Working Paper Series

#2017-021

The productivity effect of public R&D in the Netherlands

Luc Soete, Bart Verspagen and Thomas Ziesemer

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

Maastricht Graduate School of Governance (MGSoG)
email: info-governance@maastrichtuniversity.nl | website: http://www.maastrichtuniversity.nl/governance

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

Maastricht Graduate School of Governance
MGSoG

The productivity effect of public R&D in the Netherlands

Soete, Luc LG , UNU-MERIT & Maastricht University

Verspagen, Bart, UNU-MERIT and Department of Economics, Maastricht University

Ziesemer, Thomas HW, Department of Economics, Maastricht University, and UNU-MERIT[1]

Abstract

Using a vector-error-correction model (VECM) with endogenous stocks for total factor productivity (TFP), domestic and foreign public and private R&D as well as the GDP from which current resources are taken, we find that for the Netherlands for the period 1968-2014, extra investment in public Research and Development (R&D) has a clear positive effect on total factor productivity growth. Taking into account the costs of these extra investments, we find that the rate of return to such a policy is positive and generally high. Including private R&D in the policy from the beginning is better than increasing public R&D alone and private R&D only following.

Transitory and permanent shocks to only domestic public R&D in 1971 show positive effects on private domestic and foreign private and public R&D, total factor productivity and GDP. Under a permanent shock to the growth rate of domestic public R&D by 0.005 (an additional half percentage point on the baseline growth rate), TFP is 27.5% higher than baseline after 70 years, and the GDP is 61% higher because a higher TFP also attracts international capital one-to-one with GDP. Foreign private R&D reacts much more positively then foreign public R&D. Private R&D capital increases by up to 5.5 percent compared to baseline and returns to baseline in the long run. The internal rate of return is 131 percent obtained already in 1988. If domestic and foreign public R&D are increased by the same permanent shock of 0.005, there are positive effects for thirty five years in domestic private R&D but permanently so for all other variables; TFP would have been higher by 5.6% and GDP by 9.4%, much less than under the first strategy without the symmetric and simultaneous foreign policy. The rate of return is 4-6 percent for horizons 2014, 2024, and 2040 because of higher gains in later periods. If domestic and foreign public and private R&D growth get a shock of 0.0025 (each an additional quarter of a percent on baseline) TFP increases by 13 percent until 2040, GDP by 28 percent and the internal rate of return is 77%.

Keywords: R&D policy; public R&D investment; rate of return to public R&D investment

JEL Codes: O38, O30, H4

[1] The authors are grateful to Jacques Mairesse and Pierre Mohnen for useful comments on an earlier draft. The views expressed and possible remaining errors remain solely our own.

1. Introduction

Over the last years, 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 is high. The most well-known study (Guellec and van Pottelsberghe de la Potterie, 2001) 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 around 17%. Within that, the effect of universities was higher, possibly because in some countries, government laboratories had primarily non-economic objectives such as supporting defense. 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 needs to become more R&D intensive and more specialized.

Other studies confirmed the complementarities between public and private R&D. Jeaumotte and Pain (2005a, 2005b) analyzed 20 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%." (Jeaumotte and Pain, 2005b, p.38).

Another dimension of complementarity between public investment in research and private sector R&D arises from the attraction it exerts on internationally mobile R&D, an R&D 'crowding-in' effect. Factors such as the prospect of high quality collaborators, recruitment opportunities and technology transfer infrastructure feature variously in such studies. The overall message is that a high quality research base will attract international R&D (and the same factors will encourage domestic companies to retain and expand their R&D investments). More recent evidence on a large country such as the UK, found that public sector financed R&D had a significant impact on attracting foreign R&D (see e.g. Haskel and Wallis, 2013).

However, Van Elk et al. (2015), using a long R&D data set going back to 1963 for some countries, arrived at more ambiguous macroeconomic evidence for the economic returns on public R&D with results showing sometimes negative, zero or weakly positive impact, depending on the specific model used in the estimations. They implemented three classes of econometric models: (i) a Cobb-Douglas production function, (ii) a translog production function, and (iii) an augmented production function. In each of these, three separate types of R&D were correlated with total factor productivity levels: private R&D (carried out by business enterprise), foreign 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 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 depended strongly on the exact implementation. Private and public R&D both had a positive impact if the profit-maximization condition for that particular type of R&D were implemented. When the condition was not implemented for public R&D, the impact became negative. In the augmented model, which allows for different rates of return of public (and private) R&D between countries, the impact of public R&D appeared positive.

In the present paper we address three issues using an updated version of the data set used by Van Elk et al. (2015) for the Netherlands, thus extending the period under analysis to 1968-2014. We focus on the case of the Netherlands as a first application of the methodology, which is time series based, because it is a country with many innovative but not necessarily small firms. First, we estimate the relation between domestic and foreign public and private R&D as well as total factor productivity and GDP in a vector-error-correction framework. Second, we look specifically at the impact of transitory and permanent shocks of domestic public R&D on TFP, GDP and all the R&D variables including all the feedback effects from TFP and GDP on these variables. Third, we analyze the possibilities of international coordination of R&D, enhancing (i) the growth rate of foreign and domestic public by a symmetric permanent shock, and (ii) the growth rate of domestic and foreign public and private R&D.

In section 2 we explain the production function framework and its relation to the VAR (vector auto regression) model that is the basis of our estimations. In section 3 we briefly introduce the data. In section 4 we explain the econometric procedure. In section 5 we document the basis estimation results and the dynamic solution to the model. Section 6 presents simulation effects for the cases of (i) transitory and permanent domestic public R&D shocks, and (ii) internationally coordinated symmetric shock to either only public or all R&D variables. These results represent the core of our findings about the impact of private and public R&D on productivity growth in the Netherlands, and hence Section 6 (and the following section 7) are the ones that a reader who is less interested in the econometric procedure should focus on. In section 7 we calculate rates of return and net gains from policy for future generations.

2. Model

We extend the single equation approach of van Elk et al. (2015) to a multi-equation approach in the form of a vector error correction model (VECM) in order to capture multi-way causality explicitly, so that all variables can influence each other.

A is defined as total factor productivity, normalized to unity for 2011. 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[2], Y is domestic GDP and Y^* is foreign GDP aggregated over OECD countries. We assume that A, G, P, G^* and P^* can be represented by Cobb-Douglas functions using lagged values of all variables (including the variable itself and including either hY or h^*Y^* with h-terms as expenditure shares on R&D) on the right-hand side. These right-hand side variables represent a wide range of causal effects, e.g., the productivity effect of

[2] The notion of R&D capital stocks, and how they are calculated, is customary in the literature, and will be discussed in the next section. Here it suffices to think of these stocks as accumulated R&D spending over time.

various types of R&D and R&D spillovers, but also feedback effects of growth on R&D investment, and complementarity or substitution effects between various types of R&D. In line with the basic idea of the VAR method, we intend to let the estimation decide which of these effects exist, or are dominating in the actual realization that we see in the data. Each equation also has an exogenous (technical progress) term and residuals with an autoregressive process of order 1 (to be tested in the empirical part). The general form of these Cobb-Douglas equations can be represented as follows:

$$X_{t+1}(k) = \prod_k X(k)_t^{\alpha(k,j)}\, \alpha_{k,8} e^{\alpha(k,7)\times(t+1)+u_k},\ u_k \ =\ \rho_k u_k(-1) + \epsilon_k,\ k= 1,\ldots,5;\ j = 1, \ldots,6$$

where X represents the variables A, G, P, G^*, P^*, hY or h^*Y^*, u_k and ϵ_k are disturbance terms with the usual characteristics, the subscript k represents the index of the k-th variable and the corresponding equations with variable k on the left-hand side, j is a specific values of the index[3] for the j-th variable, the index k,j then represents the j-th argument in the k-th equation; t is a time subscript, and $\alpha_{k,j}$ and ρ_k represent the parameters that are to be estimated.

Taking logs, lagging backward by one period, as indicated by the (-1) operator, and suppressing the time index we get

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

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

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

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

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

Moreover, we assume that domestic output Y is produced by a production function (ignoring labour for simplicity) $Y = UAK^b$, where U is a stochastic term, K is the capital stock, and that here are (approximately) perfect capital movements for the (OECD) countries in our sample, leading to a given interest rate r in the sample. Then, the marginal productivity condition becomes $r+\delta=bY/K$ with δ as rate of capital depreciation. Solving this equation for K and inserting it into the production function for output yields $Y = UA^{1/1-b}\left(\frac{b}{r+\delta}\right)^{b/1-b}$. Depending on the value of b, 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. Taking natural logs and inserting the first equation above for $logA$ provides the sixth equation:

[3] With $j=8$ for the constant, $j=7$ for the coefficient of the time trend, $j=6$ for the GDP, and $j=1,\ldots5$, for all other variables.

$$logY = logU + \frac{1}{1-b}logA + \frac{b}{1-b}\log\left(\frac{b}{r+\delta}\right) = logU + \frac{1}{1-b}[\alpha_{11}logA(-1) + \alpha_{12}\log(G(-1) + \alpha_{13}logP(-1) + \alpha_{14}logG^{*}(-1) + \alpha_{15}logP^{*} + \alpha_{16}log(h_1Y) + \alpha_{17}t + \alpha_{18} + u_1] + \frac{b}{1-b}\log\left(\frac{b}{r+\delta}\right)$$

We define $\alpha_{6,8} = \frac{b}{1-b} log\left(\frac{b}{r+\delta}\right) + \frac{\alpha_{18}}{1-b}$ and $\alpha_{6,j} = \alpha_{1,j}/(1-b)$, $u_6 = logU+u_1/(1-b)$, and treat the interest as a constant given from the world market. However, we will estimate the equation without the implied constraints. For foreign GDP, Y^*, we assume that its growth rate goes into a constant of the VECM below and its level into the trend of the long-term relations. In order to avoid having more than six equations in the VECM, we assume that the expenditure shares h_k are a sum of a constant plus a stochastic term included in the $\alpha_{k,8}$ and the residuals.[4] Moreover, we do not have data for h_1 and therefore we cannot split R&D data into those used in the TFP equation and those used in the equation for private R&D.

3. Data

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 Total Factor Productivity (TFP) are from the Penn World Tables (version 9.0; Feenstra et al. 2015). We use the national accounts version (RGDPNA) for GDP, and calculate our own TFP variable that uses raw labour data rather than employment data corrected for a human capital index, and national accounts-based data for GDP, the capital stock and the share of wages in GDP.

R&D data come from the OECD, and as Van Elk et al. (2015), we use old versions of the OECD database 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%). Then we use a perpetual inventory method to construct the stocks: $S_t = (1\text{-}0.15)S_{t-1}+R_t$, where S is the stock and R is current expenditure.[5] We apply this to both public and private R&D, yielding a stock both types. 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). The foreign R&D capital stocks, private and public, are distance-weighted averages of the stocks in the sample of Van Elk et al. (2015), i.e., aggregated across OECD countries (excluding the country under analysis, the Netherlands).

All variables are used in natural logarithms. In the figures and in the text we use also the following symbols synonymously:

logP = p = ln(domestic private R&D stock) = lberdst,

logG = g = ln(domestic public R&D stock) = lpubst

[4] The average over the years for BERD is 0.01 and its standard deviation is 0.001; for GERD this is 0.018 and 0.001. There is no trend is these shares.

