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The productivity effect of public R&D in the Netherlands

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Abstract

Using a vector-error-correction model (VECM) with total factor productivity (TFP), domestic and foreign research and development investment (R&D) as well as GDP, we find that for the Netherlands for the period 1968-2014, extra investment in public and private R&D has a clear positive effect on TFP growth and GDP. Taking into account the costs of these extra investments, we find that the rate of return to such a policy is positive and high. We also find dynamic complementarity of public and private stocks of R&D for a long period after the initial shock. However, our results also show that the productivity effects on the Dutch economy are weaker when they are part of an internationally concerted policy effort, i.e., when other OECD countries implement policies with the same effects on R&D stocks in their countries. While complements in the long run equations of the model, in the adjustment process Dutch domestic private R&D appears to consider foreign public R&D as a substitute, i.e., when foreign public R&D rises, Dutch private R&D tends to shrink.

Keywords: R&D policy; public R&D investment; rate of return to public R&D investment; vector-error-correction model.

JEL Codes: O38, O30, H4

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1. Introduction

A number of studies have attempted to estimate the economic impact of public investment in research for different OECD countries. Until recently, a broad consensus existed concluding that the rate of return of such public investment would be high. The most well-known study (Guellec and van Pottelsberghe de la Potterie, 2004) found a long-term elasticity of Multifactor Productivity (MFP) with respect to business R&D in OECD countries over the period 1980-98 of 13%, increasing over time. For public research, the study found that the long-term elasticity of government and university-performed research on productivity was even higher around 17%.² At the same time the impact of “cross-border” spillovers appeared higher for smaller countries than for larger ones, reflecting the higher shares of international co-publication and co-patenting of smaller nations. To achieve such benefits though, the smaller country would need to become more R&D intensive and more specialized.

Other studies found that complementarities between public and private R&D exist, giving rise to the idea that there are direct and indirect effects of public R&D investments. Jaumotte and Pain (2005a, 2005b) analyzed 19 OECD countries over a 20-year period to 2001 and found evidence of significant complementarity between public sector and business sector R&D. They considered that this more than offset any negative effect from public sector R&D on labor costs in the business R&D sector. They found that “an increase of one standard deviation in the share of non-business R&D in GDP (an increase of 0.06 percentage points for the average economy) raises business sector R&D by over 7% and total patenting by close to 4%.” (Jaumotte and Pain 2005b, p.38). By contrast, Khan and Luintel (2006), dealing more specifically with the heterogeneity between countries using the interaction terms of variables with country-specific averages of the knowledge stocks, found a negative interaction effect, meaning that the effect of an increase in public or private R&D is smaller if the other variables are higher.

One dimension of complementarity between public investment in research and private sector R&D arises from the attraction it exerts on internationally mobile R&D, what could be called a R&D ‘crowding-in’ effect. Factors such as the prospect of high quality collaborators, recruitment opportunities, and the presence of a local knowledge cluster, often accompanied by a knowledge technology transfer infrastructure, feature variously in such studies (Cassiman and Veugelers 2002). The overall message is that particularly for small countries, a high quality research base will attract international R&D. The same factors will encourage domestic companies to retain and expand their R&D investments domestically. A positive impact of foreign R&D on productivity has been confirmed through country-panel analyses by Luintel and Khan (2004) and Khan and Luintel (2006). More recent evidence on a large country such as the UK, found that besides public sector financed R&D also foreign R&D had a significant impact on TFP growth (see e.g. Haskel and Wallis, 2010).

However, a recent empirical study on the subject by Van Elk et al. (2015), using R&D data going back to 1963 for some countries, arrived at different macroeconomic evidence for the economic returns on public R&D, with results depending strongly on the specific model used in the estimations. They implemented three classes of econometric models: (i) a Cobb-Douglas

² Within that, the effect of universities was again higher, possibly because in some countries, government laboratories had primarily non-economic objectives such as supporting defense.

production function, (ii) a translog production function, and (iii) an “augmented” production function as proposed by Khan and Luintel (2006). In each of these, three separate types of R&D were correlated with total factor productivity levels: domestic private R&D (carried out by business enterprise), foreign private R&D (weighted business enterprise R&D carried out in other countries representing spillovers), and non-private R&D carried out primarily in public research organizations and universities, hence used as a proxy for “publicly funded science”. The econometric models were implemented using a panel dataset in which most OECD countries were present. The results obtained can be summarized as follows: in the “raw” Cobb-Douglas estimations, none of the R&D measures appeared significant. In the error-correction model (ECM) version of the Cobb-Douglas model, private R&D had a positive impact, but public R&D a negative impact (but often not significant). In the translog model, results varied widely depending on the exact implementation of the profit-maximization conditions. In the augmented model, which allowed for different rates of return of public (and private) R&D between countries, the impact of public R&D appeared overall positive, but with widely different impacts between countries.

In the present paper we provide an alternative methodological approach to estimating the economic impact of public investment in research. Our starting point is that the literature (as reviewed above) may have reached the intrinsic limit of econometric estimations based on cross-country comparisons. Countries are very different from each other, particularly with respect to research investment activities: not just with respect to the size of such investments, but also with respect to the nature of those investments (e.g. military vs civilian), the particular institutional set-up (e.g., whether universities are fully autonomous or government controlled, see Aghion et al., 2010), the presence and funding structure of research technology organisations (RTO’s), the dominance within private firms of large multinational corporations versus small, new firms), the international openness of the country, etc.

Taking all such differences together, we argue that an econometric model that (implicitly) assumes parameter homogeneity between countries may not be very adequate. Cross-country econometric analysis, such as carried out in Guellec and Pottelsberghe (2004) or more recently Van Elk et al. (2015), (usually) assumes slope homogeneity between countries. But when heterogeneity between countries is strong, it is likely to make results insignificant in this type of analysis. As Khan and Luintel (2006) put it most explicitly, “the best empirical strategy would be to conduct country-by-country econometric analyses ... given cross-country *slope heterogeneity*”. Therefore, we adopt a time series approach within a single country to estimate the impact of public (and private) research.

We focus on the Netherlands, a relatively small country, but with significant public and private research investment and a strong scientific and technological base as reflected in both scientific output and number of patents filed. The Netherlands is also characterized by major policy efforts with respect to research support, either through increased public funding of public research organizations such as universities and RTO’s or through subsidies and tax credits to private firms.

In the next section, we go in somewhat more depth into the reasons why a country specific estimation methodology seems particularly appropriate when attempting to measure the economic impact of research and why the Netherlands appears a good choice as the first country to which we apply our methodology. In section 3 we introduce the econometric

approach and data that are the basis of our estimations, and present the basic estimation results and the dynamic solution to the model. Section 4 presents simulation effects for various cases of policy shocks: (i) transitory and permanent domestic public R&D shocks, and (ii) an internationally coordinated symmetric shock to public and private R&D. These results represent the core of our findings about the impact of private and public R&D on productivity growth in the Netherlands. Section 4 we also presents estimations of rates of return and net gains from policy for future generations. Section 5 summarizes the analysis and outcomes.

