Maastricht University

UNITED NATIONS UNIVERSITY

UNU-MERIT

Working Paper Series

#2021-015

Foreign R&D spillovers to the USA and strategic reactions

Thomas H.W. Ziesemer

Published 26 March 2021

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

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

UNU-MERIT Working Papers
ISSN 1871-9872

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

Foreign R&D Spillovers to the USA and Strategic Reactions

Ziesemer, Thomas H.W., Department of Economics and UNU-MERIT, Maastricht University[1].Email: T.Ziesemer@maastrichtuniversity.nl. ORCID: 0000-0002-5571-2238.

Abstract. We re-consider the traditional result of zero or negative foreign R&D spillovers or strategic reactions to the USA using accumulated shocks in a vector-error-correction model (VECM) for the period 1963-2017. Foreign private and public R&D stocks have a positive and statistically significant effect on US public R&D and labour-augmenting technical change (LATC). US private R&D reacts positively to foreign private R&D and negatively to foreign public R&D shocks. Foreign public and private R&D react positively to US public R&D. All variables react positively to US private R&D. From the time profile of the simulated VECM, we calculate the sum of discounted (at 4%) net gains for (i) additional private and public US R&D, and (ii) for policies reacting to foreign private and public R&D shocks with additional domestic private and public R&D. Additional private and public US R&D expenditures have very high internal rates of return. R&D investments in reaction to shocks from foreign R&D are profitable. All LATC reactions are transitional suggesting semi-endogenous growth for the USA.

Keywords: Growth, productivity, R&D, reaction functions, spillovers, CVAR.

JEL-codes: C51, O30, O38, O47, O51.

1. Introduction

Ever since foreign R&D capital stocks were introduced into firm or macro-level regressions explaining factor productivity, the literature on international R&D spillovers finds that the spillovers (including competition effects) to the United States are zero or negative (see Luintel and Khan 2004).[2] That result is based on the long-term relations of country-by-country vector-error-correction models (VECM), which are adequate in dealing with country heterogeneity. R&D capital stocks of foreign countries used in these studies include either total aggregated R&D or only business R&D expenditures. Similarly, Atukeren (2007) finds no effect of spillovers or competitive reactions from the European Union on the USA. Bernstein and Mohnen (1998) find no effect of spillovers from Japan on the USA, but rather only one from the USA to Japan. We do not deal with Japan or the European Union separately, but our analysis can be seen as one of a joint effect as the foreign R&D capital stock for the US in our data consists of those of the EU15, Japan, and Canada.

An exception to the result that the USA does not receive spillovers is a paper by Luintel and Khan (2009). They provide panel System GMM estimates with interaction terms. Foreign knowledge stocks, constructed from triadic patent data, interact with the domestic ones and domestic human capital, and have a positive impact on the change of domestic patent stocks, which in turn have a positive impact on TFP. The country-specific interaction terms and their indirect link to a country-specific TFP equation are a construct capturing heterogeneity and show a partial effect of foreign positive spillovers to the USA. This paper differs from ours in

*I am grateful to Luc Soete and Bart Verspagen for stimulating discussions and to Bart for providing the R&D stock data.

[2] Earlier literature finding the same result is summarized by Cincera and van Pottelsberghe de la Potterie (2001).

several respects: (i) They look at foreign triadic and domestic patents and TFP whereas we look at R&D expenditures and LATC; (ii) they investigate partial relations between these variables whereas we investigate multiple dynamic interactions between R&D expenditure stocks. (iii) Our R&D expenditure stocks are differentiated between publicly and privately performed R&D whereas their patent data are not distinguishing between business owned and publicly owned (as by universities and other non-university research institutions). An important contribution of their paper is that it indicates the possibility that considering heterogeneity may lead to a different result than the one of no spillovers to the USA.

We use foreign public (non-business) R&D capital stocks besides those of foreign business R&D stocks for the period 1963-2017 in a VECM. This allows extending the analysis of Luintel and Khan (2004) by way of including foreign public R&D stocks. This possibility makes two questions interesting: First, are there international R&D spillovers to the USA when we distinguish between private and public foreign R&D and include both? Second, is it advantageous for the US to react to R&D spillovers with a policy of additional private and public investment? In order to answer these questions, we do not only consider the partial effects of long-term relations, but also analyse the effects of permanent policy changes to the growth rates of R&D variables in the transition to the long-term relations of a VECM. This way we get results that include all the feedback reactions on each other of domestic and foreign private and public R&D as well as LATC from all equations of the VECM.[3]

In section 2 we briefly describe the data showing that they are in line with closely related literature. In section 3 we explain the econometric procedure for estimation of the VECM and the results from it leading to a baseline simulation in log-levels and growth rates of all variables. In section 4 we study the growth and R&D policy effects of shocks to domestic and foreign public and private R&D. In section 5 we show the results from calculating the benefits, costs and gains from additional public and private R&D, either on a country's own initiative or as reaction to foreign R&D enhancements. Section 6 argues that permanent changes leading to transitional effects on LATC suggests having a semi-endogenous growth model for the USA. Section 7 summarises and concludes.

2. Literature

2.1 Theory

In the absence of strategic behaviour, spillovers from foreign R&D are defined to be positive if foreign R&D reduces the unit costs of domestic firms. This leads to higher quantities and R&D investment, but less so if subsidies are lower than optimal in combination with spillovers close to public goods and more so if firms ignore the spillovers which strengthen their competitors (Spence 1984; Bernstein and Mohnen 1998). Under Bertrand competition with product differentiation, if goods are substitutes, both, domestic and foreign R&D, have positive effects on the domestic quantity, and there are upward (downward) sloping reaction

[3] This approach is similar to that of Bottazzi and Peri (2007) who consider different variables though, R&D workers and patents.

functions in the R&D stage if there are positive (negative) spillovers (Carlson 2008). Positive R&D investment reactions therefore can be linked to spillovers under cost minimisation without strategic reactions and under Bertrand competition in substitutes. Under Cournot competition without spillovers, reaction functions of the R&D stage are negatively sloped when goods are substitutes (d'Aspremont and Jacquemin 1988), also when R&D goes into product quality (Taba and Ishii 2016). Taba (2016) shows that in the case of Cournot competition in substitutes, foreign R&D in product quality may reduce the domestic quantity directly and also indirectly via the downward sloping R&D reaction function if spillovers are small. Conversely, for sufficiently large spillovers, we get positive direct effects of foreign R&D and positive indirect effects via the upward sloping R&D reaction function. In sum, static Cournot and Bertrand duopoly models have positively sloped R&D reaction functions, where in case of Cournot models strong spillovers are needed; in their derivation, competition on the product market stage is already taken into account. Positively sloped reaction functions are the reason why positive Granger causality from one country's R&D to another country's R&D is one way of analysing spillovers, besides effects on cost and productivity (Atukeren 2007). In racing models with 'winner-takes-all' property, reaction functions are upward sloping (de Bondt 1996) if the competition threat is stronger than the profit incentive (Beath et al. (1989). This is the case in the absence of spillovers. By implication, when using Granger causality as in Atukeren (2007) and impulse responses in this paper we do not necessarily capture spillovers on LATC, but perhaps only competitive reactions of R&D, which affect LATC. However, reaction functions for timing may have negative slopes allowing for submissive reactions, meaning a firm takes more time for invention in reaction to a quick invention by the competitor (Scherer 1991). If racing models with upward sloping reaction curves are of minor importance compared to all the other models mentioned above, concluding that there are spillovers on the basis of shocks of foreign R&D and all feedbacks enhancing the R&D and LATC of the USA may still be legitimate although some of the effects may come from strategic behaviour.[4]

In case of *n* private firms in Cournot competition getting R&D subsidies and one public research institute, reaction functions for public and private R&D depending on each other have positive (negative) reaction curves only if the public R&D has a positive (negative) spillover (Cabon-Dhersin and Gibert 2020).

In international applications it is assumed that one of the firms are foreign and the other is domestic. We therefore report above only the results for the non-cooperative equilibria of the games. Simulation results below will be interpreted in the spirit of reaction functions of the R&D literature. Positive reactions suggest spillovers in all models except those of patent races where we may get positively sloped reaction functions also without spillovers.

David and Hall (2000) model the basics of the interaction of public and private R&D with focus on the labour market for researchers. Public R&D competes researcher away from private R&D. Spillovers from public to private R&D and hiring of public R&D workers by

[4] Mohnen (1997) discusses distinguishing R&D spillovers in addition from rent spillovers, productivity spillover and knowledge spillovers.

for private R&D reduce this labour-reallocation effect. Enhancement of public and private R&D therefore requires an elastic labour supply of researchers. The complementary interaction of private and public R&D with productivity growth is also modelled in a micro-founded macroeconomic model by Gersbach et al. (2021), where the exogenous acquisition type of FDI encourages public R&D expenditures but diminishes the effects of public R&D. A theoretical growth model for the interaction of domestic public and private R&D and productivity with endogenous reaction of foreign R&D variables is Ziesemer (2020a), who discusses additional closely related theoretical literature.

2.2 Evidence

Scherer (1991) finds quick positive reactions of US R&D flows to Japan's R&D and vice versa relating them to R&D racing but not to spillovers; the US reaction is first submissive and then aggressive in terms of change of R&D expenditures.

R&D spillovers are pertinent in endogenous growth theory. Bayoumi et al. (1996) have introduced them into the MULTIMOD model in a log-log specification making total factor productivity dependent on domestic and foreign R&D capital stocks. A shock on US R&D stocks spill over to all other countries enhancing their GDP. For most countries, the increase in the GDP levels is less than for the USA (see also Helpman 2004, ch.5 for a summary). Spillovers are positive but increase international inequality. This raises the question, whether foreign R&D spills over from other countries to the USA as well.