[5] We also need to assume a fixed 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.

logG = g* = ln(foreign public R&D stock) = lfpubst*

logP = p* = ln(foreign private R&D stock) = lfberdst*

logA = a = ln(TFP level) = ltfp

logY = y = log(GDP) = LGDP

[insert Figure 1 about here]

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 sample. 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. Therefore we use 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 permanent or semi-permanent 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.

We expect that all these variables affect each other mutually. 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 theory[6] and 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 a "small country" effect.

4. Econometrics

We will estimate a time series model that accounts for mutual impact of all variables on each other, which is likely to take some time as it operates through effects of lagged variables. This is exactly the VAR perspective (with only lagged values on the right-hand side of the equations in our case). If the variables in the analysis show a unit root, i.e., are non-stationary, we need to extend this VAR perspective to a vector Error Correction Model (VECM). The VECM model estimates one or several long-run relationships between the variables (the co-integration equations). 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.

[6] 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).

For univariate unit-root analysis we use the augmented Dickey-Fuller tests including break 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 perhaps near-unit roots.[7] Therefore some of these variables are integrated of order one, I(1), whereas others are more likely I(0). Therefore we should use a (VECM).

In order to determine the lag order of the model (how many lags of each variables to use in the estimations), we estimated a VAR with endogenous GDP and TFP, domestic and foreign private and public R&D, TFP (all in natural logs), a constant and a trend. This has optimal lag length of two (for four of the standard criteria) or three (for the AIC) (we allow for a maximum of three lags in these tests[8]). However, for lag lengths two or three, the VAR model is not stable, which makes it unusable 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.

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.[9] We worked through all the four cases. The highest log likelihood is obtained under a linear trend and 4 co-integrating equations. With k=6 endogenous variables and r=4 co-integrating equations the number of unit roots is $k - r = 2$, as expected from the unit root analysis above. The estimation method is maximum likelihood.

With six variables and four co-integrating equations, identification requires that each long term relation has four constraints. In practice, one constraint imposes a coefficient of unity to one of the variables (making it similar to a "dependent" variable in a common regression framework), and the other three are zero, i.e., they exclude a variable from the equation. By implication, each long-term relation can have only two regressors besides the constant and the trend. The effects of other variables then come via the feedback relations in the whole system of six difference equations (the VAR part of the model). Support for the idea that the variables are endogenous requires that variables are significant in the long term relation and adjustment coefficients for the error correction terms are significant. Renormalization in line with these requirements allows writing the long-term relations in a way that they provide economic intuition. We first do the renormalization 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.

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

[8] 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; 26 coefficients for 47 observation results in a too low degree of freedom.

[9] A quadratic trend is a trend in the growth rate equation, which 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.

5. Estimation Results

In this section we present first the long term relations of the VECM, then the complete model which contains the long term relations. The estimation period is 1968-2014. Thereafter we present effects from temporary and permanent shocks. The permanent shocks are presented in three scenarios: a shock to domestic public R&D only; a shock of the same size also to foreign public R&D; a shock of half that size to all four R&D variables.

Long-run relations

The first co-integration equation represents a long-term equilibrium relation between TFP, domestic private and public R&D capital (*t*-values in brackets):

$$logA = -22.36 + 0.6logG + 1.8logP - 0.062t \quad (1)$$

$$[11.2] \quad [40.7] \quad [-28.4]$$

Domestic public and private R&D capital both translate positively into TFP: a one percent increase in public R&D capital leads to a 0.6 percent increase in TFP. A one-percent increase of private R&D capital increases TFP by 1.8 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.

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 an explicit short-run adjustment framework in which all variables are involved. In the equation here, we have a clearly positive impact of both public and private domestic R&D (contrary to Van Elk et al.). 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:

$$logP = 7.84 - 0.3logP^* + 0.42logG^* + 0.03t \quad (2)$$

$$[-13.3] \quad [4.96] \quad [10.9]$$

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. A foreign public R&D increase by one percent increases domestic private R&D by 0.42 percent, which is a complementarity effect.

The third long-term relation is for domestic public R&D capital, foreign public R&D capital and domestic GDP:

$$logG = -32.9 + 2.45logG^* + 0.996log(Y) - 0.067t \quad (3)$$

$$[4.8] \quad [10.7] \quad [-4.5]$$

If foreign public R&D increases by one percent domestic public R&D increases by 2.45 percent, indicating clear international complementarity in the field of public R&D. It also indicates the high costs of following foreign public R&D activities. Any percentage increase of GDP translates roughly one-to-one to public R&D, reflecting the roughly constant share of R&D in GDP, here for the public part.

The fourth and final long-run relationship is for foreign private R&D, foreign public R&D and domestic TFP:

$$logP^* = -35.9 + 4logG^* + 0.8logA - 0.08t \qquad (4)$$

[6.7] [4.26] [-4.68]

Foreign private R&D increases by four percent if its public R&D increases by one percent. If Dutch TFP increases by one percent foreign private R&D increases by 0.8 percent, perhaps because other countries' TFP increases to a similar extent.

As stressed already, all these effects are only partial long-run effects. The total system may respond differently if we take into account the interaction between these four co-integration equations, as well as the short-run adjustment dynamics represented in the VAR part of the system. Before looking at these system-wide effects by analysing the responses to transitory and permanent shocks, we will look at the estimations for the VAR part of the model.

The complete VEC model

We proceed to rewrite equations (1) – (4) to put the deviations from the long-run equilibrium relations (residuals, denoted as *CE1* – *CE4*) on the left-hand side:

$$CE1 = logA - (-22.36 + 0.6logG + 1.8logP - 0.062t)$$

$$CE2 = logP - (7.84 - 0.3logP^* + 0.42logG^* + 0.03t)$$

$$CE3 = logG - (-32.9 + 2.45logG^* + 0.996log(GDP) - 0.067t)$$

$$CE4 = logP^* - (-35.9 + 4logG^* + 0.8logA - 0.08t)$$

We include those error-correction terms in equations for the log first differences of all variables in the model, which represents the VAR part of the model. Estimation results are as follows (*t*-values in brackets; using $x = logX$ and $dx = logX - logX_{t-1}$)[10]:

$$da = - 0.35\,CE1 - 0.44CE2 + 0.043CE4 + 0.0095 + \varepsilon_A \qquad (5)$$

[-3.46] [-3.34] [2.88] [5.67]

$$dg = - 0.17CE1 - 0.24CE2 - 0.21CE3 + 0.126CE4 + 0.027 + \varepsilon_g \qquad (6)$$

[-2.97] [-2.75] [-4.6] [4.14] [31.4]

$$dp = 0.27CE1 + 0.37CE2 + 0.12CE3 + 0.027 + \varepsilon_P \qquad (7)$$

[-2.24] [2.26] [4.3] [13.2]

[10] As the underlying VAR has only one lag, the VECM has no differenced terms.

$$dp^* = 0.47CE1 + 0.74CE2 + 0.19CE3 - 0.06CE4 + 0.035 + \varepsilon_{P^*} \quad (8)$$

[11.9] [12.2] [6.06] [-2.95] [59.1]

$$dg^* = - 0.08CE2 - 0.18CE3 + 0.16CE4 + 0.03 + +\varepsilon_{g^*} \quad (9)$$

[-5.26] [-7.54] [9.83] [59.0]

$$dy = - 0.222CE1 – 0.226CE2 + 0.05CE4 + 0.025 + \varepsilon_y \quad (10)$$

[-1.455] [-1.14] [2.41] [9.95]

The error probability of rejecting the constraints on the adjustment coefficient for the long-term relation is *p-value* = 0.999. The lowest *t*-value accepted in this way is -1.14 in the last equation. The adjusted R^2 for the six equations are 0.47, 0.63, 0.24, 0.87, 0.83 and 0.34 respectively. Whenever the *CE* terms deviate from zero, they trigger changes on the left-hand side. As the expected values of the *CE* terms in long-run equilibrium (i.e., equations 1 – 4 are satisfied) and the residuals are zero, 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 indicated by the use of a production function and marginal productivity condition for capital above, the returns do not consist of TFP effects only but rather of an additional effect through capital movements on GDP that is increased twice as much as the TFP in the policy scenarios discussed below.

[insert Figure 2 about here]

Stochastic solution of the model

We solve the model dynamically with one thousand stochastic repetitions using normal random numbers (see Figure 2). Some salient findings from this dynamic solution is that Dutch GDP for the period 1979-1989 is below the long-run trend, while for 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.[11]

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

[11] 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.

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

[insert Figure 3 about here]

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 0.0165 (1.65 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 0.0068 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 some private R&D in the Netherlands. The long-run net effect of these two strong forces is to increase TFP by 0.0056 (half a percent), which is about one third of the long-run change in the public value and therefore about half of what can be expected from the first long-term relation. The crowding-out of private R&D explains a great deal of this difference.

On the other hand, foreign private and public R&D seem to work more like a strategic complement, i.e., both same into the same (positive) direction. Moreover, foreign private and public R&D show strongly different magnitudes and therefore should not be aggregated. The long-run effect of the transitory shock on Dutch GDP is 0.013, which is more than twice as much as that of the TFP and can be explained through reduction of capital outward movements, and perhaps temporarily higher employment. The difference between the long-run increase in domestic public R&D and the initial shock, 0.0165-0.0059, is roughly equal to the increase of private foreign R&D by 0.01 and domestic GDP by 0.013, the former representing the increase in competitors' effort and the latter representing the increase in gross social revenue and additional means in the domestic R&D and TFP enhancement processes. In contrast, foreign public R&D reacts only by one-tenths of this order of magnitude.

[insert Figure 4 about here]

A permanent shock to public R&D

The public R&D equation (6) has an intercept of 0.027, its long-run growth rate. We assume and impose that policy can add 0.005 to this permanently. Figure 4, in the lower left panel, shows what we have added to the intercept: nothing until 1970 and then 0.005 in 1971. In all four graphs the two lines in the middle, which are very close to each other, are the actual data and the model simulation as in Figure 2 above. The three higher lines show the level of the variables with the policy in the middle and the confidence interval around it. For all variables the values under the policy shock are higher compared to baseline, with the exception of the years 1972 and 1973 for domestic and foreign private R&D, which react negatively in the beginning period. The lowest line shows the difference between the policy and the baseline scenario, both in log variables and therefore as a percentage difference.

Public R&D and TFP run up to 74.3% and 27.5%, respectively, above baseline in the seventy years from 1971 to 2040 through the shift of the intercept in equation (6) from 0.027 to 0.032. These two variables show an increasing deviation from the baseline until the very end of the simulation period (2040), as do GDP and the foreign R&D stocks. The conclusion is that there is a clearly positive productivity effect for the Dutch economy from the policy simulation that permanently increases public R&D.

For private R&D, the change relative to the baseline goes up to only 5.6 percent beyond baseline after thirty years and then goes back to almost zero (0.002 percent) in 2040, thus, over the entire period, private R&D seems to be complementary to public R&D, as was also the case for the early phase of the effect of a transitory shock of public R&D. GDP increases by 61.4 percent above baseline, which is an additional 0.876 percent for each of the seventy years, and 2.23 times the effect on the TFP through the additional attraction of capital and perhaps other production factors.