2. Applying a time series estimation to R&D and research policy in the Netherlands

The Netherlands has had a relatively high R&D intensity for decades – in the 1960s it actually had the highest civilian R&D intensity of any OECD countries – with the presence of some large public and private research laboratories owned by some large, domestically grown, multinational companies (Philips, Shell, Unilever, Akzo, DSM), newcomers (ASML, NXP) as well as an increasing number of foreign firms. The country is characterized by an extensive public research sector with a large number of autonomous, high quality universities, an extensive set of RTO's, a limited emphasis on military research, and an international, open research culture with a growing presence of many foreign researchers.

Given its location, the Netherlands also provides a good case to consider separately the impact of private and public R&D for both domestic and foreign R&D. It will allow us to estimate the relation between domestic and foreign public and private R&D as well as total factor productivity and GDP, whereby all variables are treated as endogenous.³ Whereas in Luintel and Khan (2004) foreign total R&D stocks were treated as “weakly” exogenous, meaning that their growth rate did not react to deviations from the long-term relations, we can show how foreign private and public R&D are endogenous from the country perspective.

The case of The Netherlands, with its many research policy shifts over the last 50 years, is also a good case to look specifically at the impact of transitory and permanent shocks of domestic public R&D on TFP, on GDP and on all the R&D variables, including all the feedback effects from TFP and GDP on these variables. This helps us to reconsider (i) the question whether public and private R&D stocks are complements or substitutes, and better understand why dynamic results are so complex; and (ii) address the question of how countries can attract foreign R&D in a dynamic context, while showing the exact time paths of adjustment for each of the policy shocks. By implication, in our model, endogenous variables all react to shocks. One can observe whether and how they react differently, indicating e.g. how foreign R&D variables react and whether or not the domestic ones are complementary.

This international reaction to national policy shocks raises interesting questions as to the possibilities for different strategies of international coordination of R&D, questions which are even more relevant within the European framework of “shared” policy responsibility between national authorities and the European Commission. It will allow us to look at ways shocks enhance (i) the growth rate of foreign and domestic public R&D by a symmetric permanent shock (e.g. the successful participation with national matching in funding of European

³ Without the inclusion of the GDP the model is unstable. All other variables are standard except for our splitting into public and private for domestic and foreign R&D. Other papers do this only for domestic R&D or not at all.

framework programmes), and (ii) how they affect also the growth rates of domestic and foreign private (and public) R&D simultaneously.

The literature discussed in the previous section focusses on the issue of public R&D. The paper that is methodologically closest to our approach is Luintel and Khan (2004). They relate TFP to foreign R&D and domestic R&D, dealing with domestic business R&D separately. They do not consider public R&D explicitly and foreign R&D is not split into private and public R&D. However, their study for 10 OECD countries finds less significant effects for business R&D than for total domestic R&D. We interpret this as suggesting that non-business R&D might play a strong role.

Khan and Luintel (2006), because of lack of data, do not follow a VAR approach, but considered a heterogeneity of intercepts and slopes in a system General Method-of-Moments (GMM) panel estimation. Intercepts were considered country-specific as fixed effects. For slopes they constructed interaction terms of a range of variables with the country-specific averages of the knowledge stock variables, leading to the results reported above. As this represents economically a single equation approach, one gets country-specific regression coefficients, but it is not possible to analyse the feedbacks from productivity on the left-hand side of the equation to the knowledge stocks and the various dynamic interactions between the knowledge stocks, productivity and output.⁴ This raises questions as for how long (indirect) effects run, and how large they are. Compared to these two papers, our contribution can be briefly summarized as combining (i) the interest in public R&D from Khan and Luintel (2006) who did not use a VECM, with (ii) the VECM method used in Luintel and Khan (2004) which did not deal with public R&D and considered long-term relations only, and (iii) disaggregating foreign R&D into private and public, combined with (iv) an analysis of shocks to the system of all equations.

Other regressors than those discussed so far have been suggested by other scholars and we briefly explain here why we do not use them. Contrary to Bottazzi and Peri (2007), we do not use patents. Bottazzi and Peri (2007) considered the complementarity of domestic and foreign patent stocks in patent generation using a VECM. Where we emphasize the outcome in terms of TFP, they emphasized patented ideas, excluding by assumption non-patented ideas and all intermediate steps necessary to turn single ideas into productivity. They also do not deal with the economic impact of public R&D expenditures, which is our main focus. Other differences are that, on the cost side, they only use employment in R&D without wages or other R&D costs such as instruments and labs⁵. The broader measure of R&D costs and TFP as the direct measure of productivity rather than the indirect one of patents seems more adequate to us and is also more in line with the literature in this area (see Hall et al. 2010).

⁴ This is important because it is well-known from basic macroeconomics that impact effects may vanish after a system of equations has run through the various rounds of adjustment. The most well-known example is probably the ineffectiveness of fiscal policy in the Mundell-Fleming model under the special assumption of flexible exchange rates and perfect capital mobility. For our purpose here, this empirically controversial result is not important, but the theoretical possibility highlights the need for more empirical analyses in this area.

⁵ This is rather crucial as Bottazzi and Peri (2007) support the semi-endogenous growth approach in line with Jones (1995), who emphasized the strong growth in the numbers of researchers to defend his semi-endogenous growth approach, whereas e.g. Ha and Howitt (2007) emphasized the constancy of R&D expenditure (%GDP) and TFP growth in favour of fully-endogenous growth approaches.

Human capital is of course highly important for growth but it is strongly correlated with public R&D expenditures because of the close link between research and teaching and should hence not be included a second time. Human capital other than that in R&D may be highly important in the diffusion process but it is a cost component, and therefore correlated with output production, which we include and therefore, again, it should not be included a second time.⁶

Similarly, we do not include labour. When TFP measures are constructed, labour terms are subtracted from GDP. Therefore labour is correlated with TFP by construct. As this uses a production function (Hall et al. 2010), labour is also correlated with GDP. As we use TFP and GDP, including labour would lead to collinearity of variables by construct.

Entrepreneurship is not included as it refers to microeconomic rather than macroeconomic issues; the GDP variable in our set-up can be assumed to capture many of those aspects. The major entrepreneurial variable for our purpose relates to the initiative to do R&D and is captured by the private R&D variable.

Similarly, effects of standard regressors of cross-section growth regressions like financial development, trade openness and demography are all assumed to be already included in the GDP variable, which appears in each of our equations also on the right-hand side and has an impact on the other variables in this way.

In a dynamic system, all of these arguments should not be included again in order to avoid doubling the arguments and causing collinearity impairing the interpretation explaining non-GDP variables and the calculation of rates of return. In particular, Hall et al. (2010) emphasize that it is important to have an explanatory variable that absorbs fluctuations in the TFP growth. The GDP variable, which we include, is exactly doing this. Otherwise we would have an omitted variable bias. The second point made by Hall et al. (2010) is that collinearity with the R&D variables on the cost side is likely to reduce the rate of return estimates; so would collinearity with GDP variables on the revenue side.

Khan and Luintel (2006) use lagged high export shares and FDI variables as controls. These variables are themselves, however, determined by productivities. As we employ lagged TFP on the right-hand side of all equations in the VECM, we do not need those variables driven by TFP. In line with this reasoning, Luintel and Khan (2004) also did not use these variables in their VECM.

In general, (cointegrated) VAR models keep the number of variables small in order to keep reasonable degrees of freedom (see Luintel and Khan 2004, Bottazzi and Peri 2007, Jusélius et al. 2014). They do not follow the tradition of cross-country and panel growth regressions that work with many regressors and are confronted with collinearity (Durlauf et al. 2005).

