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Modeling R&D spillovers to productivity: The effects of tax policy

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T. von Brasch, Å. Cappelen, H. Hungnes and T. Skjerpen

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T. von Brasch, Å. Cappelen, H. Hungnes and T. Skjerpen

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Abstract:
We study the role of R&D spillovers when modelling total factor productivity (TFP) by industry. Using Norwegian industry level data, we find that for many industries there are significant spillovers from both domestic sources and from technological change at the international frontier. International spillovers contributed with 38 per cent to the total growth in TFP from 1982 to 2018 while domestic channels contributed with 44 per cent. The remaining 18 per cent is due to interaction effects. We include these channels into a large-scale econometric model of the Norwegian economy to study how R&D policies can promote economic growth. We find that current R&D policies in the form of generous tax deductions have increased growth in productivity and income in the Norwegian economy. The simulation results lend some support to the view that there are fiscal policy instruments that may have very large multipliers, even in the case of a fully financed policy change.

Keywords: R&D spillovers, total factor productivity, innovation policies

JEL classification: C32, C51, D24, E17, O32

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Address: PO Box 2633 St. Hanshaugen, NO-0131 Oslo, Statistics Norway, Research Department
E-mail: thomas.vonbrasch@ssb.no

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Sammendrag

De fleste land i OECD prøver å stimulere investeringer i forskning og utvikling (FoU). Mange land, blant dem Norge, har et mål for hvor mye FoU-investeringene skal utgjøre av BNP. Motivasjonen for de offentlige tiltakene er at FoU-aktiviteter antas å skape positive eksterne virkninger gjennom såkalte "spillover-effekter" mellom foretak og ulike næringer, som markedet ikke fanger opp.

Det synes å være stor enighet om at effekten av FoU er knyttet til kunnskapsstrømmer som FoU-kapitalen skaper. Kunnskapene fra FoU sprer seg også gjennom økonomien ved at foretakene kjøper varer og tjenester fra hverandre og produktivitetsvekst som kan slå ut i lavere pris på produktinnsats. Eksempelvis kan høyere produktivitet i transportsektoren bli ført videre til høyere produktivitet i næringer som kjøper transporttjenester, noe som i neste omgang øker produktiviteten i andre næringer igjen, osv. Slike "kryssløpskanaler" er viktige for å forstå den makroøkonomiske utviklingen i et land.

SSB har tidligere studert FoU-politikk ved bruk av generelle likevektsmodeller og funnet at FoU-politikk i en liten åpen økonomi gir langt mindre velferds- og veksteffekter enn i mer lukkede og større økonomier. Eksportfremmende tiltak rettet inn mot FoU-baserte produkter er langt mindre effektive for å stimulere FoU-investeringer enn offentlig støtte til FoU.

Det er en voksende internasjonal litteratur som analyserer de ulike virkningskanalene i sammenheng ved bruk av store makroøkonomiske modeller. Disse modellene har en bred næringsstruktur og er egnet til å analysere spillover-effekter, både gjennom en beholdning av kunnskapskapital som flere næringer kan ha glede av og gjennom en detaljert kryssløpskjerne. Selv om slike modeller inneholder både en fritt tilgjengelig beholdning av kunnskapskapital og en kryssløpskjerne, er foretakene i næringene forutsatt å være produsenter av ett enkelt produkt mens all FoU-aktivitet skjer i en tilleggssektor i økonomien. Dette er i kontrast til hvordan FoU behandles i nasjonalregnskapet, hvor hver næring produserer flere produkter, blant annet FoU-kapital.

Denne artikkelen føyer seg til tidligere litteratur om modellbasert evaluering av FoU-politikk ved at vi inkorporerer FoU-kapital i den makroøkonomiske modellen KVARTS. I tillegg kan hver næring i KVARTS produsere flere varer og tjenester. Dette tillater en mer detaljert analyse av hvordan FoU politikk påvirker FoU-aktivitetene i hver næring i økonomien. Næringsperspektivet er spesielt viktig i Norge hvor lønnsforhandlinger i industrisektoren er normgivende for lønnsveksten ellers. Vi finner at samlet faktorproduktivitet i norske næringer påvirkes både av teknologisk utvikling i utlandet, i andre norske næringer og av hvor utdanningsintensive de er.

I artikkelen studeres det også hvordan FoU-politikk påvirker samlede investeringer i FoU. Vi analyserer effekten av å stimulere private FoU-aktiviteter ved å redusere brukerprisen på FoU-kapital. En slik stimulans kan implementeres ved endringer enten i de eksisterende skattekreditter for FoU-investeringer eller i avskrivningsreglene i det norske skattesystemet for investeringer i FoU. For å motvirke reduksjonen i offentlige inntekter reduseres de offentlige overføringene til husholdningene. Vi finner at denne endringen fører til en substansiell økning i FoU-investeringene i økonomien, men det tar lang tid før FoU-kapitalen øker og en høster gevinster av spillover-effektene. På lang sikt øker produksjonen, reallønningene og forbruket med om lag ett prosentpoeng når en sammenligner med referansebanen. Produktivitetsgevinsten leder også til økt eksport.