The effects of domestic public R&D on domestic private R&D are small through the concomitant foreign R&D which has a mitigating effect on private R&D and TFP in the long run according to equation (2). This effect may have at least two interpretations. First, any action also in a small country is countered by its major competitors doing also more R&D; in this argument R&D decisions are strategic complements reducing the effect on TFP and mitigating the increase of domestic private R&D investment in spite of its complementarity.

Once the system has returned to a long run situation all CE-terms are zero. The intercept of equation (6) remains higher at 3.2 percent instead of 2.7 percent because of the permanent policy shock. The discrepancy of growth rates of the public R&D capital stock with that of TFP has become higher because TFP grows in the long-run at the rate indicated by the intercept of equation (5), which is 0.95%. But note that this does not take into account the level effect on TFP: even if the long-run growth rate of TFP remains (by assumption) unchanged by the policy experiment, 70 years of adjustment lead to very significant increases in the level of TFP. To see how this can be advantageous, especially for future generations who also inherit the cost of higher R&D growth in addition to the high TFP level, requires a rate of return analysis which will be presented in section 6.

[insert Figure 5 about here]

Internationally coordinated public R&D enhancement

In this section we assume that there is an international agreement to raise public R&D. From the Dutch perspective, this implies that domestic and foreign public R&D are all increased by a shock, which we assume is as much as that on only domestic public R&D above. The idea is to increase the intercept of the growth rate equations for public R&D by approximately that in the previous sub-section, and ask “what happens if the other countries’ governments do the same?”. We add 0.005 permanently to the constants of equation (6) and (9) for domestic and foreign public R&D. All changes are assumed again to be made from 1971 onwards. Figure 5 shows the results (the figures are constructed in the same way as Figure 4).

Figure 5 shows that the assumed policy leads to a slow start of the TFP effect in the first fifteen years. During seventy years the total effect runs up to only six percent compared to baseline. In domestic public R&D there is a similar slow start and the total effect runs up to twenty percent above baseline. Private R&D is higher for thirty years but always less than two percent above baseline. After this the effect for domestic private R&D declines and tends to zero around 2040. Also both foreign R&D variables react less strongly than under the national policy scenario. Therefore all effects are much lower than under a purely domestic shock. Foreign public R&D is going up in the beginning phase after the shock and then temporarily down whereas it was going down temporarily earlier in the national policy scenario (see Figure 5).

[insert Figure 6 about here]

Internationally coordinated public and private R&D enhancement

Finally, we increase all the four R&D variables permanently by a shock of 0.0025, which is half of what public R&D did alone in the previous scenario. The burden that was on the public R&D now is shared equally in terms of changes of growth rates with the private sector in the first period and in the long run. Figure 6 shows that all the effects are much stronger than when public R&D alone got shocked even twice as strongly in the previous scenarios. Again public R&D runs up strongly and private R&D weakly for the domestic economy and for the foreign economy it is the other way around. The TFP difference runs up to 13% percent and that for GDP to 28%, both at least twice as much as under a shock only for public R&D although the latter was twice as strong. Decreasing marginal products in the production function make it much more effective to increase all the four variables equally in the beginning. Effects from coordinating policies between public and private R&D are very high.

7. Rates of return

As the numbers above depend on the size of the shock and the length of the period under consideration, they cannot easily grasp the net effects on welfare. Therefore, we calculate the internal rates of return of the policy experiments, which are defined as the discount rate that would drive the sum of discounted net gains over time to zero. The benefits are the yearly additional GDP (deviation of policy scenario relative to baseline). The current costs are the yearly additional gross investments (re-investment plus depreciation) in domestic public and private R&D capital of the policy scenario compared to baseline. 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.

Tables A.1 - A1.3 provide the steps. Columns 1-3 present the values of the baseline scenario in natural logarithms. Columns 4-6 present the values after removing the logs. Columns 7-9 show the log differences of policy scenarios from the baseline scenario. In columns 10-12 the percentage differences of columns 7-9 are multiplied to the levels of columns 4-6 resulting in the differences of the variables from baseline. Taking differences of these latter values from the previous year gives the yearly changes of the flows of the variables in columns 13-15. Columns 16 calculates the gains as the change in policy-baseline difference of GDP from column 13 minus the corresponding change in net investments from columns 14 and 15, minus depreciation, which is the change in the difference from baseline in the stocks from columns 11 and 12. In column 17 these gains are discounted at the standard discount rate of 4 percent as it was used in much of the literature of the 20th century. In column 18 we use a discount rate for the flow of gains that should bring the sum of its discounted values in column 19 to zero in 2014. The actual work has been done for more digits than visible.

The internal rate of return for the first scenario with calculations shown in Table A.1 (columns 11-20 on the second page), where only the domestic public R&D stock gets a permanent shock of a half percent, is 131.5 percent (this includes the costs of the induced effect on domestic private R&D, which are negative in the final stage of the simulation). For the second scenario with calculations shown in Table A.2 (columns 11-20 again on the second page), where the domestic and foreign public R&D stocks get a permanent shock, the internal rate of return are four percent for the time horizon 2014, five percent for horizon 2024 and six percent for horizon 2040. These rates of return are much lower than for the first scenario But still the rate of return is clearly positive. In the third scenario with calculations shown in Table A.3 (columns 11-20 again on the second page) where the growth rates of all R&D capital stocks get a shock of a quarter of a percent the rate of return is 77 percent.

For a decision making in 1970 and the subsequent development described in the policy scenarios this analysis is appropriate. However, generations born in 2014 or later inherit not only the TFP stock but also the higher growth rates of R&D capital stock which require re- and net-investment costs. Discounting for the period before their birth may not be adequately doing justice to them. In column 20 we therefore avoid discounting and express the current flow of net gains from column 16 as percentage of GDP of the baseline scenario – using the actuals instead gives of course very similar results. In the first scenario the additional gains obtained yearly go from 0.001 in 1972 to 1.2% in 2014 and to 1.48% in 2040. For the second policy scenario, after 15 years being negative, they go 0.18% of GDP in 2014 and to 0.24% in 2040. In the third scenario they go from one negative value of -0.03% to 0.55% in 2014 and to 0.67% in 2040.

Concluding, for all three policies these gains as share of GDP are positive and increasing until 2040 (not shown) and therefore the policies are advantageous also for future generations.

8. Conclusion

Compared to our time series method that considers a wide range of causal effects, single equation panel analysis with slope homogeneity may have two disadvantages. First, if heterogeneity between countries is strong it may make results insignificant. Second, multi-way causality can better be dealt with by multi-equation modelling. Therefore we have used a vector-error-correction model for one country only, that deals with feedback mechanism explicitly and does not run into the problems of heterogeneity. That such heterogeneity is probably rather important was already shown by the augmented production function estimates in Van Elk et al. (2015), which yield strongly different rates of return to public R&D investment between OECD countries.

We have shown that feedback goes all ways between private, public, foreign R&D capital, TFP and GDP in the Netherlands. In this richer set of causal effects, the effects of policy shocks in public R&D always turn out positive in terms of total factor productivity. Thus, we conclude that the empirical evidence for 1968 – 2014 suggests that there are clear economic benefits of investing in public R&D. The internal rate of return for the Netherlands is very high except for the scenario where the growth rates of domestic and foreign public R&D get simultaneous shocks. Thus, even if we take into account the costs of extra investments in public R&D, such policies are clearly advantageous for future generations who inherit TFP and costs of growing R&D stocks.

References

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

Elk, Roel van, Bart Verspagen, Bas ter Weel, Karen van der Wiel, Bram Wouterse (2015). A macroeconomic analysis of the returns to public R&D investments. UNU-MERIT Working Paper 2015-042. September.

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.

Guellec, D., B. van Pottelsberghe, 2004, From R&D to productivity growth: do the institutional settings and the source of funds matter? *Oxford Bulletin of Economics and Statistics*, 66, 353–378.

Haskel J., G. Wallis, 2013, Public support for innovation, intangible investment and productivity growth in the UK market sector, *Economics Letters*, 119, 195–198.

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

Jeaumotte, F. and Pain, N. (2005a) 'From ideas to development: the determinants of R&D and patenting', OECD Economics Department Working Paper No. 457, OECD, Paris.

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

Appendix: Rates of return to R&D policies

Table A.1	Permanent shock to domestic public R&D									
	1	2	3	4	5	6	7	8	9	10
	Baseline			*Baseline delog*			*Deviation fr baseline in ln*			*Diff stocks*
year	*LGDP*	*lpubst*	*lberdst*	*GDP (mio)*	*PUBST*	*BERDST*	*dLGDP*	*dLpubst*	*dLberdst*	*dGDP*
1971	12.6	9.3	9.5	285501.3	11293.6	14011.1	0.000	0.005	0.000	0.0
1972	12.6	9.4	9.6	297891.5	11738.9	14483.8	0.001	0.009	0.000	198.4
1973	12.6	9.4	9.6	309850.0	12216.9	14883.1	0.002	0.013	0.000	534.9
1974	12.7	9.4	9.6	321495.5	12704.8	15248.1	0.003	0.016	0.001	992.8
1975	12.7	9.5	9.7	332388.8	13202.6	15561.5	0.005	0.018	0.003	1587.7
1976	12.7	9.5	9.7	342778.3	13699.5	15849.9	0.007	0.020	0.006	2360.3
1977	12.8	9.6	9.7	352509.8	14177.4	16136.3	0.010	0.022	0.010	3360.2
1978	12.8	9.6	9.7	361510.8	14642.5	16423.5	0.013	0.025	0.015	4636.1
1979	12.8	9.6	9.7	370685.4	15075.1	16751.2	0.017	0.028	0.021	6242.6
1980	12.8	9.6	9.7	379015.6	15491.4	17117.1	0.022	0.032	0.027	8193.1
1981	12.9	9.7	9.8	387291.9	15883.5	17521.5	0.027	0.036	0.032	10512.8
1982	12.9	9.7	9.8	395439.9	16270.4	17968.6	0.033	0.042	0.037	13197.1
1983	12.9	9.7	9.8	403381.5	16646.2	18462.8	0.040	0.049	0.042	16224.8
1984	12.9	9.7	9.9	411634.4	17033.8	18983.0	0.048	0.057	0.046	19589.0
1985	12.9	9.8	9.9	420111.6	17423.8	19538.5	0.055	0.065	0.049	23258.5
1986	13.0	9.8	9.9	428882.3	17825.0	20125.0	0.063	0.074	0.051	27207.2
1987	13.0	9.8	9.9	438051.1	18244.1	20734.0	0.072	0.084	0.053	31416.2
1988	13.0	9.8	10.0	447128.2	18676.0	21360.9	0.080	0.094	0.054	35827.9
1989	13.0	9.9	10.0	456048.7	19129.3	21989.9	0.089	0.104	0.054	40412.9
1990	13.1	9.9	10.0	465944.4	19588.3	22647.2	0.097	0.114	0.054	45264.2
1991	13.1	9.9	10.1	475693.6	20069.8	23316.4	0.106	0.124	0.055	50284.0
1992	13.1	9.9	10.1	485623.5	20569.2	23970.4	0.114	0.134	0.055	55509.2
1993	13.1	10.0	10.1	496013.2	21066.1	24646.4	0.123	0.145	0.055	60988.0
1994	13.1	10.0	10.1	506232.7	21582.3	25340.1	0.132	0.155	0.055	66662.7
1995	13.2	10.0	10.2	516677.3	22101.1	26065.9	0.141	0.165	0.055	72599.9
1996	13.2	10.0	10.2	527304.0	22624.2	26794.3	0.149	0.176	0.055	78814.3
1997	13.2	10.0	10.2	537169.7	23154.5	27538.8	0.159	0.187	0.056	85174.9
1998	13.2	10.1	10.3	547911.5	23681.3	28322.9	0.168	0.197	0.056	91946.1
1999	13.2	10.1	10.3	558445.5	24217.5	29129.0	0.177	0.208	0.056	98966.9
2000	13.3	10.1	10.3	569165.7	24758.0	29961.7	0.187	0.220	0.056	106308.1
2001	13.3	10.1	10.3	580008.6	25297.7	30834.0	0.196	0.231	0.056	113962.0
2002	13.3	10.2	10.4	591248.4	25840.7	31734.2	0.206	0.243	0.056	121985.1
2003	13.3	10.2	10.4	601829.8	26395.3	32653.4	0.216	0.255	0.055	130155.5
2004	13.3	10.2	10.4	613388.4	26952.4	33628.6	0.226	0.267	0.055	138816.7
2005	13.3	10.2	10.5	624568.6	27520.4	34646.7	0.236	0.279	0.054	147670.6
2006	13.4	10.2	10.5	635659.7	28098.4	35696.1	0.247	0.292	0.053	156770.6
2007	13.4	10.3	10.5	647367.5	28687.9	36762.5	0.257	0.304	0.052	166289.8
2008	13.4	10.3	10.5	659472.2	29285.5	37868.1	0.267	0.317	0.051	176184.7
2009	13.4	10.3	10.6	672183.5	29884.8	39030.0	0.277	0.329	0.050	186523.7
2010	13.4	10.3	10.6	684192.0	30509.4	40231.7	0.288	0.342	0.049	196948.3
2011	13.5	10.3	10.6	696618.7	31138.3	41464.3	0.298	0.355	0.048	207772.1
2012	13.5	10.4	10.7	709697.9	31788.0	42737.9	0.309	0.367	0.047	219082.3
2013	13.5	10.4	10.7	722803.5	32455.9	44023.8	0.319	0.380	0.046	230702.5
2014	13.5	10.4	10.7	736250.8	33146.7	45309.1	0.330	0.393	0.044	242740.3