Hammadou et al. (2014) show an effect from private on publicly funded R&D for a panel of 14 European countries. Link et al. (2020) provide evidence for ten European countries that firms doing R&D are using knowledge from public research institutes more than firms that do not do R&D. This is also suggestive of the complementary nature of public and private R&D, which is the second crucial link in our VECM and the shocks. Soete et al. (2020a,b) show the public-private complementarity for R&D stocks for a number of OECD countries using VECMs. Ziesemer (2020b) shows it for Japan. Ziesemer (2020a, 2021a) surveys the older literature on this complementarity. Bacchini et al. (2020) show complementarity between public and private R&D flows in a macroeconomic estimation for Italy. All these papers cite many others also finding this complementarity, which therefore is also part of this paper. Several of these papers show the two-way causality of public and private R&D.

3. Data

It follows from the introduction that we have to consider private and public domestic and foreign R&D stocks as well as the labour-augmenting technical change for the USA. We do not follow the suggestion of Luintel et al. (2014) to include human capital because R&D expenditures used here in the form of stocks include those for human capital. The LATC data from Ziesemer (2021b) are derived from CES functions including human capital for alternative elasticities of substitution; we explore using data derived for CES = 0.7, 0.8, 0.9, 0.99. The data for the R&D stocks in 2005 US dollars for the period 1963-2017 are an updated version of those used in Soete et al. (2020b) applying the perpetual inventory method to OECD flow data with depreciation rate of 0.15 (Hall et al 2010; Luintel et al. 2014) and distance weights for the construction of foreign R&D capitals stocks. In the literature, imports, foreign direct investment, and migration have been used as weights without any of them being clearly better than the others. They all depend on distance in gravity equations and therefore Soete et al. (2020a, b) use distance as a weighting scheme. Stocks of privately performed R&D grow more quickly than public R&D stocks in the periods 1978-2000 with outliers 1993/94, and 2013-2017, and public R&D grows more quickly before 1978 and in the period 2001-2012. Figure 1 below shows that the net result is a higher private R&D stock.

4. Econometrics, estimation results and baseline simulation

The culture of VECMs is to keep the models small as in Luintel and Khan (2004) and Bottazzi and Peri (2007) because the number of coefficients increases strongly with the number of regressors.[5] For univariate unit root tests, we use Dickey-Fuller GLS test, the augmented Dickey-Fuller test without and with breakpoints and the Zivot-Andrews test with breakpoint. We find that LATC and the R&D stock variables have near unit roots (see appendix) in the form of high p-values and coefficients below 0.95 when structural breaks are allowed, but often closer to unity when breaks are ignored. Breaks are strongly dispersed across variables and tests, indicating that there is no break for a joint model. The log of GDP is leaning more to being I(0) as its coefficients are between 0.44 and 0.92 rather than unity. When including it, the GDP variable reacts too strongly on R&D shocks, deviates too strongly from the LATC paths,[6] and has a low adjusted R-square, also in an earlier version of this paper with data only until 2014. We therefore exclude LGDP from the VECM.

A VAR in the five variables has three lags according to all lag length selection criteria. The stability test for the VAR with three lags shows that the model is unstable, and we use four lags, because the damage from using too short rather than too long lags is larger. The trace test for three lags and a linear trend suggests having four cointegrating equations *(r=4)* at the five percent level of statistical significance. The maximum-eigenvalue test suggests three cointegrating equations (r = 3). Jusélius et al. (2014) suggest deciding in favour of more cointegrating equations and less unit roots because of the low power of both, the individual and the system test for unit roots. By implication, we would have a system with $K\text{-}r = 5\text{-}4 = 1$ unit roots or *I(1)* components or variables. In contrast, Hjalmarsson and Österholm (2010), considering the problem of near-unit roots, which we found in the unit root analysis above, suggest rejecting a hypothesis in cointegration tests only if both, the trace test and the maximum-eigenvalue test suggest rejection. We therefore do not reject the hypothesis of 'at most 3 ce' and thereby assume having three cointegrating equations. Our result is in line with this suggestion for the five-percent significance level. At the 10 percent level we would have

[5] Lütkepohl (2007) provides a supportive non-technical discussion for this.
[6] This also happens when we treat LGDP as I(0) and model an extended VECM as suggested by Fisher et al. (2016).

r=K and thereby no unit root in the system (see Davidson and MacKinnon 2004). These and the following properties hold for alternative VECMs using LATC variables based on CES = 0.7-0.99.

The Doornik-Hansen test for multivariate normality shows that the error probability of rejecting the null hypothesis of normality is between 0.32 and 0.7 for the four CES versions, so we do not reject the null. The Lagrange multiplier test rejects the hypothesis of serial correlation at the five percent level except for lag 2 when LATC is used as derived under a CES = 0.7. The null hypothesis of no heteroscedasticity can be rejected at an error probability of 0.27 to 16.6%, so we do not reject it. As LATC from CES = 0.7 has serial correlation we do not use it. On all other criteria LATC from CES = 0.8, denoted LTH08, perform better than those from higher CES (see appendix). This value is in the ranges found for the USA by Antras (2004), 0.3 to 0.9, and Knoblach et al. (2020), 0.45-0.87.

The VECM with the linear trend[7] has the following long-term or cointegrated equations (CE) written in the form of having all variables on the same side of the equation (t-values in parentheses) as used in equations (4)-(8) below.

$$CE1 = E(u_1(-1)) = LTH08(-1) - 0.34LBERDST(-1) + 0.32LPUBST(-1) - 0.015t - 0.895 \quad (1)$$

[-3.44] [3.14] [-3.22]

Here and below, we have chosen normalisations which lead to the low coefficients allowing to test whether the variables have vanishing significance. LTH08 is positively related to the business R&D stock, BERDST, and negatively to public R&D, LPUBST, the latter two often competing for the same resources. A trend of 1.5 percent is detrending the variables and could describe the growth in the absence of R&D. As the coefficients of the R&D variables are almost identical up to the sign, LTH08 grows with one third of R&D growth plus 1.5% exogenous growth. LTH08 is therefore growing less quickly than the private R&D stocks as suggested in the recent literature on semi- versus fully endogenous growth (Minniti and Venturini 2017) and on modern stagnation (Hall 2017; Bloom et al 2020). However, it would be premature to conclude against fully- and in favour of semi-endogenous growth because we see here decreasing returns to one argument only and others may also play a role and are considered next.

$$CE2 = E(u_2(-1)) = LBERDST(-1) - 2.33LPUBST(-1) + 1.64LFPUBST(-1) - 3.29 \quad (2)$$

[-12.97] [7.87]

Public R&D is driving private R&D but is reduced by foreign public R&D. Both are only partial effects, which we can interpret as R&D reaction functions, possibly with implicit spillover effects as in duopoly models. Private R&D is partly basic R&D (see Soete et al. 2020b) and that part may be reduced if there is more foreign public R&D doing basic R&D.

$$CE3 = E(u_3(-1)) = LPUBST(-1) - 0.14LBERDST(-1) - 0.36LFBERDST(-1) - 0.017t - 5.95 \quad (3)$$

[7] Several papers mentioned above do not include a time trend in the cointegrating equation or do not report it although they are reported in the data description and are most likely not stochastic but rather deterministic.

[-1.82]   [-8.35]   [-5.64]

As all long-term relations are valid with two-way causality; the opposite direction of causality may also hold. The third equation, which can also be interpreted as R&D reaction function, shows explicitly that public R&D is driven by private R&D, the reversed causality of equation (2), besides foreign private R&D. The effect of public on private in equation (2) has a much larger coefficient than the reverse effect in equation (3). In the spirit of oligopolistic reactions functions with spillovers, foreign R&D is a spillover affecting domestic private and public R&D directly in the reaction functions (2) and (3), and LTH08 in (1) indirectly.

A deviation from the long-term equilibrium relations has an impact on the growth rates of the variables. As we have so far three equations for five variables, we need not only the long-term relations (1)-(3) but rather the whole system of five equations to have all variables determined. All variables depend on all the others in the following system of 5 equations and 5 variables.

The complete, stable VECM with CE1-CE3 from above is as follows ('…' indicating differenced terms of lag one, two and three and constants for the equations not shown):

D(LTH08) = - 0.44CE1 + 0.257CE2 + 0.8CE3 ... (4)

[-2.18]   [2.29]   [3.2]

D(LBERDST) = 0.061CE1 - 0.14CE2 - 0.295CE3 ... (5)

[0.815]   [-3.26]   [-2.88]

D(LPUBST) = 0.14CE1 + 0.063CE2 ... (6)

[4.4]   [3.97]

D(LFBERDST) = 0.066CE1 - 0.047CE2 - 0.087CE3 ... (7)

[1.34]   [-1.66]   [-1.3]

D(LFPUBST) = 0.013CE2 ... (8)

[2.51]

The estimation period is 1967-2017. The estimation method is maximum likelihood. As the multiplication of the adjustment coefficients to the long-term relations defines a non-linear econometric problem, finding the coefficients requires convergence to their values. Convergence is achieved after 610 iterations. Restrictions imposed on the long-term relations just identify all cointegrating vectors.[8] Moreover, we have successively put the three most

[8] If a VECM of the form dy = Πy(-1)... with *K* variables and equations is identified, its form dy = $\alpha\beta' y(-1)$... (with α as (K, r) matrix of adjustment coefficients and β as (K,r) matrix of long-term coefficients) is not identified (generating standard deviations) for $r < K$ as $\alpha\beta' = \alpha I \beta' = \alpha Q Q^{-1}\beta'$. As *Q* has format (*r,r*) we need to impose r^2 constraints to get a unique result for α and β', where *r* is the number of long-term relations (Pesaran 2015).

insignificant adjustment coefficients to zero (see (6) and (8)) until the p-value of the chi-square test, which is now 0.999, for the constraints, falls strongly. All left-hand variables depend on some of the long-term relations. The adj. R-squared for the five equations are 0.198, 0.89, 0.94, 0.936, 0.886. For the LTH08 equation the R-squared would be 0.487; its adjusted value is strongly lowered by the number of estimated coefficients. For the system as a whole, we get Log likelihood 1122, Akaike information criterion -39.59, Schwarz criterion -35.32. The number of estimated coefficients is 113, which is quite high and therefore the model should not have more variables or fewer observations. All growth rates on the left-hand side depend on error correction terms and are therefore endogenous. In particular, public R&D is not (weakly) exogenous but reacts to disequilibrium when LTH08 and BERDST are above their equilibrium levels. Foreign public R&D reacts also to BERDST or its own level if it is above its equilibrium level in (2). LTH08, domestic and foreign private R&D react to all three disequilibria.