⁶ If years-of-schooling was used as human capital variable, this would again be included in the wages paid according to the Mincer equation, and hence be included in the value added version of GDP and in the R&D capital stocks. Whereas Lucas (2015) claimed that there is no TFP residual if human capital is taken into account correctly in the accounting procedure, we rather prefer not to give the impression that we regress TFP on an almost identical variable coming close to estimating an identity under Lucas' suggestion.

3. Econometric model, data and estimation

3.1. Data

The model includes the following (endogenous) variables: total factor productivity (TFP, denoted by A), GDP (denoted by Y), the domestic public R&D capital stock (G), the domestic private R&D capital stock (P), the foreign public R&D capital stock (G^*), the foreign private R&D capital stock (P^*). All variables are specified as natural logs (log or $\ln$), and TFP (non-log) is normalized to unity for 2011. Data are an updated version of those in van Elk et al. (2015), using more recent sources that extend the time period to 2014. GDP and TFP are from the Penn World Tables (version 9.0; Feenstra et al. 2015). We use the national accounts version (RGDPNA) for GDP; the TFP variable uses data on employment that is not augmented with the human capital index that is available in PWT.

R&D data come from the OECD, and as in the case of van Elk et al. (2015), we use older versions of the OECD database kept at UNU-MERIT to extend the coverage of R&D data back into the 1960s. Gaps in the R&D data are filled by interpolating R&D intensity (R&D as a share of GDP) and using GDP data to recover the implied R&D expenditures. The time series for R&D expenditures are then converted into R&D capital stocks, to represent the idea that it is not only current R&D expenditures that influence productivity, but rather the accumulated knowledge that results from present and past R&D expenditures. It is also assumed that this accumulated knowledge depreciates (we use a rate of 15% as common in the literature, Hall et al. 2010). Then we use a perpetual inventory method to construct the stocks: $S_t = (1-0.15)S_{t-1} + R_t$, where S is the stock and R is current expenditure.⁷ We apply this to both public and private R&D, yielding a stock for both types of R&D. Private R&D expenditures are expenditures by business enterprises, public R&D expenditures are total domestic expenditures minus business enterprise expenditures (higher education and public labs are the largest categories of public expenditures defined in this way).⁸

By implication, both R&D variables include already the cost of hiring human capital in the flow variable. As we discussed above in section 2, adding human capital as another regressor is likely to weaken the statistical significance of the R&D stock variables, because human capital would then be taken into account twice. The foreign R&D capital stocks, private and public, are distance-weighted averages of the stocks of countries in the sample of van Elk et al. (2015), excluding the country under analysis, the Netherlands. Using patent applications as weights instead as Khan and Luintel (2006) do, would have to deal with the strong structural change in the data for the period 2000-2010.⁹ The broad discussion of this issue in Hall et al. (2010) does not lead to any better alternative than our choice.

⁷ We also need to assume a value for the growth rate of the stock for the initial period. This is chosen to minimize the difference between the initial growth rate and the next one that results from the formula. In contrast, Khan and Luintel (2006) use the average growth rate over the sample of the flow variables, which is intuitively less likely to represent the initial rate required by the PIM. With little difference in the intensities noticed by the authors, stock differences (emphasized on p.12 of their paper) must be highly sensitive to the method constructing the initial value. As depreciation is also a common rate, the sensitivity comes from the chosen growth rate.

⁸ Lucas (1988) points out that even in the richest private universities in the USA half of the money comes from governments.

⁹ For example, UK applications by nonresidents dropped by 20% in 2005/6. They do so even more strongly for Croatia and several other countries in connection with changes in their relation to the EPO.

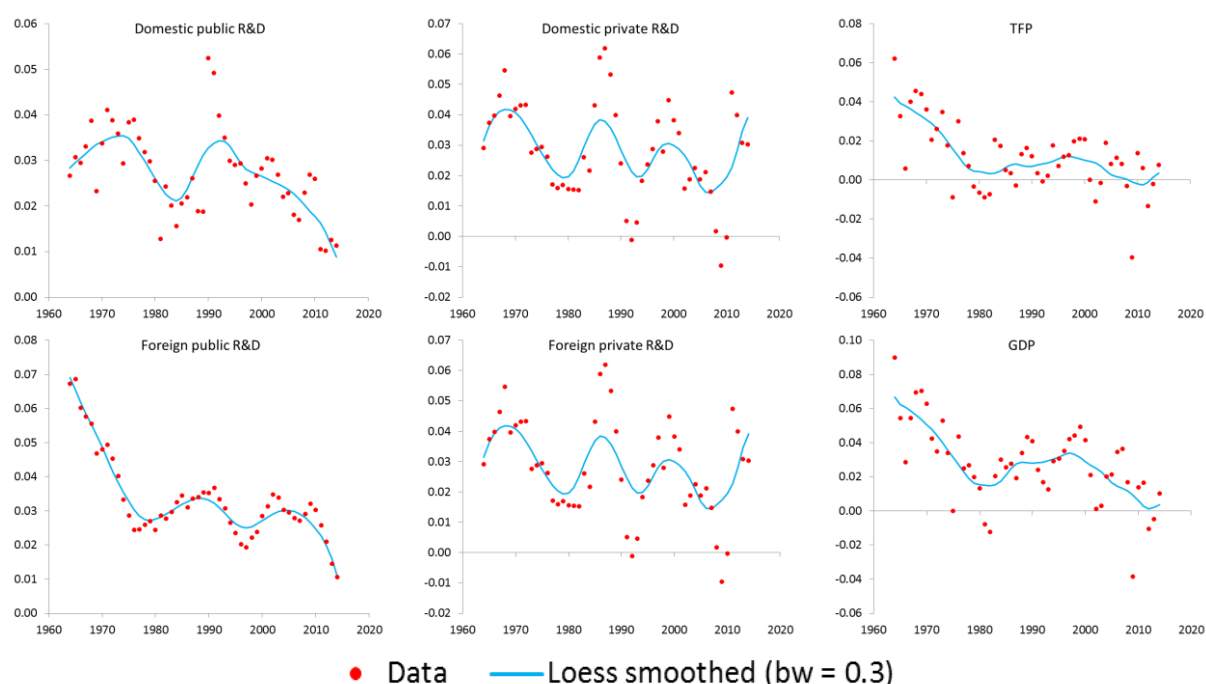


Figure 1. Growth rates 1964-2014 for all variables in the analysis

Figure 1 shows the yearly growth rates (ln differences) of all variables in the estimation. Growth rates are positive but falling with ups and downs, leaving open the question whether they have a lower limit, and at which value. Especially TFP and public R&D may come close to such a lower limit at the end of the period. The growth rates of GDP and TFP have positive and negative outliers in 1964 and 1966 respectively, as well as 2009, biasing the estimate of the relation between TFP and GDP. To avoid this, we used 1968 as the beginning year in the estimations below. We ignore the 2009 outlier, i.e., include it in the estimations, because it may well reflect a long or medium term effect of the financial crisis on growth. Moreover, in 2009, TFP and GDP have a symmetric outlier of -0.04, which does not bias the estimate.

3.2. Econometric approach and estimation results

In practical terms, we extend the single equation approaches of the literature to a multi-equation approach. This yields a so-called vector error correction model (VECM) that explicitly captures all forms of multi-way causality, i.e., all variables can influence each other. Because the VECM is a standard and well-specified model, we only present it formally (below) in its estimated form.

