152)	(0.20581)	(2.23249)	(0.40809)	(0.52635)
	[0.94843]	[-0.00993]	[-0.57692]	[3.11149]	[1.13144]	[2.61086]	[-0.19972]
D(LFPUBST(-2))	-1.946076	1.256937	1.084484	-0.007545	-2.314999	-0.870112	0.092283
	(1.85617)	(1.54464)	(1.49749)	(0.24239)	(2.62923)	(0.48061)	(0.61989)
	[-1.04844]	[0.81374]	[0.72420]	[-0.03113]	[-0.88048]	[-1.81041]	[0.14887]
D(LGDP(-1))	-0.053842	0.066975	-0.658575	-0.005092	0.424716	0.249167	-0.394532
	(0.59946)	(0.49885)	(0.48362)	(0.07828)	(0.84913)	(0.15522)	(0.20020)
	[-0.08982]	[0.13426]	[-1.36175]	[-0.06505]	[0.50018]	[1.60527]	[-1.97071]

D(LGDP(-2))	-0.726262	0.044995	-0.037308	-0.126178	-0.692484	-0.028405	0.152165
	(0.60079)	(0.49996)	(0.48470)	(0.07845)	(0.85101)	(0.15556)	(0.20064)
	[-1.20884]	[0.09000]	[-0.07697]	[-1.60830]	[-0.81372]	[-0.18260]	[0.75839]
D(LFBERDST(-1))	-0.498661	-1.568201	1.535304	-0.017758	-0.958953	0.357371	-0.291420
	(1.09844)	(0.91408)	(0.88618)	(0.14344)	(1.55593)	(0.28442)	(0.36684)
	[-0.45397]	[-1.71560]	[1.73249]	[-0.12380]	[-0.61632]	[1.25650]	[-0.79441]
D(LFBERDST(-1))	-0.045493	-1.373584	-0.700479	0.471702	-0.623533	0.200500	-1.047209
	(1.57146)	(1.30771)	(1.26779)	(0.20521)	(2.22594)	(0.40689)	(0.52481)
	[-0.02895]	[-1.05037]	[-0.55252]	[2.29865]	[-0.28012]	[0.49276]	[-1.99541]
D(LPUBST(-1))	0.242309	0.158507	-0.513514	-0.045846	0.289954	-0.132933	0.310692
	(0.42823)	(0.35635)	(0.34548)	(0.05592)	(0.60657)	(0.11088)	(0.14301)
	[0.56585]	[0.44480]	[-1.48639]	[-0.81985]	[0.47802]	[-1.19890]	[2.17250]
D(LPUBST(-2))	-0.330742	0.139261	-0.171988	-0.120858	-0.375998	-0.247659	-0.146897
	(0.46973)	(0.39089)	(0.37896)	(0.06134)	(0.66536)	(0.12163)	(0.15687)
	[-0.70411]	[0.35626]	[-0.45384]	[-1.97032]	[-0.56510]	[-2.03623]	[-0.93641]
C	0.049875	0.059509	-0.009010	0.000488	0.067166	0.014267	0.076638
	(0.04389)	(0.03652)	(0.03541)	(0.00573)	(0.06217)	(0.01136)	(0.01466)
	[1.13638]	[1.62935]	[-0.25446]	[0.08516]	[1.08038]	[1.25545]	[5.22860]
R-squared	0.521655	0.761307	0.755263	0.964033	0.506949	0.952104	0.895216
Adj. R-squared	0.126501	0.564125	0.553089	0.934322	0.099646	0.912537	0.808656
Sum sq. resids	0.003636	0.002518	0.002366	6.20E-05	0.007294	0.000244	0.000405
S.E. equation	0.012572	0.010462	0.010143	0.001642	0.017809	0.003255	0.004199
F-statistic	1.320129	3.860945	3.735710	32.44646	1.244649	24.06331	10.34208
Log likelihood	140.6170	148.5172	149.8502	228.1536	125.6454	198.7188	187.7762
Akaike AIC	-5.610094	-5.977545	-6.039546	-9.681564	-4.913739	-8.312501	-7.803546
Schwarz SC	-4.790931	-5.158382	-5.220384	-8.862401	-4.094576	-7.493338	-6.984383
Mean dependent	0.007032	0.025470	0.000668	0.028820	0.021781	0.033944	0.026405
S.D. dependent	0.013452	0.015847	0.015172	0.006406	0.018768	0.011007	0.009599

Determinant resid covariance (dof adj.)	2.61E-34
Determinant resid covariance	3.27E-36
Log likelihood	1328.706
Akaike information criterion	-53.42817
Schwarz criterion	-46.05570
Number of coefficients	180

The adjusted R-squared values are low for the GDP and TFP equations. Taking out the GDP equation brings the adj. R-square much higher for the TFP equation. However, the system becomes unstable then for lags 1 to 4. Therefore, we leave the GDP variable in the system. Heteroscedasticity is zero with p = 0.33. There is some serial correlation.