We test the robustness of the results by way of dropping successively one, two or three years at the end or the beginning of the sample. Coefficients change when more than two years are dropped at either end. Then the oil crisis of 1973/74 and the financial crisis 2007-2013 come to the end of the sample. For the shocks of public R&D for example, results change only when the end of the sample is 2014 or 2015, but not when the starting dates are later. It can be shown for the sample ending early, that four instead of three long-term relations are favoured by the Johansen tests because of changing p-values, and then the results for shocks on public R&D hold again.

In Figures 1 and 2 we show the actual data and a baseline simulation of the VECM. The actual data go to the confidence bounds in Figure 1 only in 2005 and 2012 which is after the ICT bust of 2003 and the financial crisis year 2009, respectively. All variables are shown in natural logs; the slope then is the growth rate. LTH08 has a period of zero growth rates from 1973-1983 known as the productivity slowdown. This holds not only for the data but also for the simulation suggesting that the slowdown is driven by R&D variables or their effects.

Figure 2 shows about constant long-run growth rates of the baseline simulation with ups and down in the estimation period. Domestic private and public R&D variables have the highest growth rates, followed by those of foreign R&D. In both cases the growth rates of private R&D are higher than those of public R&D. All have higher growth rates than that of LTH08 at about 0.016, indicating decreasing returns or increasing costs in these four R&D capital stocks growing at rates between 2.3 and 3.3 percent.

The Johansen default does this in the first instance through the normalization of the form $[I_{r,r}, -\beta_{K-r}]$. We have to rearrange this to present an economically meaningful and statistically significant way.

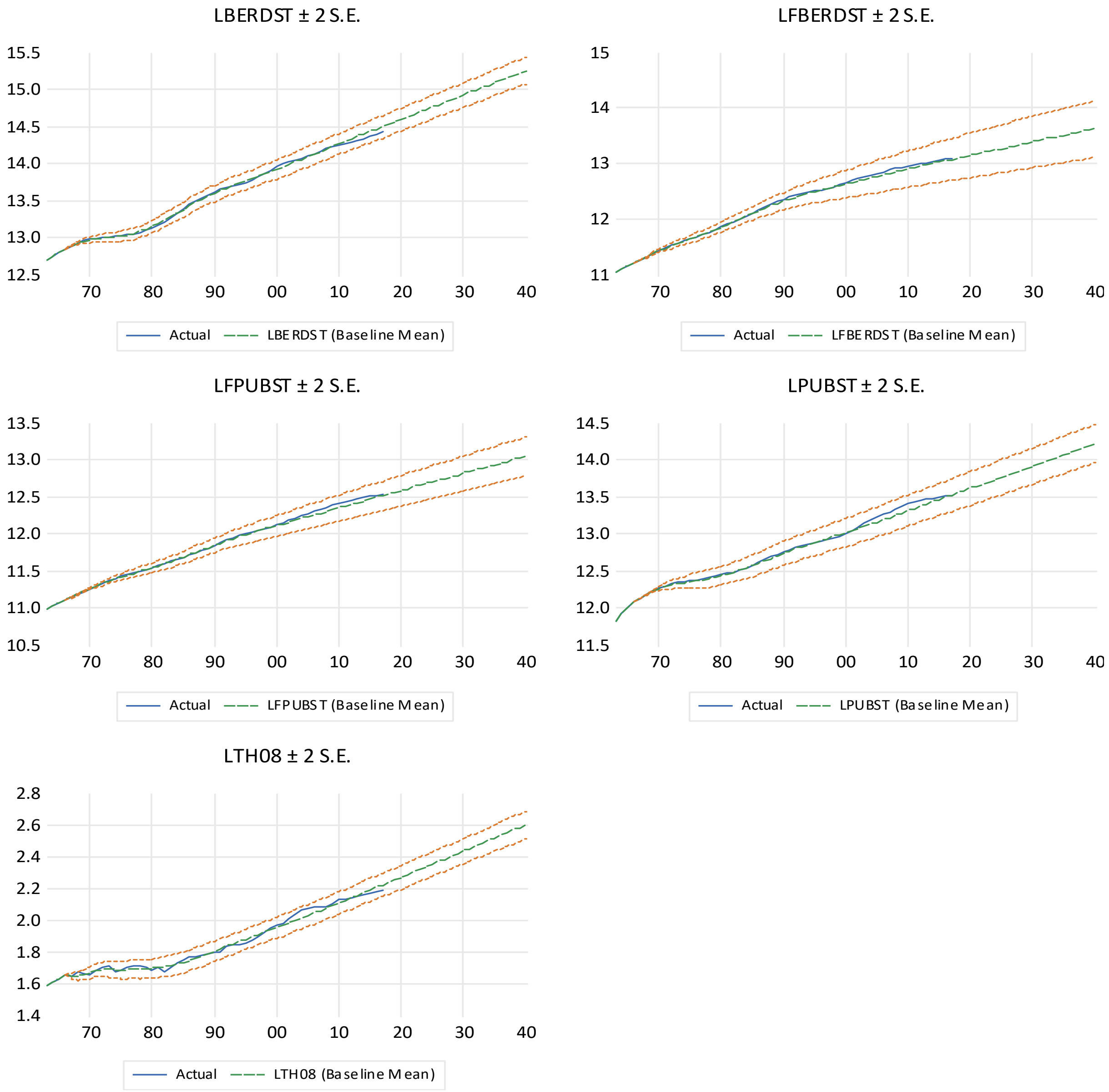

Figure 1 Actual data 1963-2017 and baseline simulation of the VECM for the USA.

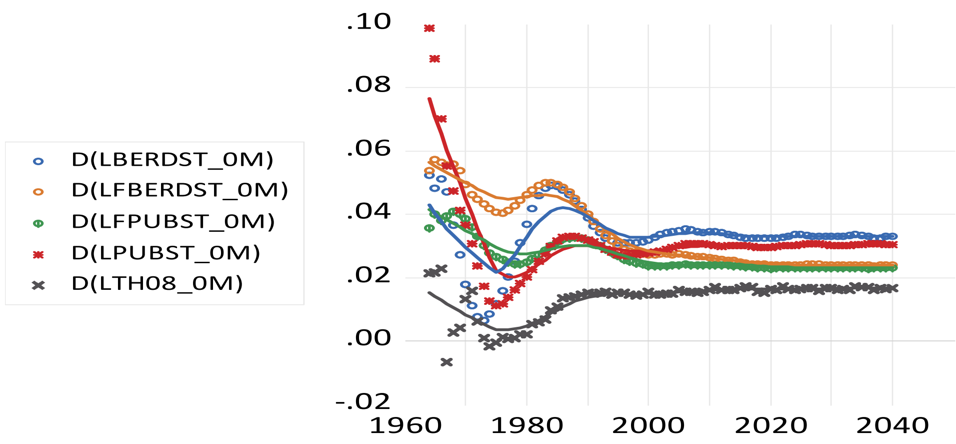

Figure 2 Growth rates of LTH08 (lowest line) and R&D stock variables over time for the USA from the baseline simulation of the VECM with linear trend for the years 1967-2040.

4 Private and public policy shocks and system reactions

Higher growth than in the baseline simulation could come from higher private R&D or higher public R&D, or from higher public or private foreign R&D. In order to test the potential for higher growth we create a permanent change by way of adding one standard deviation of the R&D growth rate variable. In this section, we show that all four shocks can increase LTH08, at least for some decennia.

We use the generalised impulse response functions (Pesaran 2015). They take into account that the residuals of the variable getting the shock, u_i may be correlated with the residuals of the variables reacting to the shock, u_j. Through the correlation $u_j = \rho_{ij} u_i$ there is an immediate effect also on the growth rate of j which may be positive, negative or zero. For the standard errors of the responses, we use bootstrapped Hall percentiles (Lütkepohl 2005) from 999 iterations with confidence interval levels of 0.90.[9] We consider the accumulated effects assuming that the same shock is imposed for all periods taking effect in 1963.