The model assumes that all variables in the model affect each other mutually, and therefore are endogenous, going possibly beyond the assumptions of Luintel and Khan (2004) where foreign R&D is weakly exogenous and Haskel and Wallis (2010) where it is fully exogenous. This implies that we also assume that variables for the Netherlands may affect the foreign R&D stocks. Thus,

we treat the Netherlands as a “large” country, as imperfect competition theory¹⁰ and, in regard to government decisions, its G20 status would suggest. However, the estimations may still show that the effect of Dutch variables on the foreign R&D capital stocks is negligible, suggesting rather a “small country” effect.

The VECM estimates one or several long-run relationships between the variables called the co-integrating equations, *CEs*. It then assesses how far the economy is from these long-run relationships by calculating the residual in the co-integration relationships and includes these in the VAR model. When the estimated model is stable, the residuals of the co-integration equations, commonly termed the error-correction terms, will tend to zero, representing a long-run “equilibrium”. Such a model can be used in simulations of the effects of exogenous shocks in one or more of the variables in the model. The reactions to the shocks take into account the dynamic interaction of all variables and in this way go beyond the merely partial effect of a statistically significant regression coefficient in a long-term relation.

In order to determine the lag order of the model (how many lags of each variable to use in the estimations), we estimate a VAR with endogenous GDP and TFP, domestic and foreign private and public R&D, a constant and a trend. This has as optimal lag length two (for three of the standard criteria) or three (for the AIC and FPE criteria) (we allow for a maximum of three lags in these tests¹¹). However, for lag lengths two or three, the VAR model is not stable, which makes it unsuitable for econometric and simulation analysis. With just one lag the VAR is stable and therefore only this model can be used as a basis for the VECM. In other words, in regard to the choice of the lag length the instability problem forces us to be even more restrictive than the Schwarz Information Criterion would suggest. An implication is that the VECM does not have lagged differenced terms. Business cycle effects are then captured by the residuals of each equation and the dis-equilibrium deviations from long-term relations. For a steadily growing economy like the Dutch one over the last 50 years this offers sufficient flexibility to capture all movements. This can be seen from Figure 2 where all observations remain in the confidence intervals and, more intuitively, in Figure 3 where returns to an approximate steady state takes more than 50 years after a transitory shock.

The maximum eigenvalue test and the trace test suggest, at the five percent significance level, two or three co-integrating equations (*CEs*) under a quadratic trend and three or four under a linear trend.¹² We worked through all the four cases, using maximum likelihood as the estimation method. The highest log likelihood is obtained under a linear trend and four co-

¹⁰ According to basic microeconomics, under fixed costs and therefore imperfect competition, firms are price setters and there are no small countries in the sense of being price takers (Helpman and Krugman 1989). In the literature on SMEs (small and medium enterprises) firms are defined as small in line with convenient statistical indicators (see Loveman and Sengenberger 1991). Firms that are small according to these indicators will normally have some fixed costs and by implication they have to determine their prices; in other words, some firms which are defined as small according to SME literature are not small according to the microeconomic definition. We use the definitions of microeconomics and international trade theory. In terms of examples, when Philips and Siemens both decide to specialize in health technology they will observe each other irrespective of the geographical size of their countries of location.

¹¹ With six variables and four lags we would have per equation 6x4 coefficients for the lags and per equation one for the constant and the trend in a VAR model; 36 coefficients for 47 observation results in a too low degree of freedom.

¹² A quadratic trend is a trend in the growth rate equation, which is relevant if growth rates are falling over a long period. A linear trend is a trend in the level equation of the co-integrated variables.

integrating equations.¹³ With $K=6$ endogenous variables and $r=4$ co-integrating equations the number of $I(1)$ variables or unit roots is $K-r = 2$ (i.e., a VECM can include both $I(1)$ and $I(0)$ variables, Lütkepohl 2005, p.250).

For univariate unit-root analysis we use the augmented Dickey-Fuller tests including break point tests, both the additive outlier test and the innovational outlier test. Domestic private R&D has almost certainly no unit root. However, domestic public R&D and foreign private R&D have a unit root according to the augmented Dickey-Fuller tests including break tests, in both the additive outlier test and the innovational outlier test. Other variables have probabilities for a unit root near twenty percent and all have coefficients below unity, indicating that these are probably near-unit roots.¹⁴

With six variables and four co-integrating equations, identification requires that each long term relation has at least four constraints on the coefficients. One of these constraints is implemented as a normalization of a coefficient to one (making the corresponding variable look similar to a “dependent” variable in a common regression framework), while the other three constraints are implemented by setting a coefficient to zero, i.e., exclude the corresponding variable from the equation. By implication, each long-term relation can have only two regressors with unconstrained coefficients besides the constant and the trend. The effects of other variables then come via the feedback from the dis-equilibrium in the long-term relations.

We first do the renormalization in a way that all coefficients in the long term relations are statistically significant and in line with economic intuition, and then set adjustment coefficients with low t -values to zero as long as the p -value for the chi-square test for the whole constraint constellation is increasing. When doing the renormalization we follow the suggestion of Boswijk (1996) and Lütkepohl (2005) to normalize the coefficients of those variables to unity which are least likely to have unit roots according to the univariate unit root analysis, because they are less likely to have zero coefficients.

We now briefly discuss the long term relations of the VECM. The estimation period is 1968-2014. The first co-integration equation represents a long-term equilibrium relation between TFP, domestic private and public R&D capital (absolute t -values in square brackets):

$$\log A = -22.084 + 0.586 \log G + 1.780 \log P - 0.061 t \quad (1)$$

[10.59] [40.69] [28.25]

Domestic public and private R&D capital both translate positively into TFP: a one percent increase in public R&D capital would lead to a 0.59 percent increase in TFP. A one-percent increase of private R&D capital increases TFP by 1.78 percent. Moreover, there is a negative time trend of about six percent, and a low intercept indicating low and falling TFP if public and foreign R&D were hypothetically absent. However, the negative 0.061 should not be attributed to the TFP alone, but is also de-trending the other variables (see Wooldridge 2013).

¹³ A single equation approach would be justified in case of finding only one cointegrating equation (Juselius et al. (2014)).

¹⁴ The hypothesis of a coefficient of 0.95 instead of unity would have a higher probability than that of a unit root.

The functional form of this equation comes close to the single-equation Cobb-Douglas estimations by van Elk et al. (2015). But here the equation is part of a larger model with three other long-run relations and other endogenous variables in an explicit long- and short-run adjustment framework in which all variables are involved. In the long-run equation here, we have a clearly positive impact of both public and private domestic R&D. This also confirms the result in the literature that private R&D has a stronger effect than public R&D (see Hall et al. 2010). However, this is only a partial effect, as the complete effect should also look at the other co-integration equations and the adjustment equations.

The next long-term equilibrium relation is between domestic private R&D capital P , foreign private R&D capital P^* and foreign public R&D capital:

$$\log P = 8.222 - 0.296 \log P^* + 0.385 \log G^* + 0.030 t \quad (2)$$

[12.6] [7.70] [19.2]

A one percent increase in foreign private R&D capital translates into 0.3% fall of domestic private R&D capital (i.e., substitution of own R&D by spillovers from abroad), which is plausible in the presence of strategic substitutes in oligopoly models, deterrence effects and low cost strategies of absorbing spillovers. This substitutability is in line with the static result of Khan and Luintel (2006). On the other hand, a one percent increase in foreign public R&D leads to a 0.4% increase in domestic private R&D, indicating positive (long-run) spillovers from the foreign public sector.