For the simulations we use the bootstrap mechanism, because the probability for a normal distribution in the VECM is rather low, p = 0.01. The shock size is 0.005, a half percentage point on the intercept of the equation for mission variable, *lm5*, shown in the middle-right graph. The baseline and shock scenario and their comparison are as follows.



The mission variable increases by about 18%% through all the feedback mechanisms. Public R&D increases by a bit less than 18 percent. Business R&D increases by 39%, TFP by 18 percent and GDP by 29 percent. These are strong reactions, but the costs may increase more than the benefits. Missions shift R&D expenditure stocks from public to private. The evaluation regarding internal rates of return and other criteria can be found in Tables 2 and 3 of the main text.

Appendix UK

There are (near) unit roots for LPUBST, LGDP, LTFP. However, they all have a low coefficient of the lagged dependent variable rather than unity. Mission-oriented R&D, *lm5*, is also likely to have a (near) unit root. A VAR is stable only with one lag. The corresponding cointegration tests clearly suggest having 5 cointegrating equations at all conventional significance levels. The VECM is as follows.

Vector Error Correction Estimates

Sample (adjusted): 1970 2014
Included observations: 45 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegration Restrictions:
A(5,4)=0,A(1,4)=0,A(2,3)=0,A(4,5)=0,A(6,5)=0, A(5,1)=0, A(3,5)=0,B(1,1)=1, B(1,3)=0, B(1,7)=0, B(1,5)=0, B(1,6)=0, B(2,6)=0, B(2,3)=1, B(2,2)=0, B(2,1)=0,B(2,5)=0, B(3,4)=0,B(3,2)=1, B(3,3)=0, B(3,5)=0, B(3,6)=0, B(4,2)=0, B(4,3)=0, B(4,4)=1,B(4,5)=0, B(4,7)=0,B(5,2)=0, B(5,7)=0, B(5,4)=0,B(5,5)=1, B(5,6)=0,
Convergence achieved after 508 iterations.

Restrictions identify all cointegrating vectors
LR test for binding restrictions (rank = 5):