The initial shock to public US R&D is 0.00289 (one standard deviation of less than 0.3 percent). It increases all variables although domestic private R&D and LTH08 are turning back towards baseline around 2025 in Figure 3. The increase in LTH08 from baseline goes up to 9% and is positive for 57 years and statistically significant for 23 years. BERDST goes only 4.2 percent beyond baseline and the effect is only 9 years statistically significant. Foreign public R&D is 40% beyond baseline and foreign private R&D by 80% after 40 periods, when significance expires. These are strong foreign reactions confirming the view in the literature that foreign countries react strongly to changes in US R&D.[10] As LTH08 reacts for some decennia much more strongly than domestic private R&D this might indicate that it is an effect of increased public R&D as in equation (3) (diminished by FBERDST), which makes CE3 a positive disequilibrium effects with positive, high adjustment coefficient in equation (4) on LTH08; but CE1 is positive with a lower negative adjustment coefficient, and CE2 has less clear size.

[9] For the studentized version we do not have sufficiently many observations.

[10] This is somewhat in contrast to Hammadou et al. (2014) who find no effect of US public R&D on European public R&D. Our foreign publicly R&D variable is not limited to European countries and it is performed publicly whereas they look at public funding variables.

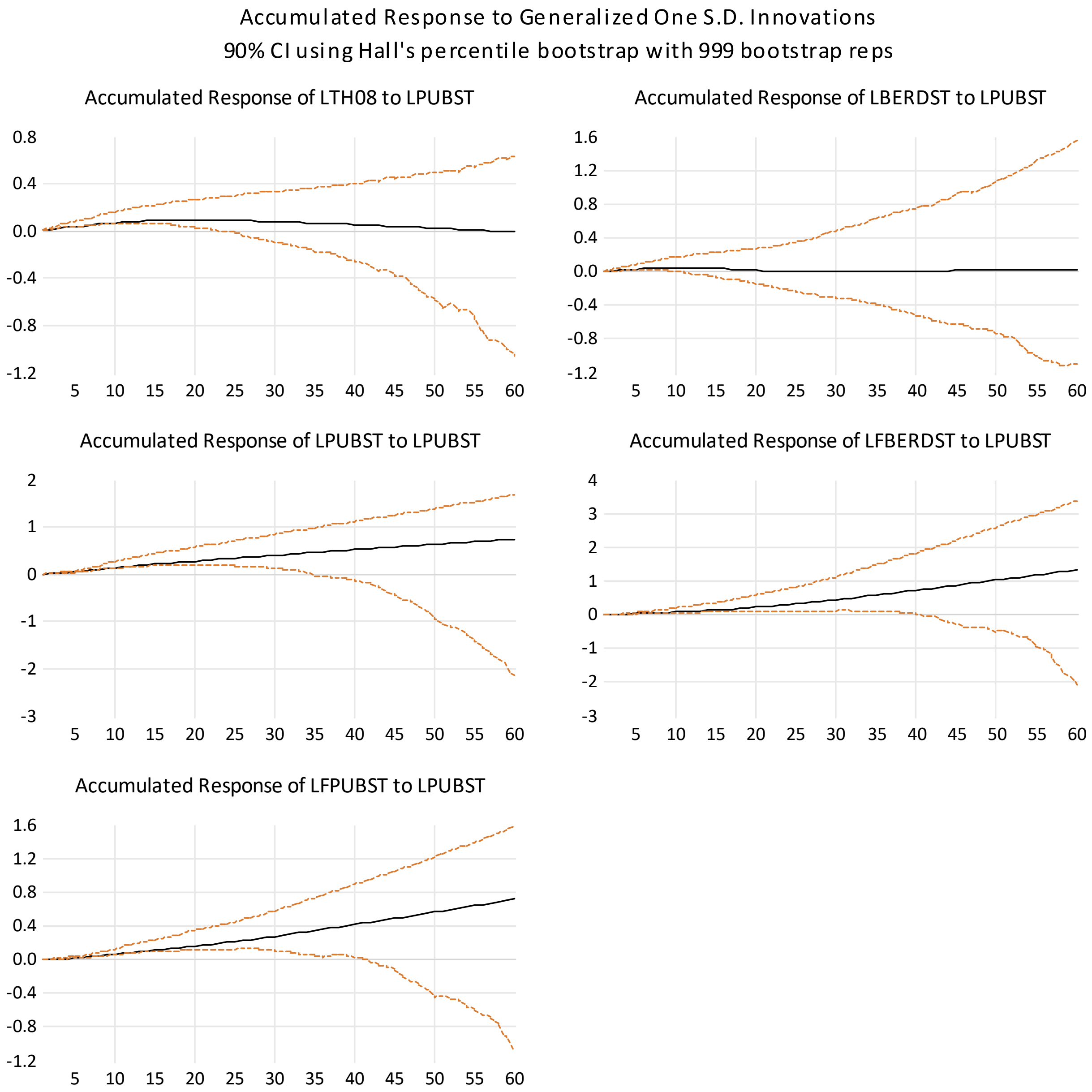

Figure 3 The effects of the shock to the public US R&D stock.

The initial value of the shock to private US R&D is 0.467 percent (one standard deviation), which is much larger than the shock on public R&D. It increases all variables in a statistically significant way according to Figure 4; only LTH08 starts going back to baseline after a peak of 0.12 above baseline in 1985 but remains above baseline for 80 years and statistically significant so for 26 years. BERDST goes 11.3 percent beyond baseline and then falls. Domestic public and foreign R&D react strongly to US R&D changes. The fact that LTH08 goes back to baseline whereas BERDST remains above it can most plausibly be explained by CE1 first getting negative because BERDST is increasing most strongly for nine periods and increases dLTH08 in (4), and then PUBST increasing most strongly up to 0.7 whereas BERDST is only 20% above baseline making CE1 positive with negative adjustment coefficient. First, private R&D change dominates, and then public R&D change dominates bring dLT08 first up and then down. Numerical analysis using the value after 60 years shows that CE2 is about -0.5 and CE3 is about +0.5; this increases dLTH08 in (4) because CE3 has a much higher positive adjustment coefficient. In (8), CE2 decreases dLFPUBST below its steady state value, mainly because US LPUBST is high in CE2, which is mitigated by the high level of LFPUBST, which is a partially unstable force, because LFPUBST in CE2 increases dLFPUBST in (8).

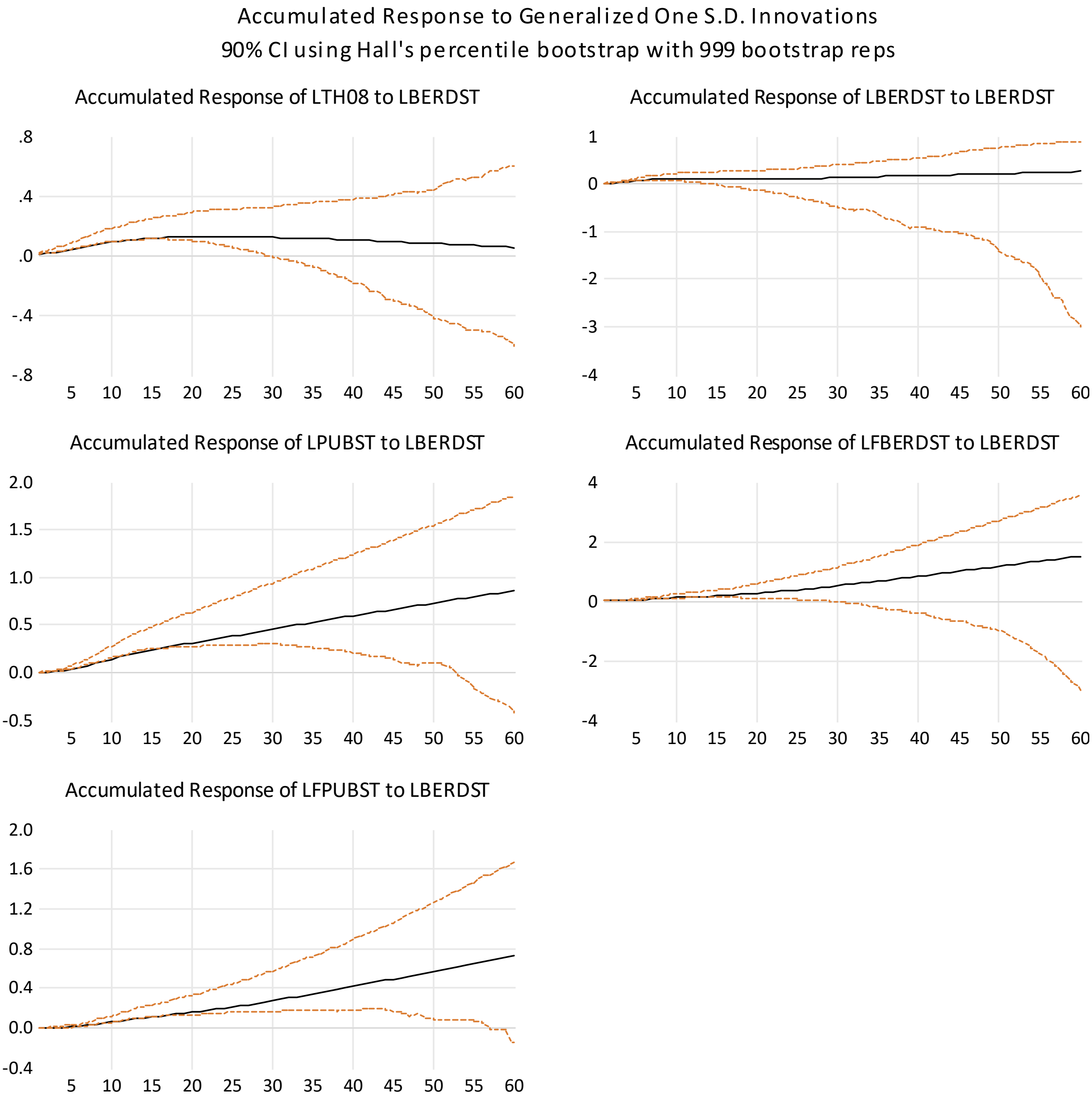

Figure 4 The effects of a shock to the private US R&D stock.