The third long-term relation is between foreign public R&D capital G^* , domestic public R&D capital G and foreign private R&D capital P^* :

$$\log G^* = 9.355 - 0.110 \log G + 0.305 \log P^* + 0.020 t \quad (3)$$

[2.08] [12.9] [12.4]

If domestic public R&D increases by one percent foreign public R&D decreases by 0.11 percent, indicating slight international substitutability in the field of public R&D. A one percent increase of foreign private R&D translates with 0.3 into foreign public R&D. A positive time trend of 0.02 de-trends all variables.

The fourth and final long-run relationship is for GDP and domestic TFP:

$$\log Y = 13.220 + 2.437 \log A + 0.006 t \quad (4)$$

[29.8] [7.36]

If Dutch TFP increases by one percent, GDP increases by 2.44 percent, because higher TFP increases capital, employment and wages. Chakraborty and Lahiri (2007) suggest that with public capital included there is an upper bound for this coefficient of 2.5. The time trend increases the GDP beyond that of TFP at an order of magnitude of the labour growth rate.

As stressed already, all these effects are only partial long-run relations among endogenous variables. The total system may respond differently if we take into account the interaction between these four co-integration equations, as well as the disequilibrium adjustment dynamics, to which we now turn.

As already explained above, the disequilibrium dynamics of the model takes into account the “error terms” that can be derived from equations (1) – (4), by subtracting the right hand side of each equation from the left hand side. We denote these error terms CE_i , with $i = 1..4$ corresponding to the long-run equations. Estimation results for this VAR part of the model are as follows (t -values in brackets; variables normalized to unity in CE_i in the headline):¹⁵

$$\begin{array}{lclclcl} & \log A & \log P & \log G^* & \log Y & \\ \Delta \log A = & -0.381 \text{ CE1} & -0.487 \text{ CE2} & -0.175 \text{ CE3} & & +0.010 + \varepsilon_A \\ & [4.125] & [4.09] & [2.52] & & [5.76] \end{array} \quad (5)$$

$$\begin{array}{lclclcl} \Delta \log G = & 0.235 \text{ CE1} & +0.484 \text{ CE2} & +0.296 \text{ CE3} & +0.207 \text{ CE4} & +0.027 + \varepsilon_G \\ & [3.00] & [4.20] & [4.46] & [4.55] & [31.4] \end{array} \quad (6)$$

$$\begin{array}{lclclcl} \Delta \log P = & & -0.123 \text{ CE2} & -0.486 \text{ CE3} & -0.107 \text{ CE4} & +0.027 + \varepsilon_P \\ & & [-.71] & [3.90] & [1.67] & [13.2] \end{array} \quad (7)$$

$$\begin{array}{lclclcl} \Delta \log P^* = & 0.060 \text{ CE1} & & -0.533 \text{ CE3} & -0.189 \text{ CE4} & +0.035 + \varepsilon_{P^*} \\ & [6.42] & & [15.3] & [11.1] & [59.1] \end{array} \quad (8)$$

$$\begin{array}{lclclcl} \Delta \log G^* = & 0.309 \text{ CE1} & +0.468 \text{ CE2} & & +0.179 \text{ CE4} & +0.031 + \varepsilon_{G^*} \\ & [7.84] & [8.91] & & [12.2] & [59.0] \end{array} \quad (9)$$

$$\begin{array}{lclclcl} \Delta \log Y = & -0.266 \text{ CE1} & -0.298 \text{ CE2} & -0.237 \text{ CE3} & & +0.025 + \varepsilon_Y \\ & [1.90] & [1.65] & [2.25] & & [9.94] \end{array} \quad (10)$$

The adjusted R^2 for the six equations are 0.47, 0.63, 0.24, 0.87, 0.83, 0.34, respectively. The error probability of rejecting the constraints on the adjustment coefficients for the long-term relations is $p\text{-value} = 0.999994$. The lowest absolute t -value accepted in this way is 1.65 in the last equation. We will not discuss these results in detail, but instead point to a few salient adjustment coefficients that will have a large impact on some of the outcomes of the simulation experiments below. In the equation for private domestic R&D (P), we see only negative coefficients. For P itself ($CE2$), this implies a tendency towards equilibrium (whenever this stock is above its long-run equilibrium, it will fall). The same holds for foreign public R&D ($G^* / CE3$), which points to a tendency for foreign public R&D to substitute for domestic private R&D in the adjustment process. Interestingly, domestic public R&D (G) has positive coefficients for all error terms. For example, domestic public R&D will tend to rise when foreign public R&D and domestic private R&D are above equilibrium values. TFP (A) will react negatively to above equilibrium values of itself and domestic R&D.

Whenever the CE terms deviate from zero, they trigger changes on the left-hand side. Unlike Luintel and Khan (2004) where foreign total R&D is weakly exogenous here foreign private and public R&D are both endogenous. As G^* and P^* are endogenous, our result also differs from Haskel and Wallis (2010) where foreign R&D is exogenous. As the expected values of the CE terms in long-run equilibrium (i.e., equations 1 – 4 have zero residuals), the model can be solved for the expected long-run growth rates, which are then equal to the constants in equations 5 - 10. These implied long-run growth rates are roughly between one percent for the TFP and 3.5 percent for foreign private R&D capital. Both foreign growth rate variables are higher than the domestic ones. As growth rates of R&D capital indicate also cumulative costs, the fact that they are higher than those of TFP indicates that the costs of making TFP are increasing more than the TFP itself. This confirms a point made by Bloom et al (2017). However, as can be imagined by the use of a production function and marginal productivity condition for capital, the returns do

¹⁵ As the underlying VAR has only one lag, the VECM has no differenced terms on the right-hand side.

not consist of TFP effects only but rather of an additional effect through capital movements on GDP that is increased 2.4 times as much as the TFP in the policy scenarios discussed below. Moreover, semi-endogenous growth would be favoured if we had found quadratic time trends, i.e. small negative trends in the long-run growth rates. But we find that the highest likelihood is with only linear trends in the long-term level equations leading to constant long-term growth rates. It takes a structural break to come to possibly worse results in the future. Fernald and Jones (2014) discuss some possible reasons for future structural breaks.