(Table 1 continued)									
11	12	13	14	15	16	17	18	19	20
; to base		*Difference of flows to baseline*				*4 perc*	*irr*		
dPUBST	*dberdst*	*ddGDP*	*ddPUBST*	*ddBERDST*	*gain*	*disc gain*	*disc gain*	*sum (18)*	*gain/gdp*
56.5	0.0		56.5		-64.9	-64.9	-64.938	-64.9383	0.000
111.1	-3.4	198.4	54.6	-3.4	131.1	126.0	35.204	-29.7342	0.000
160.8	-1.5	336.5	49.7	2.0	261.0	240.9	18.809	-10.9250	0.001
204.4	13.2	457.8	43.7	14.7	366.9	325.4	7.099422	-3.82562	0.001
243.2	45.3	595.0	38.7	32.1	480.9	409.8	2.498258	-1.32736	0.001
279.7	96.6	772.5	36.6	51.4	628.2	514.3	0.876187	-0.45117	0.002
317.9	166.6	999.9	38.2	70.0	819.1	644.3	0.306719	-0.14445	0.002
362.5	252.4	1276.0	44.6	85.8	1053.4	796.1	0.105900	-0.03855	0.003
417.8	350.4	1606.4	55.3	98.0	1337.9	971.5	0.036111	-0.00244	0.004
488.3	456.0	1950.6	70.4	105.7	1632.8	1139.2	0.011832	0.00939	0.004
576.6	564.6	2319.7	88.3	108.6	1951.6	1308.2	0.003797	0.01319	0.005
685.2	671.9	2684.3	108.6	107.2	2264.9	1458.7	0.001183	0.01437	0.006
814.6	774.3	3027.7	129.3	102.4	2557.6	1582.6	0.000359	0.01473	0.006
965.2	868.3	3364.2	150.6	94.0	2844.5	1691.1	0.000107	0.01484	0.007
1135.5	952.7	3669.4	170.3	84.4	3101.5	1771.6	0.000031	0.01487	0.007
1324.3	1026.7	3948.7	188.8	74.0	3333.2	1829.3	0.000009	0.01488	0.008
1530.3	1090.4	4209.1	206.0	63.7	3546.2	1869.9	0.000003	0.01488	0.008
1751.3	1145.1	4411.7	221.0	54.7	3701.5	1875.3	0.000001	0.01488	0.008
1986.7	1191.8	4585.0	235.3	46.7	3826.2	1862.4	0.000000	0.01488	0.008
2233.7	1234.2	4851.3	247.0	42.5	4041.7	1890.2	0.000000	0.01488	0.009
2493.6	1273.9	5019.8	259.9	39.7	4155.1	1867.0	0.000000	0.01488	0.009
2766.1	1311.4	5225.2	272.5	37.5	4303.5	1857.9	0.000000	0.01488	0.009
3048.9	1350.4	5478.8	282.8	38.9	4497.2	1865.3	0.000000	0.01488	0.009
3345.8	1391.6	5674.8	296.9	41.2	4626.0	1843.6	0.000000	0.01488	0.009
3655.5	1436.2	5937.2	309.7	44.7	4819.0	1845.2	0.000000	0.01488	0.009
3979.6	1482.6	6214.4	324.0	46.3	5024.7	1848.5	0.000000	0.01488	0.010
4319.6	1530.6	6360.6	340.1	48.1	5094.9	1800.8	0.000000	0.01488	0.009
4675.0	1580.7	6771.1	355.3	50.1	5427.3	1843.1	0.000000	0.01488	0.010
5048.9	1630.7	7020.8	374.0	50.0	5595.0	1825.5	0.000000	0.01488	0.010
5441.3	1679.5	7341.2	392.4	48.8	5831.9	1828.2	0.000000	0.01488	0.010
5851.5	1726.6	7653.9	410.2	47.1	6059.9	1825.2	0.000000	0.01488	0.010
6280.4	1770.5	8023.2	428.9	43.8	6342.7	1835.5	0.000000	0.01488	0.011
6730.3	1809.8	8170.4	449.8	39.3	6400.3	1779.5	0.000000	0.01488	0.011
7198.6	1846.1	8661.2	468.4	36.3	6799.8	1816.5	0.000000	0.01488	0.011
7687.5	1878.5	8853.9	488.9	32.4	6897.7	1770.4	0.000000	0.01488	0.011
8196.6	1906.4	9099.9	509.1	27.9	7047.5	1737.9	0.000000	0.01488	0.011
8726.2	1929.3	9519.2	529.6	22.9	7368.4	1745.8	0.000000	0.01488	0.011
9275.3	1948.7	9894.9	549.1	19.4	7642.8	1739.8	0.000000	0.01488	0.012
9841.9	1965.9	10339.0	566.6	17.2	7984.0	1746.2	0.000000	0.01488	0.012
10433.9	1980.4	10424.6	592.0	14.5	7956.0	1671.9	0.000000	0.01488	0.012
11044.7	1992.0	10823.7	610.8	11.6	8245.8	1664.8	0.000000	0.01488	0.012
11680.7	2001.4	11310.3	636.0	9.4	8612.6	1670.7	0.000000	0.01488	0.012
12341.7	2007.4	11620.1	661.1	5.9	8800.8	1640.2	0.000000	0.01488	0.012
13030.6	2009.2	12037.8	688.9	1.8	9091.1	1627.9	0.000000	0.01488	0.012

Table A.2	**Permanent shock to domestic and foreign public R&D**									
	1	2	3	4	5	6	7	8	9	10
	Baseline			*Baseline delog*			*Deviation fr baseline in ln*			*Diff stocks*
year	*LGDP*	*lpubst*	*lberdst*	*GDP (mio)*	*PUBST*	*BERDST*	*dLGDP*	*dLpubs*	*dLberdst*	*dGDP*
1971	12.56	9.33	9.55	285501.29	11293.62	14011.15	0.000	0.005	0.000	0.00
1972	12.60	9.37	9.58	297891.52	11738.87	14483.80	0.000	0.010	-0.002	15.00
1973	12.64	9.41	9.61	309849.95	12216.92	14883.07	0.000	0.014	-0.006	-93.07
1974	12.68	9.45	9.63	321495.52	12704.75	15248.09	-0.001	0.017	-0.011	-410.43
1975	12.71	9.49	9.65	332388.77	13202.58	15561.51	-0.003	0.018	-0.014	-968.89
1976	12.74	9.53	9.67	342778.30	13699.46	15849.91	-0.005	0.018	-0.017	-1751.87
1977	12.77	9.56	9.69	352509.83	14177.42	16136.25	-0.008	0.017	-0.019	-2703.27
1978	12.80	9.59	9.71	361510.76	14642.52	16423.48	-0.010	0.014	-0.018	-3741.39
1979	12.82	9.62	9.73	370685.41	15075.11	16751.18	-0.013	0.011	-0.017	-4786.09
1980	12.85	9.65	9.75	379015.61	15491.39	17117.13	-0.015	0.008	-0.014	-5739.68
1981	12.87	9.67	9.77	387291.95	15883.54	17521.47	-0.017	0.006	-0.010	-6539.81
1982	12.89	9.70	9.80	395439.89	16270.37	17968.59	-0.018	0.004	-0.005	-7134.18
1983	12.91	9.72	9.82	403381.46	16646.20	18462.84	-0.019	0.002	-0.001	-7493.02
1984	12.93	9.74	9.85	411634.37	17033.84	18983.01	-0.019	0.002	0.003	-7620.60
1985	12.95	9.77	9.88	420111.64	17423.76	19538.52	-0.018	0.003	0.007	-7529.67
1986	12.97	9.79	9.91	428882.33	17825.04	20125.03	-0.017	0.004	0.010	-7250.40
1987	12.99	9.81	9.94	438051.08	18244.06	20734.00	-0.016	0.006	0.012	-6822.49
1988	13.01	9.83	9.97	447128.19	18675.97	21360.88	-0.014	0.009	0.014	-6280.32
1989	13.03	9.86	10.00	456048.70	19129.32	21989.87	-0.012	0.012	0.015	-5665.29
1990	13.05	9.88	10.03	465944.35	19588.32	22647.21	-0.011	0.015	0.015	-5026.56
1991	13.07	9.91	10.06	475693.64	20069.83	23316.43	-0.009	0.018	0.015	-4376.64
1992	13.09	9.93	10.08	485623.49	20569.25	23970.42	-0.008	0.021	0.014	-3735.98
1993	13.11	9.96	10.11	496013.15	21066.10	24646.40	-0.006	0.024	0.014	-3112.21
1994	13.13	9.98	10.14	506232.66	21582.34	25340.13	-0.005	0.027	0.014	-2497.35
1995	13.16	10.00	10.17	516677.30	22101.11	26065.92	-0.004	0.029	0.013	-1882.74
1996	13.18	10.03	10.20	527304.00	22624.24	26794.30	-0.002	0.032	0.013	-1251.18
1997	13.19	10.05	10.22	537169.73	23154.46	27538.85	-0.001	0.034	0.013	-581.94
1998	13.21	10.07	10.25	547911.48	23681.28	28322.88	0.000	0.037	0.013	141.61
1999	13.23	10.09	10.28	558445.48	24217.46	29128.98	0.002	0.039	0.014	938.51
2000	13.25	10.12	10.31	569165.73	24757.98	29961.71	0.003	0.042	0.014	1822.84
2001	13.27	10.14	10.34	580008.65	25297.68	30834.02	0.005	0.045	0.015	2804.36
2002	13.29	10.16	10.37	591248.39	25840.65	31734.21	0.007	0.048	0.015	3889.86
2003	13.31	10.18	10.39	601829.76	26395.26	32653.42	0.008	0.051	0.015	5072.47
2004	13.33	10.20	10.42	613388.42	26952.39	33628.64	0.010	0.054	0.016	6361.39
2005	13.34	10.22	10.45	624568.64	27520.39	34646.74	0.012	0.058	0.016	7738.84
2006	13.36	10.24	10.48	635659.68	28098.44	35696.08	0.014	0.061	0.016	9198.37
2007	13.38	10.26	10.51	647367.46	28687.93	36762.46	0.017	0.065	0.015	10742.30
2008	13.40	10.28	10.54	659472.22	29285.45	37868.10	0.019	0.068	0.015	12362.27
2009	13.42	10.31	10.57	672183.47	29884.76	39030.03	0.021	0.072	0.015	14058.48
2010	13.44	10.33	10.60	684191.98	30509.40	40231.68	0.023	0.076	0.014	15799.77
2011	13.45	10.35	10.63	696618.68	31138.31	41464.31	0.025	0.080	0.014	17607.15
2012	13.47	10.37	10.66	709697.91	31788.00	42737.85	0.027	0.083	0.013	19489.10
2013	13.49	10.39	10.69	722803.45	32455.92	44023.77	0.030	0.087	0.013	21432.50
2014	13.51	10.41	10.72	736250.85	33146.72	45309.10	0.032	0.091	0.012	23450.09