The shock to foreign public R&D shown in Figure 5 leads to a slightly weaker reaction of US public R&D but no statistically significant reaction of domestic and foreign private R&D. The model of Cabon-Dhersin and Gibert (2020) would therefore suggest that there are no spillovers from foreign public to US private R&D because there is no positive reaction as the model would show under positive spillovers. The increase in LTH08 is limited to a maximum of four percent above baseline, and it becomes statistically insignificant after ten years. It indicates effects of positive spillovers of foreign public R&D or strategic reactions of US public R&D. With clearly increasing, positive and about equal long-term effects on LPUBST and LFPUBST, CE1 and CE3 get positive and CE2 gets negative. The only clear effect than is that dLFPUBST goes below its old steady-state value because LPUBST and LFPUBST are high, implying that LFPUBST has a destabilising and US LPUBST a stabilising partial effect in (8). For accumulated permanent changes, the long-term relations do not return to zero.

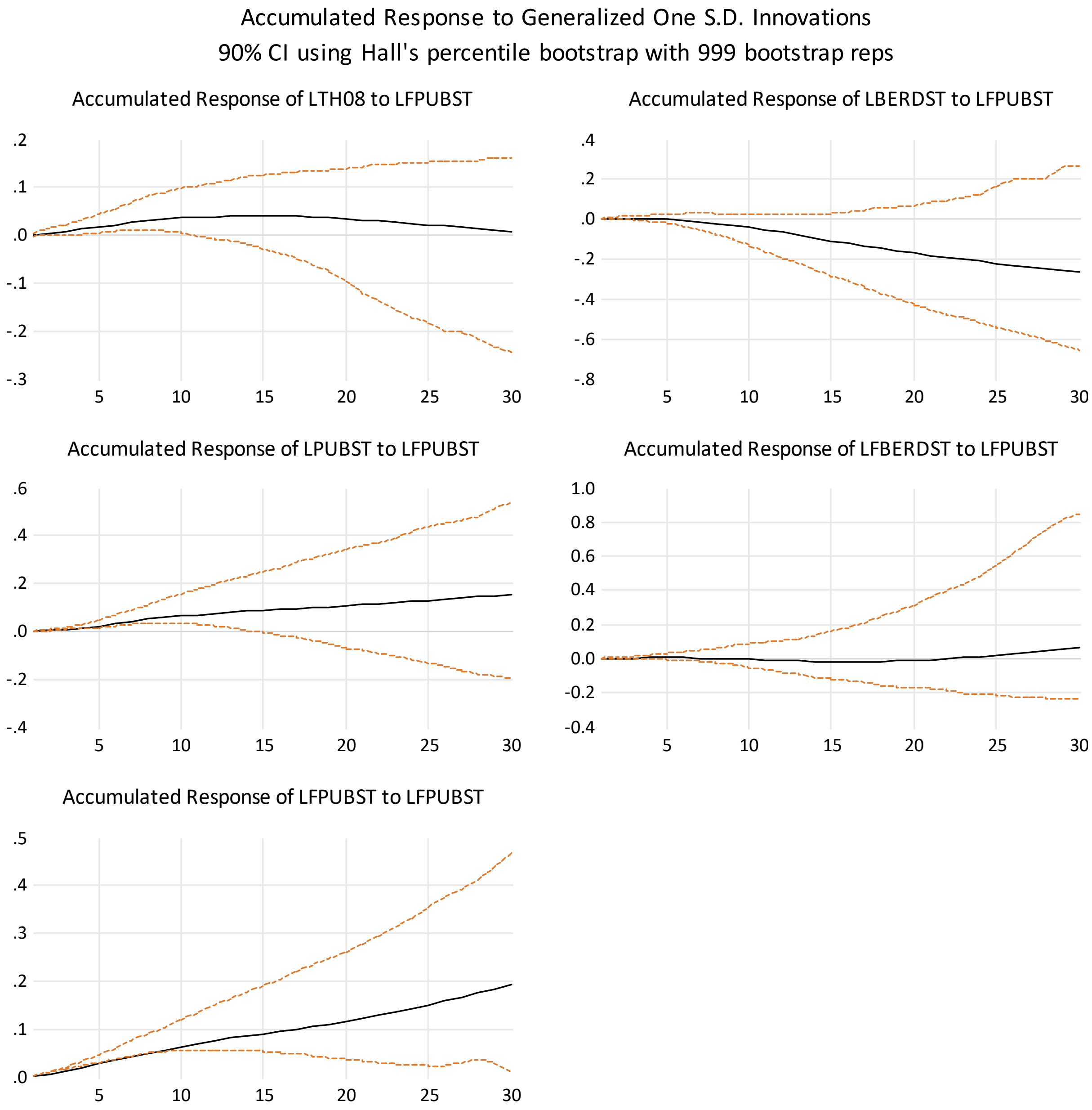

Figure 5 The effects of the shock to the foreign public R&D stock.

Figure 6 shows that a shock of 0.3% to foreign private R&D has a slightly positive impact on US private R&D going four percent beyond baseline. The effect is statistically significant for seven years. A zero effect as in Luintel and Khan (2004), or a submissive effect Atukeren (2007) or the first-year effect in Scherer (1991) appears only after 14 years and is insignificant. The impact on LTH08 is positive as in Eaton and Kortum (1997) the panel analysis of Coe and Helpman (1995) but less than the effect on domestic private R&D. Foreign private and domestic and foreign public R&D show a larger reaction of similar size. This makes CE1 and CE3 again positive and CE2 negative. The latter implies again that dLFPUBST goes below its old steady-state growth rate.

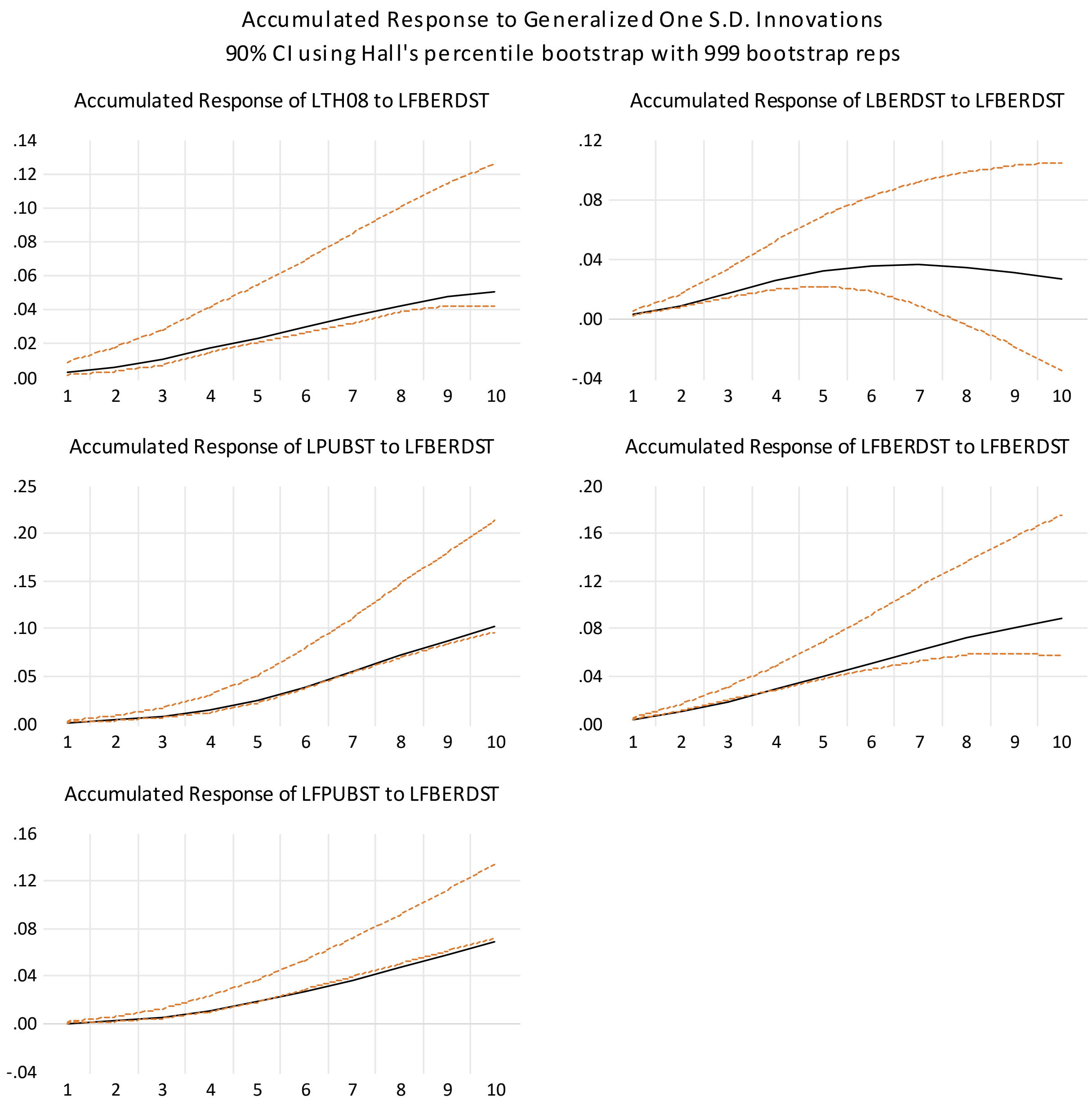

Figure 6 The effects of the shock to the foreign private R&D stock 1967-2200.