As the final stage of the econometric analysis, we solve the model dynamically with one thousand stochastic repetitions using normal random numbers. These model solutions will be the baseline in the simulations, and are documented in Figure 2. One salient finding from this dynamic solution is that Dutch GDP for the period 1979-1989 is below the long-run trend, while for the period 1996-2008 it is above the long-run trend. The crash in 2009 brings the economy back to the trend line, immediately for TFP and slowly for GDP.¹⁶

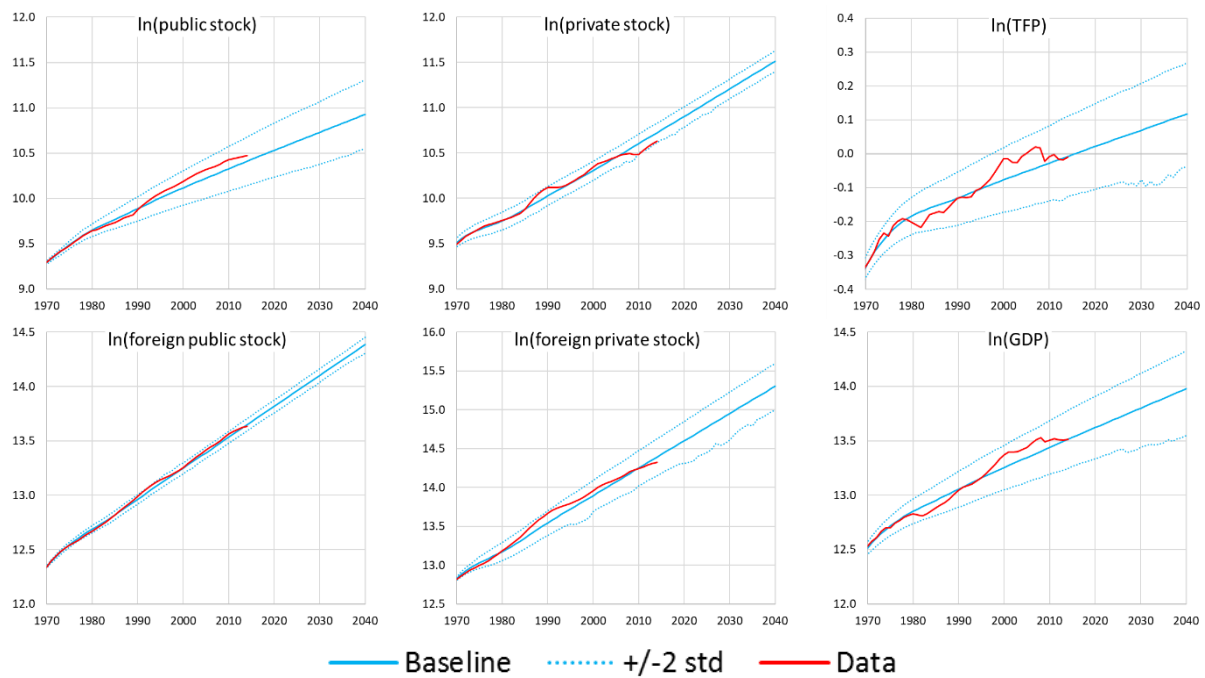


Figure 2. Baseline scenarios (dynamic stochastic model solutions) and data

3.3. Internal rate of return

In the next section, we will implement a number of policy simulations, by introducing exogenous shocks to the R&D stock variables. As the values of TFP, GDP and the R&D expenditures increase after such a policy shock, we have both benefits (productivity increases leading to extra GDP) and costs (extra R&D expenditures). The question is therefore whether the benefits are larger than the costs. Both depend on the size of the shock and the length of the

¹⁶ If we only use data until 2011, the estimated trend line is above the data of the crisis period. The difference between these trend lines may come close to a long lasting (bad bank) effect on growth.

period under consideration. To answer this question, we will calculate rates of return to R&D investment for each of the scenarios. We adopt the notion of the “internal rate of return”, which is defined as the discount rate that yields a zero sum of discounted net flow gains over the time horizon (which we take as the start of the policy shock until 2040, i.e., a long period of over 70 years).

We specify the benefits as the yearly additional GDP due to increases of TFP. This is calculated as the percentage difference between baseline TFP and TFP in the scenario, multiplied by the baseline GDP, in each year. An alternative would be to use the increase of GDP that is generated in the scenario itself (because GDP is one of the six endogenous variables, the scenarios produce a time path for it). The scenario increases in GDP are usually higher than those for TFP, i.e., besides productivity, there is also a “factor-intensive” part of growth. We do not follow this road for the calculation of the internal rate of return, because this would also require us to estimate the costs of the increased factor use (capital and labour) that is associated to this part of growth.

The current costs are the yearly additional gross investments in domestic R&D (private and public). These costs consist of net investment and depreciation, and are calculated as the yearly gross investment in the baseline minus gross investment in the scenario. Foreign R&D investments are not considered in the rate of return calculations, because we also do not include foreign GDP increases as welfare benefits. In other words, we look at national benefits and costs, not the international ones.

With yearly benefits and costs available, we calculate yearly net benefits (benefits minus costs; these may be negative), and then numerically solve for the discount rate that sets the discounted sum of these net benefits to zero. This definition of the rate of return differs from the cross-section or panel literature, which tends to estimate the rate of return as the elasticity of output with regard to R&D capital divided by the capital-output ratio.¹⁷ The first (elasticity) is obtained by econometric estimation, while the latter (capital-output ratio) is calculated from the data as an average (see Hall et al. 2010, for slightly different procedures for direct estimates). Such a procedure is impossible in our VECM approach, because we do not estimate directly comparable elasticities.

4. The economic effects of public and private R&D

We now proceed to analyse the economic effects of public and private R&D in the Netherlands for the period 1968 – 2014. In our time series-based VECM approach, this is done by simulations that analyse the effects of an exogenous shock to the R&D capital stock variables. When these variables are shocked, either once or permanently, they will invoke deviations from long-run equilibrium (equations 1 – 4 above). These deviations will lead to adjustment dynamics in the short run (non-zero *CE* terms and their repercussions in equations 5 – 10). Given that the estimated model is stable, the economy will, over time, return to a new long-run equilibrium, in which the shock may have caused some changes relative to the original equilibrium state. These changes are considered as the (causal) effects of the original shocks,

¹⁷ In the medical literature, Sussex et al. (2016) report calculating rates of return for medical research on the basis of a VECM.

i.e., as the economic effects of public or private R&D (depending on which variables were shocked in the first place).

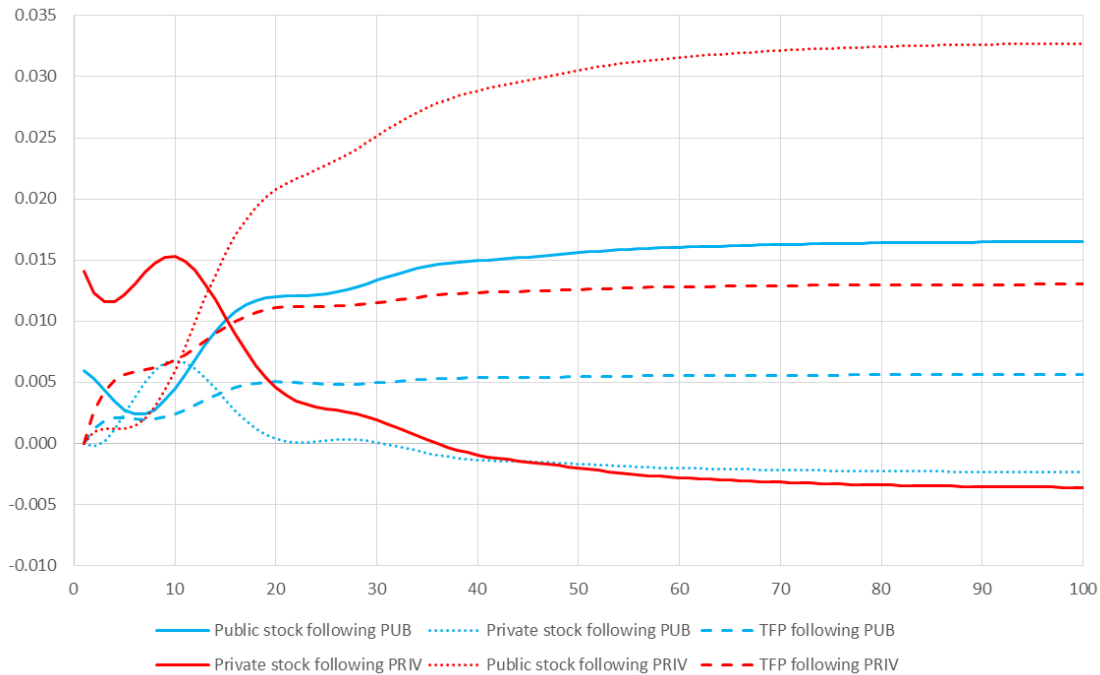


Figure 3. Impulse responses to a 1 standard deviation transitory shock in public and private R&D stocks