1. Introduction

Most OECD countries support R&D through various policies; direct support to R&D institutions as universities and government labs, tax credits to support business R&D, support to higher education that supplies vital inputs to R&D activities in all parts of the economy. Many countries – Norway is no exception – have a target for their R&D spending as share of GDP. Underlying these policies is the belief that R&D activities create spillover effects between firms that are not fully reflected in markets and therefore provide a rationale for government interventions of some form, see e.g. Romer (1990) and Jones (2016).

There seems to be a consensus that R&D is a key determinant of economic growth and that R&D reverberate throughout the economy via knowledge flows from R&D capital, see e.g., Mohnen (1997) and Hall et al. (2010). For example, Coe et al. (2009) concluded that both domestic and foreign R&D capital have measurable impacts on total factor productivity (TFP) even after controlling for human capital. Based on industry data for many OECD countries, but not including Norway, Bournakis, Christopoulos, and Mallick (2018) found that international spillovers is an important driver of output per worker and that countries with stronger protection of intellectual property rights experience a larger increase in the effectiveness of spillovers. Griffith et al. (2004) studied international R&D spillovers in a panel of 12 OECD countries, including Norway, and found that roughly half of the growth effects of higher R&D and skill intensity in TFP in Norwegian manufacturing is due to their proxy for technology transfer. Several studies have analyzed Norwegian R&D policies in a macroeconomic perspecitive. Bye et al. (2009) found that the small, open nature of the Norwegian economy implies far less welfare and growth effects of innovation policies than for larger economies. Bye et al. (2011) find that export promotion is inferior to R&D support in spurring R&D, but not in terms of welfare generation. The reason for their finding is that existing and politically persistent policy interventions create inefficiencies that can be counteracted by R&D-based export promotion as a second-best policy.

From a microeconometric perspective, Cappelen et al. (2012) analysed *SkatteFUNN*, the Norwegian government introduced tax-based incentive programme introduced in 2002. They found that receiving tax credits resulted in the development of new production processes and to some extent the development of new products. Also, they found evidence of spillovers in the sense that firms that collaborate with other firms are more likely to be successful in their innovation activities. A general overview of the literature analysing innovation surveys can be found in Mairesse and Mohnen (2010).

R&D propagates throughout the economy also via input-output linkages, i.e., the benefit that an industry enjoys from productivity growth in other delivering industries through cheaper intermediates. For example, higher productivity in the transportation sector increases productivity in the sectors that use transportation as an input, which again increases the productivity in other sectors and so on. Since the work of Leontief (1936), the analysis of input-output linkages has been essential in understanding how industry interconnectedness matters for aggregate economic performance, see also Griliches (1992). The field of input-output analysis and industry network-effects have gained increased interest in recent years, see Carvalho and Tahbaz-Salehi (2019) and references therein.

Most papers in the literature focus the analysis on one of the abovementioned aspects only, i.e. either how policies may impact the level of R&D investments, how R&D propagates through a spillover pool of knowledge or how productivity propagates through the role of input-output linkages. There is a growing literature that considers all these channels simultaneously by applying macroeconomic models with several industries and spillover mechanisms, both through a spillover pool of knowledge and a large input-output core. To our knowledge, the best-known examples are the RHOMOLOs model (Mandras et al. (2019)), the GEM-E3 R&D model (Capros et al., 2013)), the QUEST model (Varga and Veld, 2011) and the NEMESIS model (Fougeyrollas et al., 2017), see also Comite and Kancs (2015).

We add to this literature along two dimensions. First, we decompose the importance of domestic and international channels for aggregate TFP growth. To this end, we estimate a model for TFP that depends on domestic R&D investments, including the impact of spillover effects across industries, skill intensity and the international technological frontier. Our analysis shows that domestic R&D spillovers and increased skill intensity contributed with 44 per cent of the total growth in TFP over the period 1982 to 2018. The impact from international spillovers through technology adoption amounted to 38 per cent. The remaining 18 per centage points are due to interaction effects.