5 Internal rates of return and sum of discounted net gains from permanent shocks

For all four types of shocks, we have seen that all variables react positively, with only the case of a shock to foreign public R&D having statistically insignificant reactions of domestic and foreign private R&D. This does not yet ensure though that the costs incurred in terms of additional private and public investment are larger than the returns. We define the returns here as the change of GDP as obtained from the change of LATC compared to baseline,[11] which is the hypothetical increase of the GDP from getting more LATC, calculating the elasticity from a CES function and keeping other factors like labour and capital constant. The costs are the additional private and public R&D expenditures. We take the log-difference between baseline and shock simulation for each point in time and then calculate the cost change per period. Having flow changes, we can take the difference between gross gains and additional costs, discount them and add them up. In the first instance, we discount with the standard interest rate of four percent and calculate the sum of discounted net gains from 1963 until 2017 where the GDP data end. Then we try to find the internal rate of return, defined as the discount rate that brings the sum of discounted net gains to zero. We also consider the gain per period as a share of GDP without any discounting. The results are summarised in Table 1.

Table 1 Effects of permanent shocks of one standard deviation of the growth rate

Shock on growth rate of equation	Sum of net gains discounted at 4% in US$ bill.	Internal rate of return	Average gain /GDP 1963-2017
(6) public domestic R&D stock	5496	∞ (a)	0.035
(5) private domestic R&D stock	8317.4	∞ (a)	0.055
(8) public foreign R&D stock	761 (b)	0.0225	0.0026
(7) private foreign R&D stock	2676.7 (c)	-0.034	0.016

(a) There are no periods of losses. (b) gains followed by losses after 1997. (c) Gains followed by losses after 2004.

For the shock to public domestic R&D stocks of one standard deviation in the USA in Figure 3 , the sum of net gains discounted at 4% is positive for all years and goes to 5496 billion US dollars in 2017. The internal rate of return is infinity because there are no periods of losses. The undiscounted gains as a share of GDP are 3.5% on average over 1963-2017.

A shock to private domestic R&D stocks of one standard deviation in a VECM, considering all sub-sequent costs of domestic private and public R&D and all effects on LATC shown in

---

[11] Ziesemer (2021) obtains the LATC data from the CES function $Y = [\alpha K^{\rho} + (1-\alpha)(AH^{\delta}L)^{\rho}]^{\frac{1}{\rho}}$, solving it for A and using mainly PWT9.1 data. For this function, the elasticity of production of *Y* with respect to *A* is $\varepsilon_{YA} = (1-\alpha)\left(\frac{AHL}{Y}\right)^{\rho}$. This elasticity can be calculated for each year also by inserting data from PWT9.1. It goes from 0.64 in 1950 to 0.656 in 1991 where it remains with ups and downs until 2009; then it goes down to 0.653 in 2017. Then we calculate *dlog(GDP)* $= \varepsilon_{YA} dlog(LATC)$ for every year, where *dlog(LATC)* is the percentage deviation from baseline. Multiplication of *dlog(GDP)* with *GDP* gives *dGDP*, the increase of *GDP* through the policy shock representing the benefit or return.

Figure 4, has an effect of 8317 billion US dollars until 2017 when the discount rate is 4%. The internal rate of return is again infinity because there are no periods of losses.

For reactions to shocks from foreign public investment in Figure 5, the sum of net gains when discounting at 4% is 762 billion US dollars, meaning that expected losses from foreign R&D effects can be turned positive through own public and private investment reactions. Competition or spillovers trigger profitable reactions. As late losses dominate early gains in the absence of discounting, the internal rate of return of only 2.6% is needed to give low weight to late losses.

For reactions to shocks from private foreign investment in Figure 6, we find positive discounted gains when using a 4% rate of 2676 billion US dollars with an internal rate of return of -0.034 percent. The investments following a foreign spillover or competition shock are profitable from 1963 to 2004 and then gains get negative; the internal rate of return is negative because gains come first and losses later. Early gains are not outweighed by later losses. To find the rate of return which makes gains zero we need to give higher weights to late losses. If the project could be stopped in 2004 and losses are thereby avoided, the discounted gains would be US$ bill. 3050 (15219) for a discount rate of 4% (-0.034%).

The old standard result, showing no or negative spillovers or competition effects does not hold for our VECM for the USA distinguishing public and private domestic and foreign R&D. The USA react to foreign private R&D what may be seen as spillover under perfectly competitive reactions or competition under oligopolistic strategic reaction. The reactions appear in the long-term relation and in the impulse responses.

The yearly net gains averaged over all periods for the four scenarios range between 1.6 and 5.5 percent of the GDP. Those from foreign spillovers are at the lower end of the range but far from negligible.

6 Permanent policy effects?

If the long-term relations are in equilibrium, the model of equations (4)-(8) could in principle be solved for five growth rates. Figures 3-6 plot LATC growth rate differences comparing the policy scenarios 1-4 to those of the baseline. Expected effects are positive for domestic public R&D shocks for 57 years, for domestic private R&D shocks for 80 years, for reactions to foreign public R&D shocks 32 years, and for reactions to foreign private R&D shocks 43 years. The evidence from our model for the USA would support semi-endogenous growth theory because growth rate effects from permanent policy shocks are not permanent. In line with of the decreasing returns shown in Figure 2 we get a temporary policy effect from permanent changes in the spirit of semi-endogenous growth. This is in line with Ziesemer (2020c) and Fernald and Jones (2014), but in contrast to Ha and Howitt (2007).

As four of the five residuals have received permanent shocks, it is instructive to look at the effects on the growth rates of public and investment in Figure 3-6 . Public investment compared to baseline keep growing in all four cases of self-initiated policies or policies reacting to foreign shocks. Private investment keeps growing only when the shock also comes from private investment. In conclusion, public investment a backbone for all types of growth policies, especially when the economy reacts to foreign shock.

7 Summary and conclusion

Summing up, empirical econometrics can identify spillovers only when abstracting from strategic behaviour (Bernstein and Mohnen 1998). Economic theory can distinguish between spillovers and reaction functions only when pre-fixing ideas as to which oligopoly model is relevant. Combining economic theory and empirical econometrics also only works when pre-fixing on a model as Scherer (1991) did abstracting from spillovers. Similarly, Granger causality (Atukeren 2007) and VECM without (Luintel and Khan 2004) and with impulses (this paper) can analyse countries' reactions without knowing whether they are from reaction functions with or without spillover.

Instead of following the empirical literature using one stock variable for total foreign R&D expenditures we have used two, one for business R&D and one for non-business R&D. A VECM for the USA then shows that foreign and domestic public and private R&D stocks are all endogenous variables. Applying the methodology of looking at the consequences of permanent changes shows that shocks to foreign public and private R&D stocks affect the US economy positively (not zero, negative, submissive) by way of driving US public R&D and LATC upward whereas private R&D goes up temporarily in response to foreign private R&D shocks and even goes down in response to a foreign public R&D shock. Permanent changes of US public and private R&D have transitional effects on LATC for some decennia.

Calculation of the net gains, discounted at 4% interest rate, from the time paths of model solutions of the VECM (first done by Soete et al (2020b) shows that the investments in reaction to shocks of the two foreign R&D variables are profitable. This result complements that of Luintel and Khan (2009) who show significantly positive effects for patent data. By implication, it is unlikely that both old results of no spillovers to the US from the EU and Japan hold simultaneously, but we cannot exclude the possibility that there are no spillovers, and the reactions are completely strategical in the spirit of oligopolistic reaction curves.

In a perspective of publicly or privately financed R&D the period of shift to private financing goes from 1985-2013 interrupted in 2009 where privately financed R&D falls (Archibugi and Filippetti 2018), which is seven years later than that for performance perspective. In a basic versus applied perspective for 16 countries listed by Gersbach et al. (2020) the average shifts to basic R&D and so do 9 of 16 countries (including the USA) comparing the year 2000 to 2009. All together this means that after 2000 there is a shift to basic, publicly performed R&D, which is increasingly financed privately. Van Reenen (2020) suggests a.o. to increase federal funding for the USA. Our results show that additional US public and private R&D would have a net gain per unit of GDP, a high net present value after discounting at a rate of four percent, and a positive gain/GDP ratio. Permanent shocks have transitory effects for several decennia on growth rates and therefore suggest a semi-endogenous growth potential for the USA.

References

Antras, Pol. (2004). “Is the U.S. Aggregate Production Function Cobb-Douglas? New Estimates of the Elasticity of Substitution.” Contributions to Macroeconomics 4 (1): 1–34, Article 4.

Archibugi, Daniele, Andrea Filippetti (2018) The retreat of public research and its adverse consequences on innovation. Technological Forecasting & Social Change 127, 97–111.

Atukeren, Erdal (2007) A Causal Analysis of the R&D Interactions between the EU and the US. Global Economy Journal, Volume 7, Issue 4, Article 1, 1-29.

Bacchini, Fabio, Roberto Golinelli, Cecilia Jona-Lasinio, Davide Zurlo (2020) Modelling public and private investment in innovation. GROWINPRO Working Paper 6/2020 March.

Bayoumi, Tamim, David T. Coe and Elhanan Helpman, "R&D Spillovers and Global Growth," CEPR Discussion Paper No. 1467, 1996.