(Table 2 cont.)									
11	12	13	14	15	16	17	18	19	20
to base		*Difference of flows to baseline*				*4 perc*	*irr*		
dPUBST	*dberdst*	*ddGDP*	*ddPUBST*	*ddBERDST*	*gain*	*disc gain*	*disc gain*	*sum (18)*	*gain/GDP*
56.47	0.00		56.47		-64.94	-64.94	-64.94	-64.94	-0.0002
117.57	-35.64	15.00	61.10	-35.64	-22.76	-21.87	-21.87	-86.81	-0.0001
173.87	-94.24	-108.06	56.30	-58.60	-117.70	-108.65	-108.65	-195.46	-0.0004
217.60	-161.79	-317.36	43.73	-67.55	-301.90	-267.77	-267.77	-463.22	-0.0009
243.86	-224.80	-558.46	26.26	-63.01	-524.57	-447.01	-447.01	-910.24	-0.0016
250.53	-272.76	-782.98	6.67	-47.96	-738.36	-604.52	-604.52	-1514.75	-0.0022
238.25	-298.90	-951.40	-12.27	-26.14	-903.89	-711.03	-711.03	-2225.78	-0.0026
210.64	-299.88	-1038.12	-27.61	-0.99	-996.14	-752.87	-752.87	-2978.64	-0.0028
172.74	-276.44	-1044.70	-37.91	23.45	-1014.68	-736.81	-736.81	-3715.46	-0.0027
131.00	-231.14	-953.59	-41.74	45.30	-942.13	-657.30	-657.30	-4372.75	-0.0025
91.58	-168.52	-800.13	-39.42	62.62	-811.79	-544.16	-544.16	-4916.91	-0.0021
60.06	-94.31	-594.37	-31.52	74.21	-631.92	-406.98	-406.98	-5323.89	-0.0016
40.55	-14.59	-358.84	-19.51	79.72	-422.94	-261.71	-261.71	-5585.61	-0.0010
35.69	64.80	-127.58	-4.86	79.39	-217.19	-129.12	-129.12	-5714.73	-0.0005
46.46	138.69	90.93	10.78	73.89	-21.51	-12.29	-12.29	-5727.01	-0.0001
72.51	203.14	279.27	26.04	64.45	147.43	80.91	80.91	-5646.10	0.0003
112.35	255.57	427.91	39.84	52.43	280.46	147.88	147.88	-5498.22	0.0006
163.71	294.93	542.16	51.36	39.36	382.64	193.85	193.85	-5304.37	0.0009
224.02	321.46	615.03	60.31	26.53	446.37	217.27	217.27	-5087.10	0.0010
290.42	337.22	638.73	66.40	15.75	462.43	216.26	216.26	-4870.83	0.0010
360.69	344.51	649.92	70.27	7.29	466.58	209.65	209.65	-4661.19	0.0010
432.90	345.95	640.66	72.20	1.44	450.18	194.35	194.35	-4466.84	0.0009
505.30	345.18	623.77	72.40	-0.77	424.58	176.11	176.11	-4290.73	0.0009
577.76	344.90	614.85	72.47	-0.28	404.27	161.11	161.11	-4129.62	0.0008
649.96	347.51	614.61	72.19	2.61	390.18	149.40	149.40	-3980.22	0.0008
722.54	354.11	631.56	72.58	6.59	390.89	143.80	143.80	-3836.42	0.0007
796.66	365.55	669.24	74.12	11.45	409.34	144.68	144.68	-3691.74	0.0008
873.27	382.10	723.55	76.61	16.55	442.09	150.13	150.13	-3541.61	0.0008
954.21	402.82	796.90	80.94	20.72	491.69	160.43	160.43	-3381.18	0.0009
1040.62	426.60	884.33	86.41	23.78	554.06	173.69	173.69	-3207.49	0.0010
1133.38	452.18	981.52	92.76	25.58	625.34	188.35	188.35	-3019.14	0.0011
1233.46	477.84	1085.50	100.08	25.67	703.06	203.46	203.46	-2815.69	0.0012
1341.75	502.01	1182.61	108.29	24.16	773.60	215.09	215.09	-2600.60	0.0013
1457.97	524.00	1288.92	116.22	21.99	853.41	227.98	227.98	-2372.62	0.0014
1582.45	542.71	1377.46	124.48	18.71	915.49	234.97	234.97	-2137.65	0.0015
1714.85	557.41	1459.52	132.40	14.70	971.58	239.59	239.59	-1898.06	0.0015
1854.82	567.70	1543.93	139.96	10.29	1030.30	244.11	244.11	-1653.96	0.0016
2001.63	574.08	1619.98	146.81	6.38	1080.43	245.95	245.95	-1408.01	0.0016
2154.33	577.21	1696.21	152.70	3.13	1130.64	247.28	247.28	-1160.73	0.0017
2314.22	577.41	1741.30	159.89	0.20	1147.47	241.12	241.12	-919.60	0.0017
2479.52	575.20	1807.37	165.30	-2.21	1186.08	239.46	239.46	-680.14	0.0017
2651.41	571.38	1881.96	171.89	-3.82	1230.47	238.69	238.69	-441.45	0.0017
2829.81	566.12	1943.39	178.40	-5.25	1260.86	234.99	234.99	-206.46	0.0017
3015.40	559.72	2017.59	185.59	-6.40	1302.13	233.17	233.17	**26.71**	0.0018

Table A.3	Permanent shocks to domestic and foreign public and private R&D									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Baseline			*Baseline delog*			*Deviation fr base in ln*			*Diff stocks*
year	*LGDP*	*lpubst*	*lberdst*	*GDP (mio)*	*PUBST*	*BERDST*	*dLGDP*	*dLpubst*	*dLberdst*	*dGDP*
1971	12.56	9.33	9.55	285501.29	11293.62	14011.15	0.000	0.0025	0.0025	0.00
1972	12.60	9.37	9.58	297891.52	11738.87	14483.80	0.000	0.0053	0.0037	125.98
1973	12.64	9.41	9.61	309849.95	12216.92	14883.07	0.001	0.0080	0.0042	307.45
1974	12.68	9.45	9.63	321495.52	12704.75	15248.09	0.002	0.0104	0.0044	499.90
1975	12.71	9.49	9.65	332388.77	13202.58	15561.51	0.002	0.0122	0.0047	684.04
1976	12.74	9.53	9.67	342778.30	13699.46	15849.91	0.003	0.0136	0.0053	864.66
1977	12.77	9.56	9.69	352509.83	14177.42	16136.25	0.003	0.0147	0.0065	1063.89
1978	12.80	9.59	9.71	361510.76	14642.52	16423.48	0.004	0.0155	0.0083	1315.17
1979	12.82	9.62	9.73	370685.41	15075.11	16751.18	0.004	0.0163	0.0107	1660.42
1980	12.85	9.65	9.75	379015.61	15491.39	17117.13	0.006	0.0172	0.0135	2132.59
1981	12.87	9.67	9.77	387291.95	15883.54	17521.47	0.007	0.0185	0.0167	2765.94
1982	12.89	9.70	9.80	395439.89	16270.37	17968.59	0.009	0.0203	0.0199	3581.98
1983	12.91	9.72	9.82	403381.46	16646.20	18462.84	0.011	0.0226	0.0230	4590.81
1984	12.93	9.74	9.85	411634.37	17033.84	18983.01	0.014	0.0255	0.0259	5799.31
1985	12.95	9.77	9.88	420111.64	17423.76	19538.52	0.017	0.0290	0.0285	7200.71
1986	12.97	9.79	9.91	428882.33	17825.04	20125.03	0.020	0.0330	0.0306	8783.89
1987	12.99	9.81	9.94	438051.08	18244.06	20734.00	0.024	0.0375	0.0323	10535.50
1988	13.01	9.83	9.97	447128.19	18675.97	21360.88	0.028	0.0423	0.0335	12425.86
1989	13.03	9.86	10.00	456048.70	19129.32	21989.87	0.032	0.0473	0.0344	14432.23
1990	13.05	9.88	10.03	465944.35	19588.32	22647.21	0.036	0.0526	0.0349	16576.16
1991	13.07	9.91	10.06	475693.64	20069.83	23316.43	0.040	0.0580	0.0351	18812.20
1992	13.09	9.93	10.08	485623.49	20569.25	23970.42	0.044	0.0634	0.0353	21145.15
1993	13.11	9.96	10.11	496013.15	21066.10	24646.40	0.048	0.0688	0.0353	23587.76
1994	13.13	9.98	10.14	506232.66	21582.34	25340.13	0.052	0.0743	0.0352	26114.88
1995	13.16	10.00	10.17	516677.30	22101.11	26065.92	0.056	0.0797	0.0352	28751.88
1996	13.18	10.03	10.20	527304.00	22624.24	26794.30	0.060	0.0852	0.0352	31506.83
1997	13.19	10.05	10.22	537169.73	23154.46	27538.85	0.064	0.0907	0.0352	34330.81
1998	13.21	10.07	10.25	547911.48	23681.28	28322.88	0.068	0.0963	0.0353	37334.83
1999	13.23	10.09	10.28	558445.48	24217.46	29128.98	0.072	0.1020	0.0354	40459.61
2000	13.25	10.12	10.31	569165.73	24757.98	29961.71	0.077	0.1078	0.0354	43739.04
2001	13.27	10.14	10.34	580008.65	25297.68	30834.02	0.081	0.1137	0.0355	47174.57
2002	13.29	10.16	10.37	591248.39	25840.65	31734.21	0.086	0.1198	0.0354	50793.26
2003	13.31	10.18	10.39	601829.76	26395.26	32653.42	0.091	0.1259	0.0353	54504.79
2004	13.33	10.20	10.42	613388.42	26952.39	33628.64	0.095	0.1322	0.0351	58453.68
2005	13.34	10.22	10.45	624568.64	27520.39	34646.74	0.100	0.1387	0.0349	62514.82
2006	13.36	10.24	10.48	635659.68	28098.44	35696.08	0.105	0.1452	0.0345	66709.08
2007	13.38	10.26	10.51	647367.46	28687.93	36762.46	0.110	0.1518	0.0341	71108.43
2008	13.40	10.28	10.54	659472.22	29285.45	37868.10	0.115	0.1584	0.0335	75692.83
2009	13.42	10.31	10.57	672183.47	29884.76	39030.03	0.120	0.1651	0.0329	80490.05
2010	13.44	10.33	10.60	684191.98	30509.40	40231.68	0.125	0.1719	0.0323	85343.61
2011	13.45	10.35	10.63	696618.68	31138.31	41464.31	0.130	0.1787	0.0316	90387.11
2012	13.47	10.37	10.66	709697.91	31788.00	42737.85	0.135	0.1855	0.0309	95658.14
2013	13.49	10.39	10.69	722803.45	32455.92	44023.77	0.140	0.1924	0.0301	101079.6
2014	13.51	10.41	10.72	736250.85	33146.72	45309.10	0.145	0.1993	0.0294	106698.7