6.1 Transitory shocks to domestic public R&D stocks

We start by looking at the effects of a transitory shock to the domestic public R&D stock. In Figure 3, all values are measured as deviations from the baseline, which is the long-run solution of the model in Figure 2. The domestic public R&D stock starts with a transitory (i.e. once-off) shock of 0.0059 (one standard deviation). This shock has effects on the whole difference equation system, which first reacts one period later (as indicated by the fact all other variables start at zero and deviate from this in the next period).

In the long run this leads to an enhancement of the public R&D stock by 0.0156 (1.56 percent), i.e., the transitory shock becomes a larger permanent shock. Domestic private R&D has about thirty years of positive effects, with a peak of 0.0065 after ten years, but shows a negative effect in the long run. This indicates that in the long run, an increase in public R&D crowds out a small part ($0.0023/0.0156 = 0.147$ in figure 3) of private R&D in the Netherlands as suggested by Khan and Luintel (2006), but this happens only after 30 years. Before that, looking at the short and medium run dynamics of Figure 3, private R&D is a complement to public R&D in terms of deviation from baseline with some delay under the transitory shock. All of these effects are decreasing though as the changes go the opposite way after 12 years.

The long-run net effect of these two strong forces is to increase TFP by 0.005 (half a percent), which is about one third of the long-run change in the public value and therefore about half of what may be expected from the coefficient of 0.59 in the first long-term relation of equation (1).

The partial crowding-out of private R&D after all feedback effects explains a great deal of this difference. Similarly, a transitory shock to domestic private R&D shows the same long-run relation between public R&D and TFP; but the private shock starts phasing out after 10 years, and is zero after 35 years.

6.2 Permanent shocks to R&D

We now proceed to analyse the effect of permanent shocks to the R&D variables. We will implement this by adding a value to the intercepts of equations (6) to (9), which are the short-run equations for the R&D stocks. By adding a value (either 0.005 or 0.0025) to this intercept, we effectively increase the growth rate of this stock by a fixed percentage (either 0.5% or 0.25%, respectively). We document the results for 4 distinct experiments, which are defined in the first column of Table 1.

In the first experiment, only the domestic public R&D stock is shocked, by 0.5%. This represents a policy in which only public R&D expenditures in the Netherlands are targeted, and the trends in the other variables are reactions to this policy. In the second experiment, domestic public and private R&D are both shocked, by 0.25%, representing a policy in which both public and private R&D are targeted, in more or less equal magnitudes. In the third experiment, only domestic private R&D is shocked, by 0.5%, i.e., a policy in which only private R&D is shocked. In the fourth and final experiment, policy is internationally coordinated, and all four R&D stocks are shocked by 0.25%. Note that when there is a policy shock to private R&D, our model and rate of return calculations assume that there are no direct costs to the public sector for this policy.

Table 1. Scenario description and rates of return

Scenario	Internal rate of return	Average net gain / GDP	Share of private R&D costs in total costs (discounted)
1. Increasing the intercept of domestic public R&D by 0.5%	162.5%	12.8%	-0.8%
2. Increasing the intercept of domestic public R&D and domestic private R&D by 0.25% each	153.3%	12.9%	54.3%
3. Increasing the intercept of domestic private R&D by 0.5%	145.0%	13.1%	98.6%
4. Increasing the intercept of all R&D stocks (foreign and domestic) by 0.25%	139.2%	5.7%	59.5%

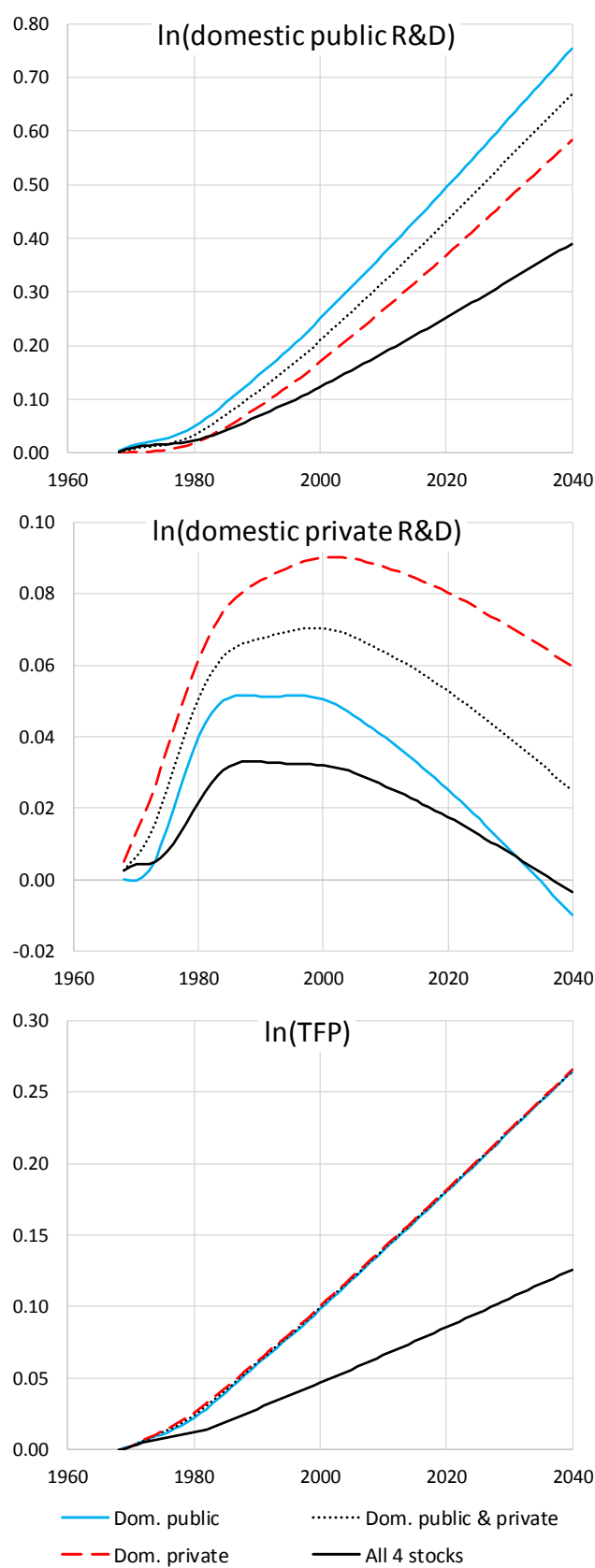


Figure 4. A permanent shock to the intercept of the short-run R&D equations, deviations to baseline

Figure 4 shows the results of the four policy simulations for TFP and the two domestic R&D stocks. Each subgraph shows the deviations for the variable from the baseline scenario in Figure 2. These deviations are always statistically significant, as their estimated standard deviations are very small. The policy is always implemented for the period 1968 – 2040.