Chi-square(7)	0.453192
Probability	0.999600

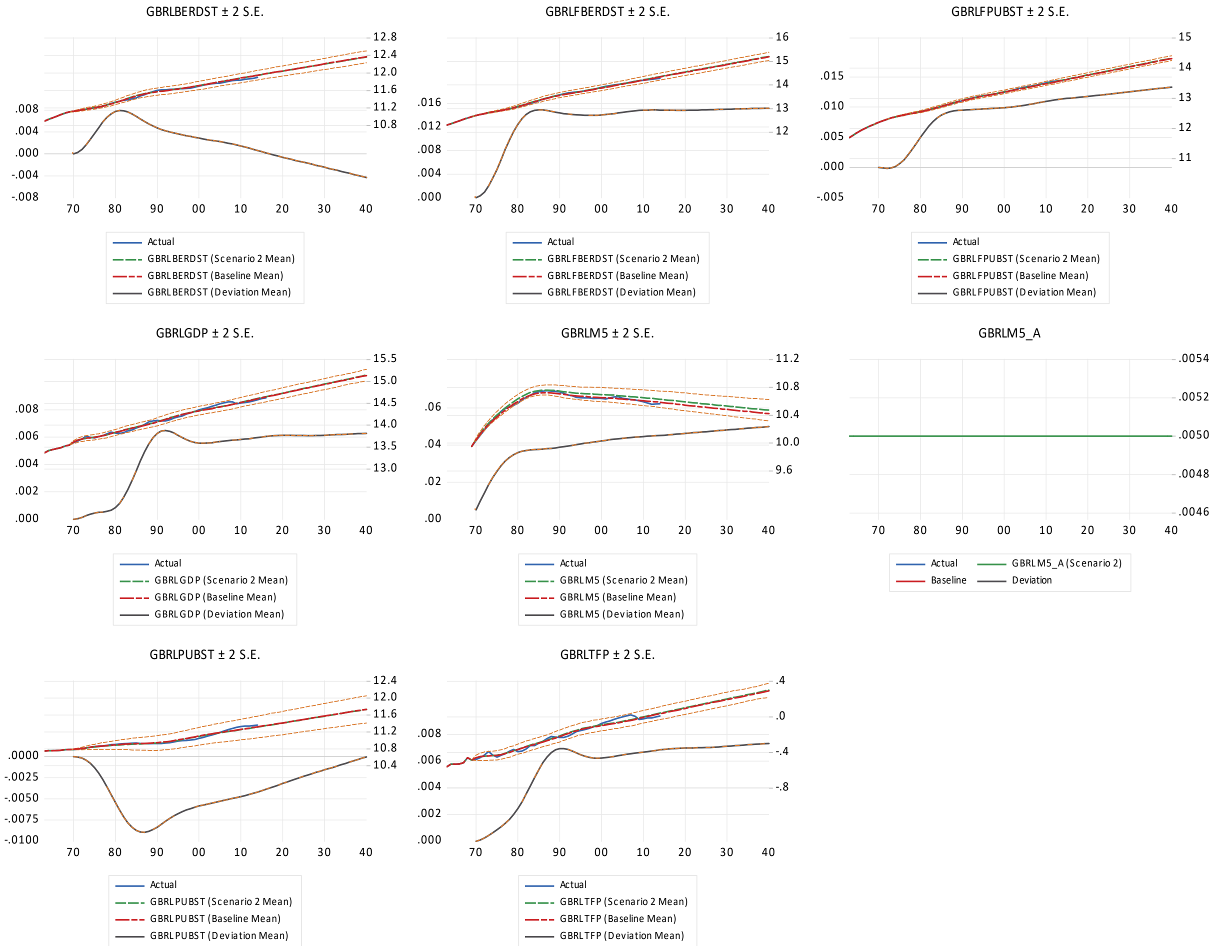
Cointegrating Eq:	CointEq1	CointEq2	CointEq3	CointEq4	CointEq5
GBRLTFP(-1)	1.000000	0.000000	4.226340	-4.870205	-2.117574
			(0.34031)	(0.20831)	(0.09566)
			[12.4191]	[-23.3793]	[-22.1365]
GBRLBERDST(-1)	-0.295252	0.000000	1.000000	0.000000	0.000000
	(0.03098)				
	[-9.52994]				
GBRLM5(-1)	0.000000	1.000000	0.000000	0.000000	0.171325
					(0.01449)
					[11.8268]
GBRLFPUBST(-1)	-0.950358	-1.332093	0.000000	1.000000	0.000000
	(0.02754)	(0.49676)			
	[-34.5105]	[-2.68155]			
GBRLGDP(-1)	0.000000	0.000000	0.000000	0.000000	1.000000
GBRLFBERDST(-1)	0.000000	0.000000	0.000000	1.127129	0.000000
				(0.07978)	
				[14.1286]	
GBRLPUBST(-1)	0.000000	-0.483365	0.660693	0.000000	0.000000
		(0.23645)	(0.06992)		
		[-2.04430]	[9.44952]		
@TREND(63)	0.021385	0.050877	-0.068320	-0.017136	0.001338
	(0.00102)	(0.01788)	(0.00449)	(0.00381)	(0.00123)
	[21.0448]	[2.84538]	[-15.2192]	[-4.50338]	[1.08603]
C	15.28049	10.48613	-15.91246	-28.72711	-16.41087