Table A.3 cont.									
11	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
to base		*Difference of flows to baseline*				*4 perc*	*irr*		
dPUBST	*dberdst*	*ddGDP*	*ddPUBST*	*ddBERDST*	*gain*	*disc gain*	*disc gain*	*sum (18)*	*gain/gdp*
28.23	35.03		28.23	35.03	-72.75	-72.75	-72.7512	-72.7512	-0.0003
62.25	54.21	125.98	34.02	19.19	55.31	53.14	25.6074	-47.1438	0.0002
97.83	62.76	181.47	35.58	8.55	113.25	104.54	24.2783	-22.8655	0.0004
131.57	66.93	192.46	33.74	4.16	124.79	110.68	12.3864	-10.4791	0.0004
161.44	72.42	184.14	29.87	5.49	113.69	96.88	5.22503	-5.25404	0.0003
186.70	84.03	180.62	25.26	11.61	103.15	84.46	2.19509	-3.05895	0.0003
207.76	104.95	199.23	21.06	20.92	110.34	86.80	1.08715	-1.97180	0.0003
226.47	136.61	251.28	18.72	31.67	146.43	110.67	0.66803	-1.30377	0.0004
245.10	179.27	345.25	18.62	42.66	220.31	159.98	0.46536	-0.83841	0.0006
266.77	231.71	472.17	21.67	52.44	323.29	225.55	0.31618	-0.52223	0.0009
294.20	291.84	633.35	27.44	60.13	457.88	306.93	0.20734	-0.31489	0.0012
330.21	357.12	816.04	36.01	65.28	611.65	393.92	0.12824	-0.18665	0.0015
376.54	424.88	1008.83	46.33	67.76	774.53	479.26	0.07519	-0.11146	0.0019
434.88	491.94	1208.50	58.34	67.06	944.08	561.27	0.04243	-0.06903	0.0023
505.50	556.15	1401.41	70.62	64.22	1107.32	632.51	0.02305	-0.04598	0.0026
588.51	615.63	1583.18	83.01	59.48	1260.08	691.54	0.01214	-0.03384	0.0029
683.52	668.99	1751.61	95.01	53.36	1400.35	738.40	0.00625	-0.02759	0.0032
789.47	715.66	1890.36	105.94	46.67	1511.97	765.99	0.00312	-0.02447	0.0034
905.64	755.35	2006.38	116.17	39.69	1601.37	779.47	0.00153	-0.02294	0.0035
1030.22	789.76	2143.93	124.59	34.40	1711.94	800.62	0.00076	-0.02218	0.0037
1163.12	819.51	2236.04	132.90	29.75	1776.00	798.01	0.00036	-0.02182	0.0037
1303.47	845.06	2332.95	140.35	25.55	1844.77	796.41	0.00018	-0.02164	0.0038
1449.54	869.13	2442.61	146.08	24.07	1924.66	798.31	0.00008	-0.02156	0.0039
1602.66	892.85	2527.12	153.11	23.71	1975.97	787.46	0.00004	-0.02152	0.0039
1761.82	917.70	2637.00	159.17	24.85	2051.05	785.33	0.00002	-0.02150	0.0040
1927.56	943.29	2754.95	165.74	25.59	2132.99	784.68	0.00001	-0.02149	0.0040
2100.71	970.37	2823.98	173.15	27.08	2163.10	764.56	0.00000	-0.02148	0.0040
2281.00	999.67	3004.02	180.29	29.30	2302.34	781.86	0.00000	-0.02148	0.0042
2470.34	1030.18	3124.78	189.34	30.51	2379.85	776.50	0.00000	-0.02148	0.0043
2668.96	1061.46	3279.43	198.62	31.28	2489.97	780.57	0.00000	-0.02148	0.0044
2876.86	1093.23	3435.53	207.90	31.77	2600.34	783.21	0.00000	-0.02148	0.0045
3094.88	1124.30	3618.69	218.02	31.07	2736.72	791.96	0.00000	-0.02148	0.0046
3324.34	1153.63	3711.53	229.46	29.32	2781.05	773.24	0.00000	-0.02148	0.0046
3564.29	1181.89	3948.88	239.95	28.26	2968.75	793.06	0.00000	-0.02148	0.0048
3815.85	1208.13	4061.15	251.56	26.24	3029.75	777.62	0.00000	-0.02148	0.0049
4078.92	1231.63	4194.26	263.07	23.51	3111.10	767.19	0.00000	-0.02148	0.0049
4353.64	1251.78	4399.35	274.72	20.15	3263.66	773.25	0.00000	-0.02148	0.0050
4639.42	1269.36	4584.39	285.78	17.58	3394.72	772.77	0.00000	-0.02148	0.0051
4935.11	1285.06	4797.23	295.69	15.70	3552.82	777.04	0.00000	-0.02148	0.0053
5244.56	1298.50	4853.55	309.45	13.45	3549.20	745.82	0.00000	-0.02148	0.0052
5564.34	1309.65	5043.50	319.78	11.15	3681.48	743.28	0.00000	-0.02148	0.0053
5897.49	1319.04	5271.03	333.16	9.39	3846.01	746.05	0.00000	-0.02148	0.0054
6243.93	1325.98	5421.42	346.44	6.94	3932.55	732.93	0.00000	-0.02148	0.0054
6604.98	1330.26	5619.13	361.05	4.28	4063.52	727.64	0.00000	-0.02148	0.0055

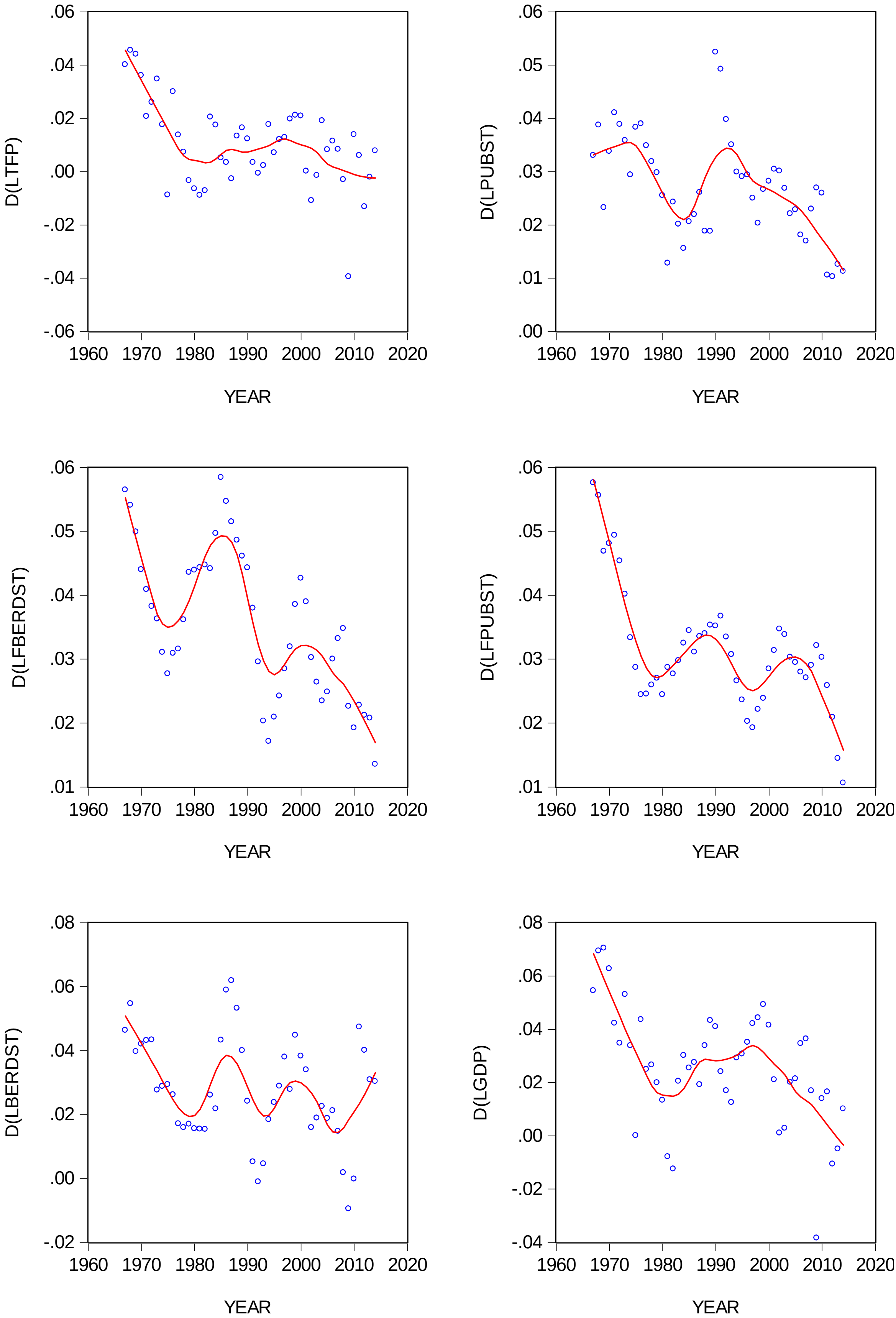

Figure 1: Growth rates 1964-2014 for GDP and TFP, domestic and foreign private and public R&D. Lines are from loess fit regressions.