In terms of the overall nature of the movement of the three core variables in Figure 4, i.e., the two domestic GDP stocks and TFP, the four scenarios are very similar. The domestic public R&D stock shows a clear upward movement, i.e., the deviation from the baseline is positive and increasing over time. The same holds for TFP. Thus, there is a clearly positive productivity effect for the Dutch economy from all four policy simulations. For domestic business (private) R&D, we see an inverted U-shaped pattern, with the deviation rising at first, then levelling off and eventually declining. For two scenarios, domestic private R&D ends with a negative deviation from the baseline towards the very end of the period (2035 – 2040).

Looking in detail at the differences between the four scenarios, we can point to four salient facts. First, in terms of productivity, three of the four scenarios produce almost identical results. The scenario with international coordination of R&D policy is the one with a lower trend for Dutch TFP. In the three scenarios with only Dutch policy, it makes almost no difference for productivity how Dutch R&D is distributed between the public and private sector. The similarity for productivity trends occurs despite the fact that these three scenarios yield total domestic R&D expenditures that differ substantially. Extra R&D expenditures are between 200 and 245 billion euro, over the entire period up to 2040. In the scenario with international coordination, extra domestic R&D is about 170 billion.

Second, although a shock to domestic public R&D can sustain an increase in domestic private R&D for a medium-range period (i.e., for about 15-20 years), a longer period of increases for domestic private R&D only results when there is a shock to that R&D stock itself. In this case, the increasing deviation of domestic R&D from the baseline continues for about 30-35 years. However, even with the shock to domestic R&D remaining positive until 2040, deviations to the baseline start declining after this period. Thus, looking at the (very) long run, domestic public R&D has a much stronger tendency to sustain its own growth than domestic private R&D and this keeps TFP growth increasing.

Third, and contrary to the previous point, domestic private R&D stimulates domestic public R&D for the entire period. Even without a shock to domestic public R&D itself (in the third scenario), the domestic public R&D stock shows increasing deviation to the baseline until the very end of the period. While this deviation amounts to about 60% in 2040, shocks to domestic public R&D itself only add about 10-20% to this (scenarios 1 and 2).

Fourth, the Dutch economy does not seem to benefit from shocks to the international R&D stocks. The productivity effect in the fourth scenario is much lower than in the other three scenarios, and so are the deviations for the two domestic R&D stocks. The explanation for this result lies in the estimated coefficients in the long-run and short-run equations of the econometric model, in particular equations (2), (5) and (7).

Equation (2), the long-run equation for domestic private R&D has a negative effect for foreign private R&D (hence this is a long-run substitute for domestic private R&D), and a positive sign

for foreign public R&D (which is therefore complementary to domestic private R&D in the long-run). However, the short-run equation for domestic private R&D, equation (6), shows a negative sign for foreign public R&D. Because adjustment to long-run equilibrium takes a substantial amount of time, the negative short-run effect of foreign public R&D on domestic private R&D comes to dominate the scenario with a foreign R&D shock. It makes deviations from the baseline for domestic private R&D much weaker than in the scenarios without a foreign shock. Consequently, the deviation from baseline for domestic public R&D also becomes weaker, because there is a positive feedback from domestic private R&D to domestic public R&D (equation 7).

Looking at the rates of return in Table 1, we notice that these are fairly high, i.e., between 145 and 165%. What this really means is that the benefits of the policy shocks (i.e., increased GDP due to increased R&D) quickly outweigh the costs (extra domestic R&D expenditures). Net yearly benefits turn positive very quickly after the policy shock occurs, which requires high discount rates to make the discounted flow of net benefits zero (remember our definition of internal rates of return). The quick turn to positive net benefits after the initial policy shock may be something that is specific to the macro level at which we estimate our model (e.g., because R&D expenditures immediately count as contributions to GDP). Therefore the high (internal) rates of return in our policy scenarios do not necessarily apply at a micro level.

The net gains expressed as a percentage of GDP are also sizeable: between 6 and 13% annually. The main driving factor behind these relatively large numbers is the fact that the productivity effects are cumulative. Each yearly extra growth effect for TFP is added to the cumulative effect of previous years, cumulating to more than 25% higher productivity in 2040.

Finally, Table 1 also shows how total (gross) costs of the domestic R&D shocks are distributed in the scenarios. This closely follows intuition from the definition of the scenarios. When the shock is applied to domestic public R&D only, i.e., scenario 1, the burden is entirely on public R&D (private R&D expenditures are even slightly lower than baseline). This is reversed in scenario 3, where the shock is exclusively on domestic private R&D, and costs are 98% for the private sector. The other two scenarios have shocks to both public and private R&D, and the burden is shared about equally in those cases.

5. Summary and conclusions

Compared to our time series method that considers a wide range of causal effects, single equation panel analysis with slope homogeneity have two major disadvantages. First, if heterogeneity between countries is strong, as is typically the case here, it is likely to make results insignificant. Second, feedback effects are missing unless multi-equation modelling is used, as we have done here, allowing for a better analysis of the multi-way causalities operating in this area. Therefore, we have used here a vector-error-correction model for one country only, the Netherlands, thus avoiding problems of slope homogeneity in panels and dealing with feedback mechanisms explicitly. That such heterogeneity is probably rather important was already shown by Luintel and Khan (2004) and Khan and Luintel (2006) in general and the augmented production function estimates in van Elk et al. (2015) for public R&D; the latter showing strongly different rates of return to public R&D investment between OECD countries.

With respect to the question of public and private R&D being substitutes or complements the simple but contradictory results in the literature based on interaction effects get more complicated in our dynamic model taking into account feedback effects between all variables and showing also where the R&D variables move. For transitory domestic shocks to public R&D, they are first complements and later substitutes. For permanent domestic shocks they are complements but first to an increasing extent and then to a decreasing extent. For simultaneous permanent shocks to domestic and foreign public and private R&D, they are complements, first to an increasing and then to a decreasing extent. Thus, it matters whether shocks are transitory or permanent and also whether foreign countries act simultaneously or only later. These effects are not constant but changing over time.

The simulation results for permanent shocks to the R&D variables suggest that extra public and/or private R&D will increase the growth rate of TFP and GDP in the Netherlands. The rates of return in such simulation experiments are positive, i.e., the (discounted) total costs (extra R&D) are lower than the gains (extra GDP). Thus, we conclude that the empirical evidence for 1968 – 2014 suggests that there are clear economic benefits to investing in both public and private R&D in the Netherlands.

However, our results also show that these productivity effects on the Dutch economy are weaker when they are part of an internationally concerted policy effort, i.e., when other OECD countries implement policies with the same effects on R&D stocks in their countries. The reason why the effects are weaker in this case is that Dutch domestic private R&D considers foreign public R&D as a substitute during the adjustment process, i.e., when foreign public R&D rises, Dutch private R&D tends to shrink.

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