Beath, J, Y Katsoulacos, D Ulph (1989) The game-theoretic analysis of innovation: A survey. Bulletin of Economic Research 41(3), 163-184.

Bernstein, Jeffrey I. and Pierre Mohnen (1998) International R&D spillovers between U.S. and Japanese R&D intensive sectors. Journal of International Economics 44, 315–338.

Bloom, Nicholas, Charles I. Jones, John Van Reenen, Michael Webb (2020), Are Ideas Getting Harder to Find? American Economic Review 110(4): 1104–1144.

Bottazzi, Laura and Giovanni Peri (2007) The international dynamics of R&D and innovation in the long run and in the short run. The Economic Journal, 117 (March), 486–511.

Cabon-Dhersin, Marie-Laure and Romain Gibert (2020) R&D cooperation, proximity and distribution of public funding between public and private research sectors. The Manchester School. 88:773–800.

Carlson, Julie (2008) Cooperative R&D and Strategic Trade Policy with Bertrand Competition. Review of International Economics, 16(2), 355–367.

Cincera, M. and B. van Pottelsberghe de la Potterie (2001) International R&D spillovers: A survey. Cahiers Economiques de Bruxelles, 1st Trimester 2001, iss. 169, pp. 3-31.

Coe, David T. and Elhanan Helpman (1995) International R & D spillovers. European Economic Review 39, 859-887.

David, Paul A., Bronwyn H. Hall (2000) Heart of darkness: modeling public–private funding interactions inside the R&D black box. Research Policy 29, 1165–1183.

Davidson, R. and J.G. MacKinnon (2004) Econometric Theory and Methods. Oxford University Press. New York et al.

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

De Bondt, Raymond (1996) Spillovers and innovative activities. International Journal of Industrial Organization 15: 1-28.

Eaton, Jonathan, and Samuel Kortum. 1997. Engines of growth: Domestic and foreign sources of innovation. Japan and the World Economy 9: 235–59.

Fernald, John G. and Charles I. Jones (2014) The Future of US Economic Growth. American Economic Review: Papers & Proceedings, 104(5): 44–49.

Fisher, Lance A., Hyeon-Seung Huh, and Adrian R. Pagan. 2016. Econometric Methods for Modelling Systems with a Mixture of I(1) And I(0) Variables. Journal of Applied Econometrics 31: 892–911.

Gersbach, Hans, Ulrich Schetter and Maik T. Schneider (2021) Macroeconomic Rationales for Public Investments in Science. Economic Inquiry 59 (2), 575–599.

Ha, Joonkyung, Peter Howitt (2007) Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory. Journal of Money, Credit and Banking, Vol. 39, No. 4, 734-774.

Hall, Robert E. (2017) The Anatomy of Stagnation in a Modern Economy. Economica 84, 1–15.doi:10.1111/ecca.12210.

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

Hammadou, Hakim, Sonia Paty, Maria Savona (2014) Strategic interactions in public R&D across European countries: A spatial econometric analysis. Research Policy 43 (7), 1217-1226.

Helpman, E. (2004), The Mystery of Economic Growth, MA: Belknap Press of Harvard University Press.

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

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

Knoblach, Michael, Martin Roessler, and Patrick Zwerschke. 2020. “The Elasticity of Substitution Between Capital and Labour in the US Economy: A Meta-Regression Analysis.” Oxford Bulletin of Economics and Statistics 82 (1): 62–82.

Link, Albert N., Cody A. Morris, Martijn van Hasselt (2020) The Impact of the Third Sector of R&D on the Innovative Performance of Entrepreneurial Firms. Department of Economics Working Paper Series, April, Working Paper 20-02.

Luintel, Kul B. and Mosahid Khan (2004) Are International R&D Spillovers Costly for the United States? The Review of Economics and Statistics, Vol. 86, No. 4, Nov., pp. 896-910.

Luintel Kul B. and Mosahid Khan (2009) Heterogeneous ideas production and endogenous growth: an empirical investigation. Canadian Journal of Economics / Revue Canadienne d’Economique, Vol. 42, No. 3, August, 1176-1205.

Lütkepohl, Helmut (2005) New Introduction to Multiple Time Series Analysis. Springer, Heidelberg New York.

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

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

Minniti, Antonio and Francesco Venturini (2017) The long-run growth effects of R&D policy. Research Policy 46, 316–326.

Mohnen, Pierre (1997) Introduction: Input–Output Analysis of Interindustry R&D Spillovers, Economic Systems Research, 9:1, 3-8.

Pesaran, H. M. 2015. Time Series and Panel Data Econometrics. Oxford, New York: Oxford University Press.

Reenen, John Van (2020) Innovation policy to restore American prosperity. CentrePiece Spring 2020, 14-17.

Scherer, FM (1991) International R&D races: theory and evidence. In L.G. Mattsson and L. Stymne (eds.) *Corporate and Industry Strategies for Europe*. Elsevier, Amsterdam, 117-137.

Soete, Luc, Bart Verspagen and Thomas Ziesemer (2020a) The productivity effect of public R&D in the Netherlands. Economics of Innovation and New Technology, Vol 29, Issue 1, 31-47.

Soete, Luc, Bart Verspagen, Thomas Ziesemer (2020b) The economic impact of public R&D: An international perspective. UNU-MERIT WP 2020-14.

Spence, Michael (1984) Cost Reduction, Competition, and Industry Performance. Econometrica 52(1): 101-122.

Taba, Yumiko (2016) Optimal Product R&D Policies with Endogenous Quality Choices and Unilateral Spillover. BE Journal of Economic Analysis and Policy 16(1): 365–391.

Taba, Yumiko and Yasunori Ishii (2016) Product R&D Investment Policies in an International Duopoly. Review of Development Economics, 20(2), 574–582.

Ziesemer, Thomas H.W. (2020a) Semi-endogenous growth models with domestic and foreign private and public R&D linked to VECMs, Economics of Innovation and New Technology, online, DOI: 10.1080/10438599.2020.1760423.

Ziesemer, Thomas H.W. (2020b) Japan's Productivity and GDP Growth: The Role of Private, Public and Foreign R&D 1967–2017. Economies 8 (4), 77.

Ziesemer, Thomas H.W. (2020c) Can we have growth when population is stagnant? Testing linear growth rate formulas of non-scale endogenous growth models, Applied Economics, 52:13, 1502-1516.

Ziesemer, Thomas H.W. (2021a) The Effects of R&D Subsidies and Publicly Performed R&D on Business R&D: A Survey. Hacienda Pública Española /Review of Public Economics 236-(1/2021). https://dx.doi.org/10.7866/HPE-RPE.21.1.6.

Ziesemer, Thomas H.W. (2021b) Labour-augmenting technical change data for alternative elasticities of substitution, growth, slowdown, and distribution dynamics. UNU-MERIT WP 2021-003.

Appendix unit root tests

Unit root tests without and with break point (a)

Variable	LGDP	LTFP	LBERDST	LPUBST	LFBERDST	LFPUBST	PROIL
ADF without breakpoints. Dependent Variable: D(logx); coefficient of lagged level variable.							
Coeff.	-0.12	-0.1	-0.06	-0.055	-0.0039	-0.0024	-0.103
t-value p-val.	-2.01 0.58	-1.66 0.756	1.97 0.60	-2.13 0.51	-2.72 0.0765	-2.25 0.19	-1.79 0.38
Dickey-Fuller-GLS without breakpoints. Dependent Variable: D(GLSRESIDUAL); coefficient of lagged residual.							
Coeff.	-0.08	-.096	-0.05	-0.03	0	-0.0147	-0.0677
t-val. (e) p-val.(g)	-1.56 0.125	-1.63 0.11	-3.11 0.0031	-1.93 0.06	0.69 0.49	-0.973 0.335	-1.32 0.19
Zivot-Andrews unit-root test with breakpoint determination for intercept and trend.							
t-value unit r (f)	-5.577 no	-4.19 Yes	-4.415 yes	-4.21 yes	-3.62 Yes	-4.22 yes	-3.31 yes
Break year	2008	1974	1995	2001	1984	2008	1986
ADF unit-root test with break							
Coeff.(b)	0.443 0.46	0.39 0.64	0.798 0.91	0.775 0.926	0.94 0.87	0.81 0.898	0.75 0.008
p-val. (c)	0.018 <0.01	0.31 0.29	<0.01 0.80	<0.01 0.76	0.777 <0.01	0.0245 <0.01	0.84 0.0112
Break date (d)	2007 2008	1978 1984	1994 1985	1974 1974	1990 1996	2006 2004	1983 1986
Unit root	No or near	Near	near	near	Near	near	near

(a) In DF-GLS and ADF, intercept and trend (if significant); AIC for lag length; (b) Coefficient for a lagged level in the ADF equation; F-test for intercept + trend break point, or Dickey-Fuller min-t in the absence of trend or intercept break; first value in cell for innovational outlier, second for additive outlier, also for p-values and break dates. (c) p-value for unit root. (d) break date for innovational outlier and additive outlier. (e) critical 10% value about (-2.6, -2.9); value not more negative have a unit root. (f) t-Statistic critical value: for 1%, -5.57, for 5% -5.08, for 10%, -4.82. (g) p-value for the coefficient given above.