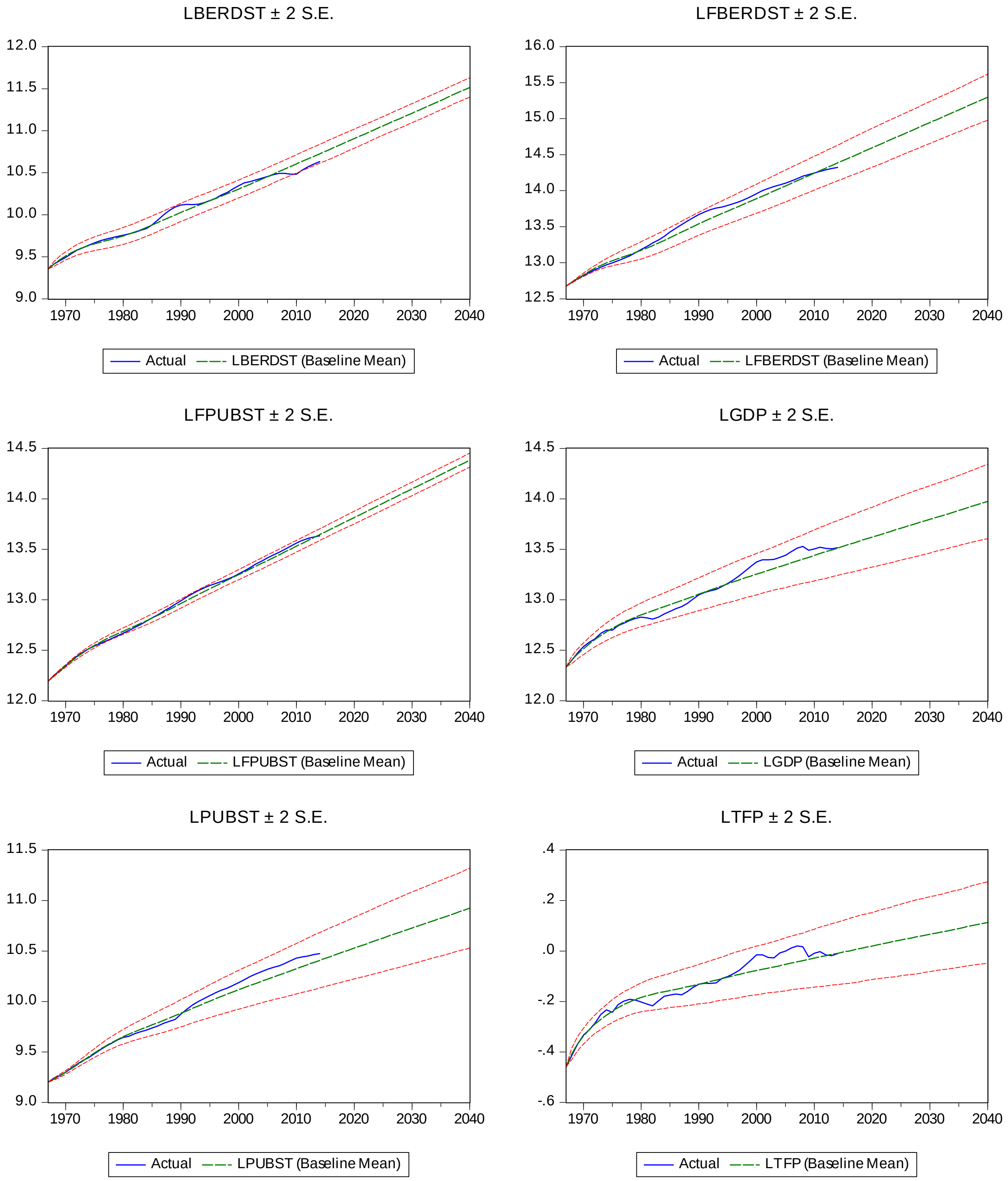

Figure 2: Dynamic stochastic solution of the VEC model (5)-(10) with confidence intervals, and actual data in natural logarithms.

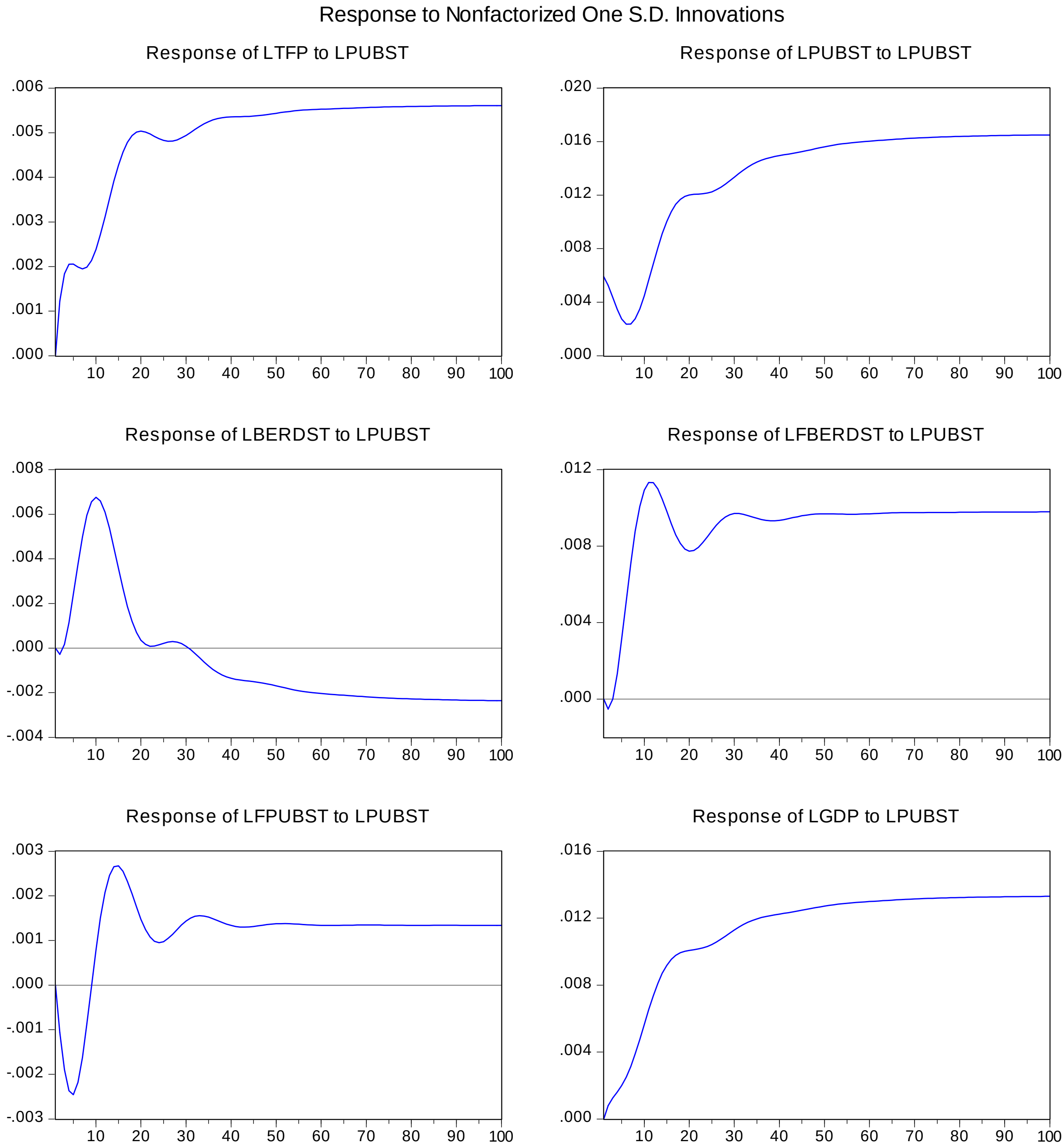

Figure 3: A transitory shock to the public R&D stock by about 0.6% goes to almost three times of its initial value permanently. TFP increases by one third of this in the long run. GDP increases by twice the percentage of TFP. Foreign public R&D reacts less strongly and foreign private R&D more strongly than there domestic counterparts.

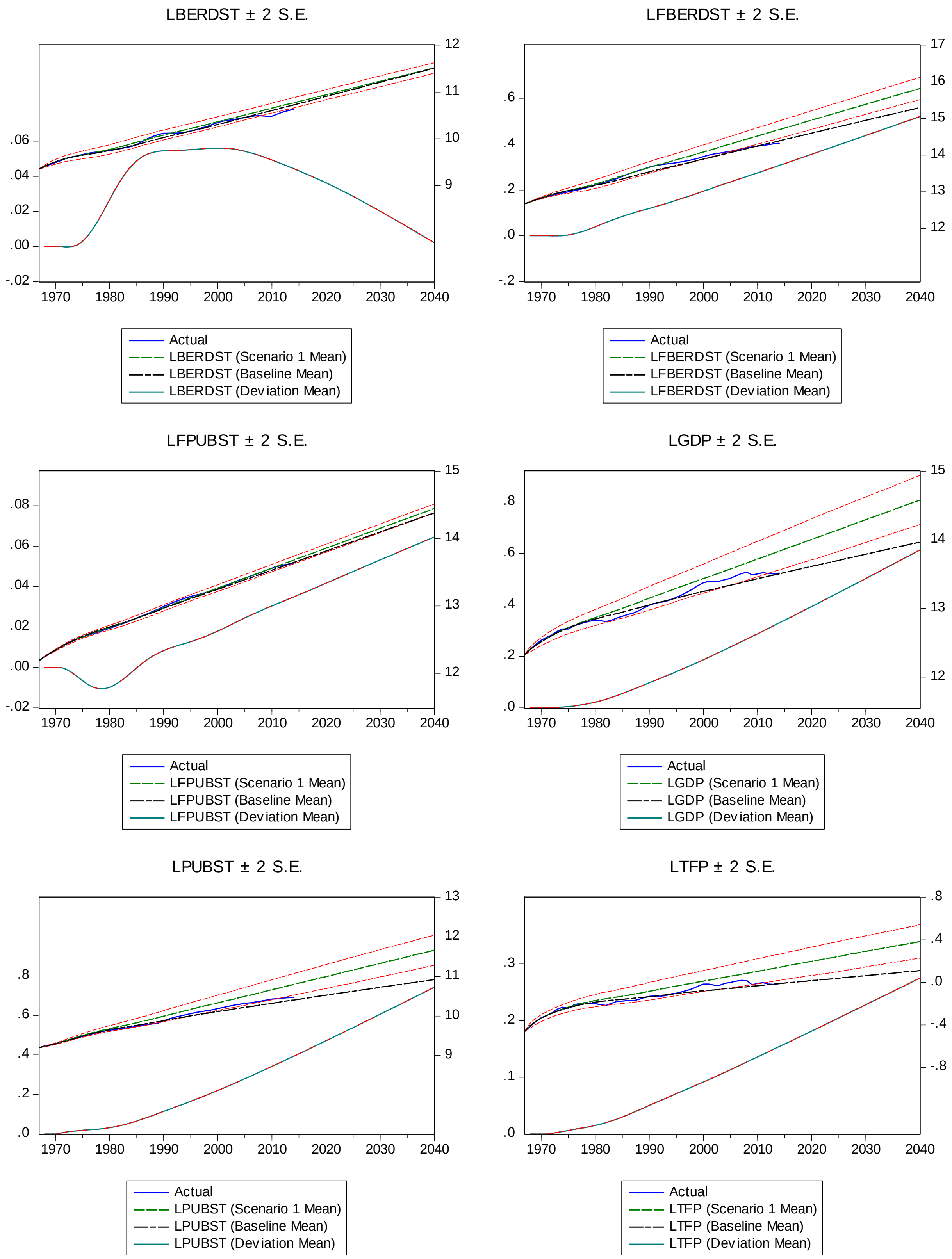

Figure 4: A permanent shock to the intercept of the public R&D stock growth equation by 0.005 in 1971 increases the domestic private R&D stock transitionally and all others permanently. The vertical axis on the right denotes the capital values in logs in the order of magnitude 9-15. The left axis measures changes through policy compared to baseline in percent, as log differences, in all graphs. Confidence intervals belong to the policy scenario.