Error Correction:	D(GBRLTFP)	D(LBERDST)	D(GBRLM5)	D(LFPUBST)	D(GBRLGDP)	D(LFBERDST)	D(GBRLPUBST)
CointEq1	-0.066689	0.280555	0.243386	0.589226	0.000000	0.574410	-0.252035
	(0.04121)	(0.04186)	(0.11543)	(0.02597)	(0.00000)	(0.05595)	(0.06443)
	[-1.61836]	[6.70157]	[2.10852]	[22.6868]	[NA]	[10.2658]	[-3.91169]
CointEq2	0.083329	0.035288	-0.041749	-0.015910	0.126262	0.061643	-0.020033
	(0.02393)	(0.00889)	(0.01381)	(0.00360)	(0.02647)	(0.00655)	(0.01006)
	[3.48194]	[3.96720]	[-3.02247]	[-4.41519]	[4.76982]	[9.41803]	[-1.99168]
CointEq3	-0.119984	0.000000	-0.102362	0.162804	-0.169365	0.042534	-0.034906
	(0.02670)	(0.00000)	(0.03788)	(0.00811)	(0.03027)	(0.01848)	(0.02158)
	[-4.49307]	[NA]	[-2.70219]	[20.0788]	[-5.59453]	[2.30205]	[-1.61722]
CointEq4	0.000000	0.018732	-0.046778	0.256781	0.000000	0.145336	-0.141842
	(0.00000)	(0.01435)	(0.05528)	(0.01170)	(0.00000)	(0.02698)	(0.02880)
	[NA]	[1.30496]	[-0.84617]	[21.9390]	[NA]	[5.38690]	[-4.92571]
CointEq5	-0.387631	0.120037	0.000000	0.000000	-0.683200	0.000000	0.053074
	(0.10294)	(0.03908)	(0.00000)	(0.00000)	(0.11826)	(0.00000)	(0.03905)
	[-3.76557]	[3.07119]	[NA]	[NA]	[-5.77697]	[NA]	[1.35912]

C	0.010993	0.017551	0.013619	0.032131	0.023058	0.036072	0.012848
	(0.00233)	(0.00097)	(0.00154)	(0.00040)	(0.00259)	(0.00071)	(0.00095)
	[4.72512]	[18.0362]	[8.85389]	[79.9497]	[8.90587]	[50.4896]	[13.4998]
R-squared	0.310897	0.578687	0.901288	0.921832	0.451700	0.847376	0.660346
Adj. R-squared	0.222550	0.524673	0.888632	0.911810	0.381405	0.827809	0.616800
Sum sq. resids	0.009499	0.001662	0.004152	0.000283	0.011764	0.000896	0.001590
S.E. equation	0.015607	0.006528	0.010319	0.002696	0.017368	0.004793	0.006384
F-statistic	3.519061	10.71355	71.21763	91.98448	6.425787	43.30599	15.16452
Log likelihood	126.5705	165.7931	145.1891	205.5871	121.7579	179.6978	166.7940
Akaike AIC	-5.358689	-7.101916	-6.186181	-8.870540	-5.144798	-7.719901	-7.146402
Schwarz SC	-5.117801	-6.861028	-5.945293	-8.629651	-4.903909	-7.479013	-6.905514
Mean dependent	0.010993	0.017551	0.013619	0.032131	0.023058	0.036072	0.012848
S.D. dependent	0.017700	0.009468	0.030920	0.009078	0.022083	0.011550	0.010313

Determinant resid covariance (dof adj.)	8.02E-32
Determinant resid covariance	2.94E-32
Log likelihood	1186.462
Akaike information criterion	-49.08718
Schwarz criterion	-45.79504
Number of coefficients	82

Heteroscedasticity is absent with p = 0.17. There is some serial correlation in the residuals. Residuals are multi-variate normal with p = 0.85. A shock on the residuals of the equation for mission R&D by 0.005 yields the following comparison of baseline and shock scenario.



Mission R&D goes up, first quickly then slowly. Private R&D first increases increasingly beyond baseline and then returns to it in 2017. For public R&D we see the opposite indicating that mission-oriented R&D shifts R&D from public to private in the UK. Effects on TFP, GDP and foreign R&D are also small. The numerical evaluation is available in Table 2 and 3.

Summary We deal with the following questions. A) Does mission-oriented R&D affect business and public R&D, TFP and GDP? B) Do the returns, which are positive if the above effects are positive, outweigh the costs? C) Can we derive a common model from the country models and what are the limitations for this? We do research on these questions on a country-by-country basis avoiding country-heterogeneity bias from slope homogeneity assumptions. Finally, we discuss the limitations for the whole approach.

Methodology and data. **We estimate dynamic country specific models for five R&D variables, TFP and GDP and analyze how enhancing mission-oriented R&D affects private R&D, TFP and GDP.** We use variables for domestic and foreign private and public as well as mission-oriented R&D stocks from R&D expenditure flows according to OECD Main Science and Technology Indicators. Data for mission-oriented R&D are more limited in availability. Together with TFP and GDP data we estimate systems of difference equation models per country for all these variables using a vector error-correction approach also called cointegrated VAR model. This approach captures all mutual interactions between these variables: long-term relations for log-levels and short-term relations for growth rates, and the interaction between short term and long-term variables. Enhancing one of the variables by assumption allows looking at the effects on all the others and interpreting them as consequences of permanent policy shocks. Shocks to mission-oriented oriented R&D are of special interest in this paper. We want to get to know what their effects on private and public R&D, TFP and GDP are; but also, effects on foreign R&D variables are of interest.