The ADF test would suggest that all variables have a unit root, with the exception of LFBERDST at the ten percent level. As the test has low power it may give us too many unit root results. However, the DF-GLS test, which is known to have better power properties indicates unit roots at the five percent level except for LBERDST. In the presence of breaks there might be less unit roots. However, the Zivot-Andrews unit root test assuming one break suggests unit roots for all variables except for LGDP. The Vogelsang-Perron ADF test with breakpoints allows (rejection of) breakpoints for intercept, trend or both. It indicates unit roots except for LGDP and LFPUBST although the coefficients are fairly high for LFPUBST. Overall, the tests allowing for breakpoints suggest no unit root for LGDP; ignoring breaks we have near unit roots. For LFPUBST the evidence is mixed, and we assume that there is a near unit root. The coefficients are all below unity and even below 0.95. Except for LGDP and LPUBST, the variables have different break years across tests. They may be caused by shocks in related variables, which are not included in the uni-variate tests. Break years also differ across variables rather than showing a common break period for a joint model.

Unit root tests without and with break point for labour-augmenting technical change (a)

Variable	Lth07	Lth08	Lth09	Lth099
ADF without breakpoints. Dependent Variable: D(logx); coefficient of lagged level variable.				
Coeff.	-0.0056	-0.054	-0.052	-0.05
t-value p-val.	-1.27 0.88	-1.23 0.89	-1.185 0.90	-1.14 0.91
Dickey-Fuller-GLS without breakpoints. Dependent Variable: D(GLSRESIDUAL); coefficient of lagged residual.				
Coeff.	+0.02	+0.032	-0.0466	-0.045
t-val. (e) p-val. (g)	+1.88 0.0657	+2.89 0.0056	-1.077 0.286	-1.04 0.30
Zivot-Andrews unit-root test with breakpoint determination for intercept and trend.				
t-value unit root (f)	-3.62 yes	-3.96 yes	-4.257 yes	-4.448 yes
Break year	1974	1979	1979	1979
ADF unit-root test with breakpoint				
Coeff. (b)	0.147 0.375	0.06 0.339	-0.01778 0.175	-0.081 0.277
p-val. (c)	0.0765 0.215	0.0367 0.1775	0.0193 0.175	0.0138 0.1941
Break date (d)	1992 1980	1992 1980	1992 1980	1992 1980
Unit root	near	near	near	near

(a) LTH0x abbreviates for labour-augmenting technical from CES functions with human capital and elasticity of substitution 0.x from Ziesemer (2021b). In DF-GLS and ADF, intercept and trend (if significant); AIC for lag length; (b) Coefficient for a lagged level in the ADF equation; F-test for intercept + trend break point, or Dickey-Fuller min-t in the absence of trend or intercept break; first value in cell for innovational outlier, second for additive outlier, also for p-values and break dates. (c) p-value for unit root. (d) break date for innovational outlier and additive outlier. (e) critical 10% value about (-1.6, -3.75); values not more negative have a unit root. (f) t-Statistic critical value: for 1%, -5.57, for 5% -5.08, for 10%, -4.82. (g) p-value for the coefficient given above.

Appendix Statistical properties of VAR and VEC models

Model for LATC	CES 0.7	CES 0.8	CES 0.9	CES 0.99
Lag length (all criteria (a))	3 (4)	3 (4)	3 (4)	3 (4)
stable	No (yes)	No (yes)	No (yes)	No (yes)
Trace test:	At most 4 ce, 0.06	At most 4 ce, 0.047	At most 4 ce, 0.0384	At most 4 ce, 0.0325
Max. eigenvalue: H_0, p	At most 3 ce, 0.0977	At most 3 ce, 0.0997	At most 3 ce, 0.0989	At most 3 ce, 0.0964

(a) LR, FPE, AIC, SC, HQ

Appendix Statistical properties of final VEC models

Model for LATC	CES 0.7	CES 0.8	CES 0.9	CES 0.99
P normality	0.7	0.58	0.498	0.32
autocorrel. (a)	L2: p = 0.056 L1 to 4: p=0.045	L2: p = 0.062	L2: p = 0.071	L2: p = 0.076
heteroscedast. (b)	P = 0.27	P = 0.24	P = 0.19	P = 0.166
Log likelihood	1127.67	1122.7	1117.55	1112.6
AIC, SIC	-39.79, -35.5	-39.6, -35.3	-39.39, -35.1	-39.2, -34.9

(a) Results indicating serial correlation for Null hyp ‘no autocorrelation at lag h, or at lags 1 to h’ for Rao F-test of LM test.
(b) H_0: no heteroscedasticity.

Appendix	**Short-term relations of the VECM**				
	D(LTH08)	D(LBERDST)	D(LPUBST)	D(LFBERDST)	D(LFPUBST)
D(LTH08(-1))	-0.004	0.113	-0.144	0.040	0.007
	-(0.023)	(1.692)	-(3.464)	(0.869)	(0.214)
D(LTH08(-2))	-0.119	-0.094	-0.092	0.047	0.003
	-(0.537)	-(1.192)	-(1.885)	(0.871)	(0.076)
D(LTH08(-3))	-0.024	0.042	-0.051	0.051	-0.069
	-(0.124)	(0.612)	-(1.191)	(1.088)	-(1.973)
D(LBERDST(-1))	0.587	1.286	0.228	0.208	-0.113
	(1.066)	(6.571)	(1.886)	(1.568)	-(1.153)
D(LBERDST(-2))	-0.543	-0.645	0.045	-0.078	0.157
	-(0.719)	-(2.402)	(0.271)	-(0.427)	(1.164)
D(LBERDST(-3))	-0.284	0.372	0.060	0.235	-0.170
	-(0.480)	(1.768)	(0.462)	(1.644)	-(1.615)
D(LPUBST(-1))	0.857	-0.243	0.942	-0.002	0.092
	(0.935)	-(0.747)	(4.670)	-(0.008)	(0.566)
D(LPUBST(-2))	0.575	0.197	-0.096	-0.045	-0.147
	(0.458)	(0.441)	-(0.347)	-(0.149)	-(0.659)
D(LPUBST(-3))	-1.012	-0.003	-0.228	-0.073	0.177
	-(1.430)	-(0.014)	-(1.466)	-(0.428)	(1.407)
D(LFBERDST(-1))	-0.775	-0.074	-0.260	0.802	0.263
	-(0.930)	-(0.251)	-(1.419)	(3.983)	(1.769)
D(LFBERDST(-2))	1.098	-0.125	0.138	-0.443	0.113
	(0.995)	-(0.319)	(0.566)	-(1.661)	(0.576)
D(LFBERDST(-3))	0.194	-0.334	0.132	0.136	-0.031
	(0.215)	-(1.042)	(0.666)	(0.624)	-(0.190)
D(LFPUBST(-1))	1.069	0.662	0.280	0.234	0.724
	(1.085)	(1.890)	(1.293)	(0.984)	(4.121)
D(LFPUBST(-2))	-2.656	-0.809	-0.436	-0.679	-0.013
	-(2.234)	-(1.914)	-(1.666)	-(2.366)	-(0.060)
D(LFPUBST(-3))	0.916	0.468	0.288	0.365	-0.096
	(1.021)	(1.465)	(1.457)	(1.684)	-(0.599)
C	0.009	0.011	-0.001	0.012	-0.002
	(0.547)	(1.860)	-(0.246)	(2.828)	-(0.568)

t-values in parentheses marked yellow for differenced terms when above 1.65.

The UNU-MERIT WORKING Paper Series

2021-01 *Transformation towards sustainale development goals: Role of innovation* by Michiko Iizuka and Gerald Hane

2021-02 *Access to social protection for platform and other non-standard workers: A literature review* by Tamara A. Kool, Giulio Bordon and Franziska Gassmann

2021-03 Labour-augmenting technical change data for alternative elasticities of substitution, growth, slowdown, and distribution dynamics by Thomas Ziesemer

2021-04 *Democracy and COVID-19 Outcomes* by Gokhan Karabulut, Klaus F. Zimmermann, Mehmet Huseyin Bilgin and Asli Cansin Doker

2021-05 *Patent landscaping using 'green' technological trajectories* by Önder Nomaler & Bart Verspagen

2021-06 *Macroeconomic stimulus packages and income inequality in developing countries: Lessons from the 2007-9 Great Recession for the Covid-19 crisis in South Africa* by Alexis Habiyaremye, Peter Jacobs, Olebogeng Molewa and Pelontle Lekomanyane

2021-07 *Deepening or delinking? Innovative capacity and global value chain participation in the ICT sectors* by Rasmus Lema, Carlo Pietrobelli, Roberta Rabellotti and Antonio Vezzani

2021-08 *COVID-19 policy responses, mobility, and food prices: Evidence from local markets in 47 low to middle income countries* by Stephan Dietrich, Valerio Giuffrida, Bruno Martorano and Georg Schm erzeck

2021-09 *Attitudes towards inequality in Brazil: An analysis of a highly unequal country* by Cintia Denise Granja and Ana Maria Carneiro

2021-10 *Mobile phones and HIV testing: Multi-country evidence from sub-Saharan Africa* by Francesco Iacoella and Nyasha Tirivayi

2021-11 *What makes a productive Ph.D. student?* by Alberto Corsini, Michele Pezzoni and Fabiana Visentin

2021-12 *Do institutions and ideology matter for economic growth in Latin America in the first two decades of the 21st century?* by Pamela L. Navarrete Gallo and Jo Ritzen

2021-13 *How social assistance affects subjective Well-being: Lessons from Kyrgyzstan* by Franziska Gassmann, Bruno Martorano and Jennifer Waidler

2021-14 *Do pandemics lead to rebellion? Policy responses to COVID-19, inequality, and protests in the USA* by Francesco Iacoella, Patricia Justino and Bruno Martorano

2021-15 *Foreign R&D spillovers to the USA and strategic reactions* by Thomas H.W. Ziesemer