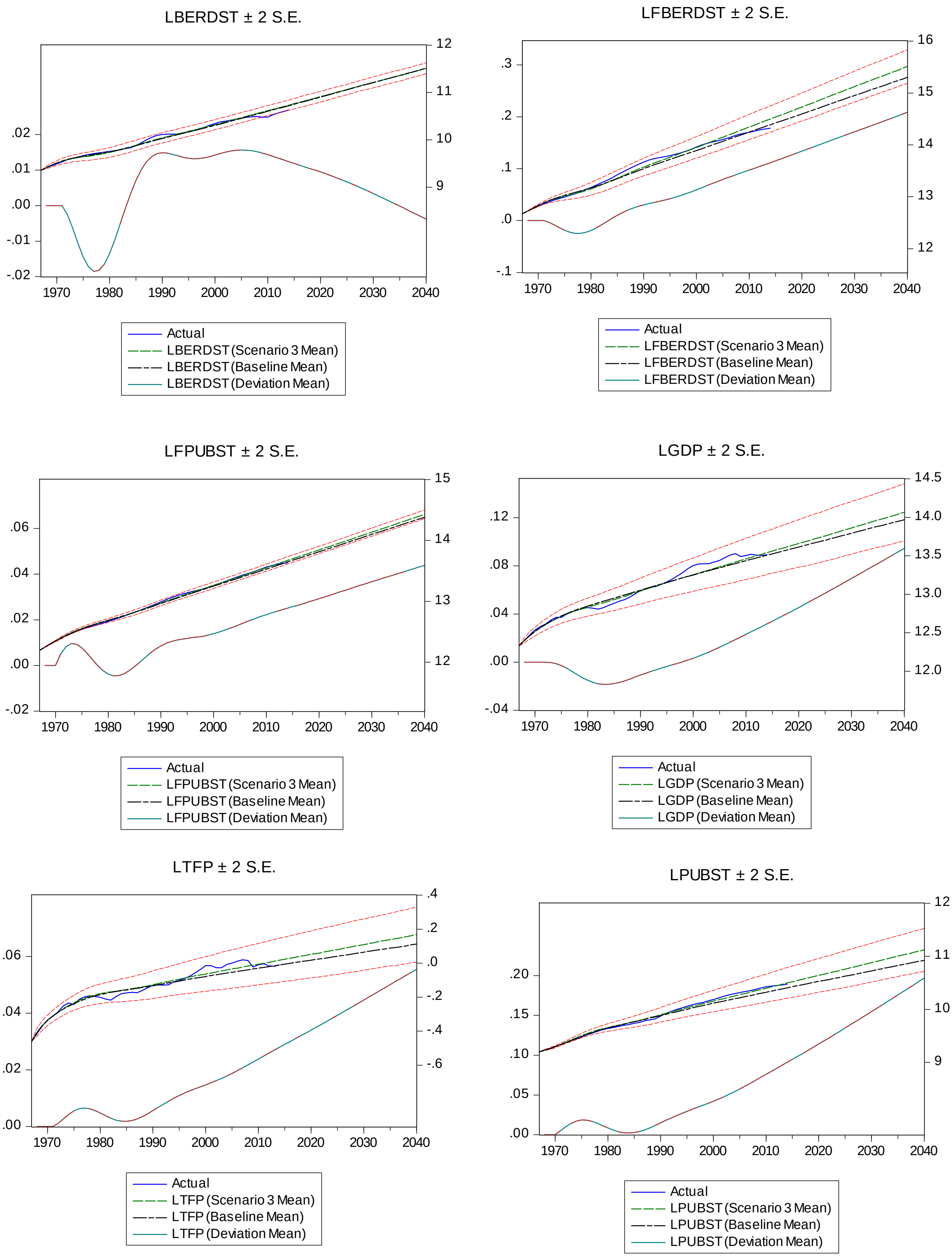

Figure 5: A shock to domestic and foreign public R&D comparable to that of Figure 5 leads to much weaker effects. In particular, foreign variables and domestic private R&D react less strongly. Confidence intervals belong to the policy scenario.

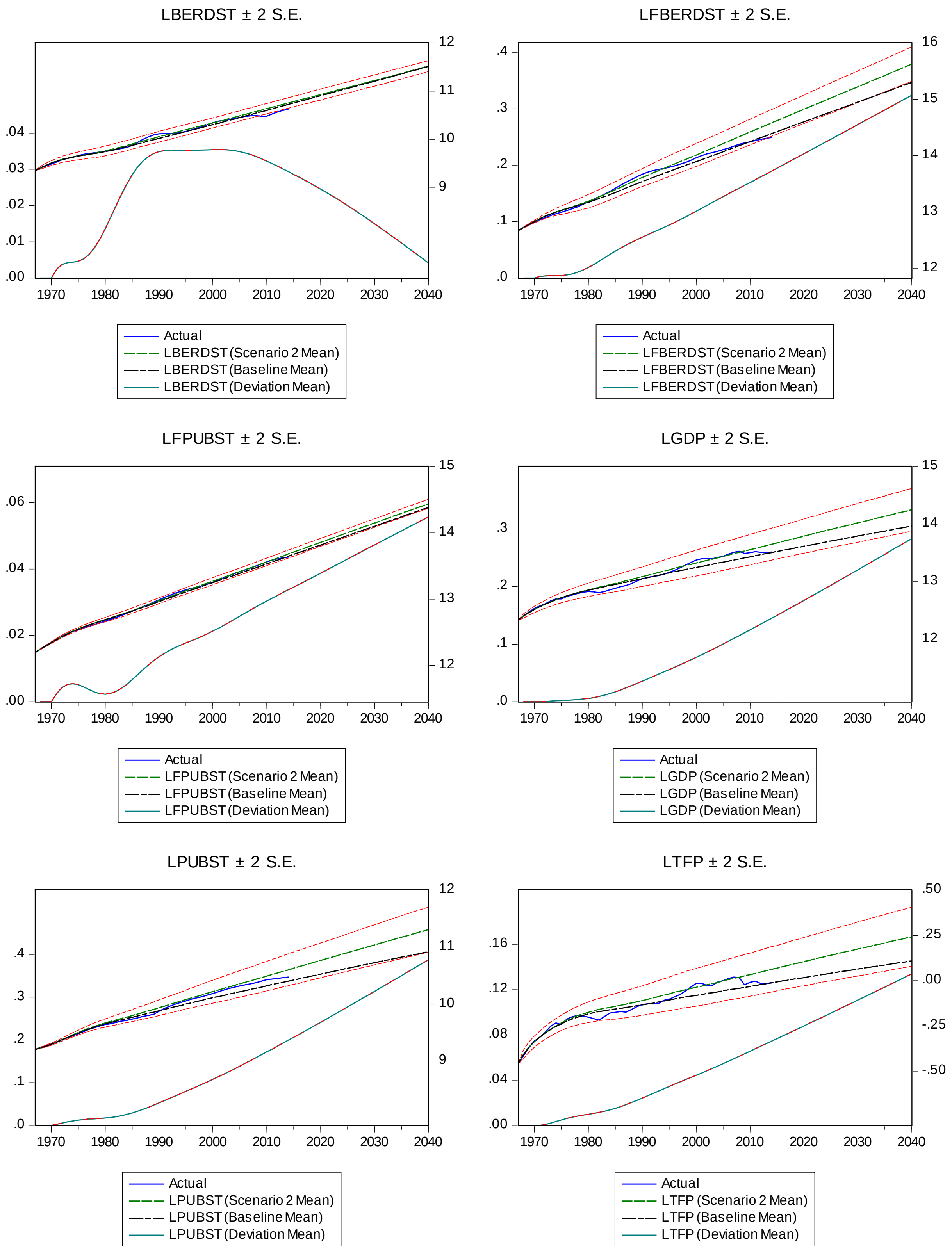

Figure 6: A simultaneous permanent shock to all R&D variables by 0.0025 increases GDP and TFP more than twice as much as under twice as strong public shocks only in Figure 6.

The UNU-MERIT WORKING Paper Series

2017-01 *The economic impact of East-West migration on the European Union* by Martin Kahanec and Mariola Pytliková
2017-02 *Fostering social mobility: The case of the 'Bono de Desarrollo Humano' in Ecuador* by Andrés Mideros and Franziska Gassmann
2017-03 *Impact of the Great Recession on industry unemployment: a 1976-2011 comparison* by Yelena Takhtamanova and Eva Sierminska
2017-04 *Labour mobility through business visits as a way to foster productivity* by Mariacristina Piva, Massimiliano Tani and Marco Vivarelli
2017-05 *Country risk, FDI flows and convergence trends in the context of the Investment Development Path* by Jonas Hub Frenken and Dorcas Mbuvi
2017-06 *How development aid explains (or not) the rise and fall of insurgent attacks in Iraq* by Pui-Hang Wong
2017-07 *Productivity and household welfare impact of technology adoption: Micro-level evidence from rural Ethiopia* by Tigist Mekonnen
2017-08 *Impact of agricultural technology adoption on market participation in the rural social network system* by Tigist Mekonnen
2017-09 *Financing rural households and its impact: Evidence from randomized field experiment data* by Tigist Mekonnen
2017-10 *U.S. and Soviet foreign aid during the Cold War: A case study of Ethiopia* by Tobias Broich
2017-11 *Do authoritarian regimes receive more Chinese development finance than democratic ones? Empirical evidence for Africa* by Tobias Broich
2017-12 *Pathways for capacity building in heterogeneous value chains: Evidence from the case of IT-enabled services in South Africa* by Charlotte Keijser and Michiko Iizuka
2017-13 *Is innovation destroying jobs? Firm-level evidence from the EU* by Mariacristina Piva and Marco Vivarelli
2017-14 *Transition from civil war to peace: The role of the United Nations and international community in Mozambique* by Ayokunu Adedokun
2017-15 *Emerging challenges to long-term peace and security in Mozambique* by Ayokunu Adedokun
2017-16 *Post-conflict peacebuilding: A critical survey of the literature and avenues for future research* by Ayokunu Adedokun
2017-17 *Effects of health insurance on labour supply: A systematic review* by Nga Le, Wim Groot, Sonila M. Tomini and Florian Tomini\
2017-18 *Challenged by migration: Europe's options* by Amelie F. Constant and Klaus F. Zimmermann
2017-19 *Innovation policy & labour productivity growth: Education, research & development, government effectiveness and business policy* by Mueid Al Raee, Jo Ritzen and Denis de Crombrugghe
2017-20 *Role of WASH and Agency in Health: A study of isolated rural communities in Nilgiris and Jalpaiguri* by Shyama V. Ramani
2017-21 *The productivity effect of public R&D in the Netherlands* by Luc Soete, Bart Verspagen and Thomas Ziesemer