A. **Policy evaluation considers net gains from increasing mission-oriented R&D and the sum of their discounted values.** Effects on the GDP, to the extent that they are caused by changes of the TFP, are considered as benefits and increases of private and public R&D are considered as cost in addition to the initial costs from mission R&D shocks. The difference between benefits and costs are the gains of a policy. Discounting the gains at a rate of 4% and adding them up over all periods gives the discounted net present value of the policy. The discount rate that brings discounted net present value to zero is the internal rate of return. Internal rates of return are inversely related to the number of periods with losses (payback periods).

B. **Mission-oriented R&D has strongly positive effects in terms of stimulating private and public R&D** with only 3 (of 14) exceptions for 7 countries for each.

C. **The effect of mission-oriented R&D on TFP and GDP is positive** in all countries with one exception: in France mission-oriented R&D should first be reduced (or perhaps reformed) and later expanded again. Approximately, a 1% increase in mission-oriented R&D in 7 countries goes together with an additional 0.485% public R&D, 0.705% private R&D, 48.5% for TFP, and 0.56% GDP.

D. **The internal rates of return for mission-oriented 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. We also show years of positive gains, the sum of discounted net present value, and the average yearly gains/GDP ratio. Mission-oriented R&D has high internal rates of return.

E. **Mission-oriented R&D should be expanded according to the needs of society**. The policy recommendation is that, mission-oriented R&D has to be defined on the project level according to the criterion of current and future needs in order to make sure that it is as successful from a macro-policy perspective as it was in the past.

F. **Efforts to derive a common model** confirm the common sense that GDP is driven by TFP, TFP by private R&D and private R&D by public R&D. In addition, there are two-causality relation between TFP, domestic private R&D and foreign public R&D. In particular, the latter serves as policy reaction function when a country's TFP is changing. Countries have different numbers of cointegrating equations, different variables in the cointegrating equations even if the numbers are identical, and there is slope heterogeneity if there are similarities otherwise.

G. **Limitations for the VECM approach are mainly in the data availability and in potential structural breaks of mission-oriented R&D policies**. First, 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 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 analyse 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. In the future, new projects will be defined and must proof that they support growth and welfare. 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 then 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.

The UNU-MERIT WORKING Paper Series

2019-01 *From "destructive creation" to "creative destruction": Rethinking Science, Technology and innovation in a global context* by Luc Soete

2019-02 *Do young innovative companies create more jobs? Evidence from Pakistani textile firms* by Waqar Wadho, Micheline Goedhuys and Azam Chaudhry

2019-03 *What gains and distributional implications result from trade liberalization?* by Maria Bas and Caroline Paunov

2019-04 *FDI, multinationals and structural change in developing countries* by André Pineli, Rajneesh Narula and Rene Belderbos

2019-05 *The race against the robots and the fallacy of the giant cheesecake: Immediate and imagined impacts of artificial intelligence* Wim Naudé

2019-06 *The middle-technology trap: The case of the automotive industry in Turkey* by Ibrahim Semih Akçomak and Serkan Bürken

2019-07 *The impact of a mathematics computer-assisted learning platform on students' mathematics test scores* by Marcelo Perera and Diego Aboal

2019-08 *Health insurance and self-employment transitions in Vietnam* by Nga Le, Wim Groot, Sonila M. Tomini and Florian Tomini

2019-09 *Knowledge economy and economic development in the Arab region* by Samia Mohamed Nour

2019-10 *Migration of higher education students from the North Africa region* by Samia Mohamed Nour

2019-11 *Job automation risk, economic structure and trade: a European perspective* by Neil Foster-McGregor, Önder Nomaler an Bart Verspagen

2019-12 *The breadth of preferential trade agreements and the margins of* exports by Rod Falvey and Neil Foster-McGregor

2019-13 *What a firm produces matters: diversification, coherence and performance of Indian manufacturing firms* by Giovanni Dosi, Nanditha Mathew and Emanuele Pugliese

2019-14 *Brazilian exporters and the rise of Global Value Chains: an empirical assessment* by Caio Torres Mazzi

2019-15 *How has globalisation affected the economic growth, structural change and poverty reduction linkages? Insights from international comparisons* by Aradhna Aggarwal

2019-16 *R&D, innovation and productivity* by Pierre Mohnen

2019-17 *Domestic intellectual property rights protection and exports: Accessing the credit channel* by Gideon Ndubuisi

2019-18 *The role of early-career university prestige stratification on the future academic performance of scholars* by Mario Gonzalez-Sauri and Giulia Rossello

2019-19 *The employment impact of product innovations in sub-Saharan Africa: Firm-level evidence* by Elvis Korku Avenyo, Maty Konte and Pierre Mohnen

2019-20 *Embodied and disembodied technological change: the sectoral patterns of job-creation and job-destruction* by G. Dosi, M. Piva, M. E. Virgillito and M. Vivarelli

2019-21 *Can we have growth when population is stagnant? Testing linear growth rate formulas and their cross-unit cointegration of non-scale endogenous growth models* by Thomas H.W. Ziesemer

2019-22 *Technical progress and structural change: a long-term view* by Alessandro Nuvolari and Emanuele Russo
2019-23 *No evidence of an oil curse: Natural resource abundance, capital formation and productivity* by Mueid al Raee, Denis Crombrughe and Jo Ritzen
2019-24 Far from random? The role of homophily in student supervision by Giulia Rossello and Robin Cowan
2019-25 *Semi-endogenous growth models with domestic and foreign private and public R&D linked to VECMs* by Thomas H. W. Ziesemer
2019-26 *Characterizing growth instability: new evidence on unit roots and structural breaks in long run time series* by Emanuele Russo, Neil Foster-McGregor and Bart Verspagen
2019-27 *Measuring attitudes on gender equality and domestic violence in the Arab context: The role of framing, priming and interviewer effects* by Ann-Kristin Reitmann, Micheline Goedhuys, Michael Grimm and Eleonora E. M. Nillesen
2019-28 *Imported intermediates, technological capabilities and exports: Evidence from Brazilian firm-level data* by Caio Torres Mazzi and Neil Foster-McGregor
2019-29 *Japan's productivity and GDP growth: The role of GBAORD, public and foreign R&D* by Thomas Ziesemer
2019-30 *The decline in entrepreneurship in the West: Is complexity ossifying the economy?* by Wim Naudé
2019-31 *Modern industrial policy in Latin America: Lessons from cluster development policies* by Carlo Pietrobelli
2019-32 *Testing the employment and skill impact of new technologies: A survey and some methodological issues* by Laura Barbieri, Chiara Mussida, Mariacristina Piva and Marco Vivarelli
2019-33 *The Potential for innovation in mining value chains. Evidence from Latin America* by Michiko Iizuka, Carlo Pietrobelli and Fernando Vargas
2019-34 *Enforcing higher labour standards within developing country value chains: Consequences for MNEs and informal actors in a dual economy* by Rajneesh Narula
2019-35 *A comment on the multifaceted relationship between multinational enterprises and within-country inequality* by Rajneesh Narula and Khadija van der Straaten
2019-36 *The effects of R&D subsidies and publicly performed R&D on business R&D: A survey* by Thomas H.W. Ziesemer
2019-37 *Does it pay to do novel science? The selectivity patterns in science funding* by Charles Ayoubi, Michele Pezzoni and Fabiana Visentin
2019-38 *Regulation and innovation under Industry 4.0: Case of medical/healthcare robot, HAL by Cyberdyne* by Michiko Iizuka and Yoko Ikeda
2019-39 *The future of work and its implications for social protection and the welfare state* by Franziska Gassmann and Bruno Martorano
2019-40 *Return, circular, and onward migration decisions in a knowledge society* by Amelie F. Constant
2019-41 *Mining and quality of public services: The role of local governance and decentralisation* by Maty Konte and Rose Camille Vincent
2019-42 *Corruption and tax morale in Africa* by Amadou Boly, Maty Konte and Abebe Shimeles
2019-43 *Remittances and Bribery in Africa* by Maty Konte and Gideon Ndubuisi

2019-44 *Women's Political and Reproductive Health Empowerment in Africa: A literature review* by Maty Konte, Victor Osei Kwadwo and Tatenda Zinyemba

2019-45 *The effect of public funding on scientific performance: A comparison between China and the EU* by Lili Wang, Xianwen Wang, Fredrik Niclas Piro and Niels J. Philipsen

2019-46 *Credit constraints and trade performance: Does trust-based social capital matter?* By Gideon Ndubuisi and Maty Konte

2019-47 *The impact of mission-oriented R&D on domestic and foreign private and public R&D, total factor productivity and GDP* by Thomas H.W. Ziesemer