Second, we extend the literature on model-based evaluation of R&D policies by incorporating the estimated spillover pools of R&D knowledge into a large-scale macroeconomic model of the Norwegian economy. Although some of the abovementioned models contain both a spillover pool of knowledge and an input-output core, the firms in these models are single product firms, i.e. they do not produce multiple goods. This contrasts with how R&D is treated in the National Accounts, where multiple products are being produced in each industry, one of the products being R&D. To account for how R&D policies affect R&D activities in all sectors of the economy, one must apply a model where firms produce multiple products in each industry. The macroeconomic model we apply (KVARTS) has a large input-output core and it allows for multiple products being produced in each sector of the economy, see e.g. Biørn et al. (1987) and Boug et al. (2013b) for documentation of earlier versions of the model. This opens for a more detailed analysis of how R&D policies impact R&D activities in each sector of the economy. We find that stimulating R&D activities through a reduction in the user cost of R&D capital leads to a substantial increase in R&D investments in the economy. However, it takes a long time before R&D capital stocks increase and knowledge flows to other industries. As the R&D capital stocks are gradually increased in the various industries, there are spillover effects both from abroad and from domestic sources. In the short and medium term, the effects on aggregate output are small and the changes in capital stocks by industry are modest. After a decade, output in the economy increases and continues to grow so that the level of GDP increases steadily. This implies that the growth rate of output is permanently higher due to the policy shift. Thus, the balanced budget multiplier is positive and increasing over time due to supply side effects from stimulating R&D. After roughly 40 years the level of output, real wages and consumption are around one per centage point higher in our R&D tax policy scenario compared to baseline. The productivity gain leads to higher real wages and consumption but also to more exports. In the long run, imposing a balanced budget policy, the level of output, real wages and consumption are around one per centage point higher in our R&D tax policy scenario compared to baseline. The productivity gain leads to higher real wages and consumption but also to more exports.

The paper proceeds as follows. In Section 2, we provide a general overview of the macroeconomic model KVARTS and a detailed description of how R&D impacts total factor productivity. In Section 3 the data used in the analysis are described. Section 4 describes the econometric specification, estimation results and decomposes the contributions from domestic and international channels for aggregate TFP growth. Policy simulations are presented in Section 5. Section 6 concludes.

2. R&D in the macroeconomic model[1]

The macroeconomic model, KVARTS, is relatively disaggregated, with an input–output system based on the National Accounts. In the short run, the production level is determined by aggregate demand along the lines of the traditional Keynesian framework for an open economy with inflation targeting. In the longer run, the supply side contributes to the determination of production through labor supply and the production structure. The model has been developed continuously since the 1980s, and all

[1] For a list of symbols referred to in this paper see Appendix B.

structural equations in the model have theoretical underpinnings. These equations are estimated in blocks (mainly) using a co-integrated VAR framework. Recent documentation of some of the main blocks, such as factor demand, the consumption function and the distribution sector and price setting behaviour, can be found in Hungnes (2011), Jansen (2013), Boug et al. (2020), Boug et al. (2013a) and Boug et al. (2017), respectively. As these articles illustrate, the methodology underlying the macroeconomic model is to apply econometric specifications that encompass several economic theories and include only those theories into the model that pass the empirical tests. Bårdsen et al. (2005) provide an overview of the methodology upon which the model is based. In the following, we comment on how R&D, together with other input factors, is incorporated in the macroeconomic model. In Appendix A we describe the other blocks in the model.

2.1 Factor input

The level of production, *X*, in an industry is given by

(1) $$X = TFP \times F(M, H, K, K^{RD})$$

where K^{RD}, *K*, *H* and *TFP* represent R&D capital, other capital, labor services and technology, respectively, and where we have dropped industry subscripts for notational convenience. Both other capital and intermediates are divided into three categories. Other capital includes buildings, transport equipment and machinery, whereas intermediates include electricity, fuel and other materials. The production function *F* has a Cobb–Douglas form. We return to the description of factor demand below and particularly how R&D capital impacts the level of technology, TFP.

R&D capital, other capital, material inputs and employment are determined by conditional factor demand functions. Since the production function in Eq. (1) is Cobb–Douglas, cost minimization implies log-linear factor demand equations, i.e.,

(2) $$K_t^{RD} = \alpha_{K^{RD}}^{*}(X_t / TFP_t)(P_{Kt} / P_{K^{RD}t})^{\alpha_K}(W_t / P_{K^{RD}t})^{\alpha_H}(P_{Mt} / P_{K^{RD}t})^{\alpha_M},$$

$$K_t = \alpha_K^{*}(X_t / TFP_t)(P_{K^{RD}t} / P_{Kt})^{\alpha_{K^{RD}}}(W_t / P_{Kt})^{\alpha_H}(P_{Mt} / P_{Kt})^{\alpha_M},$$

$$H_t = \alpha_H^{*}(X_t / TFP_t)(P_{K^{RD}t} / W_t)^{\alpha_{K^{RD}}}(P_{Kt} / W_t)^{\alpha_K}(P_{Mt} / W_t)^{\alpha_M},$$

$$M_t = \alpha_M^{*}(X_t / TFP_t)(P_{K^{RD}t} / P_{Mt})^{\alpha_{K^{RD}}}(P_{Kt} / P_{Mt})^{\alpha_K}(W_t / P_{Mt})^{\alpha_H},$$

where $\alpha_{K^{RD}}$, α_K, α_H, and α_M are the output elasticities with respect to R&D capital, other capital, labor and materials, respectively,[2] $\alpha^*_{K^{RD}}$, α^*_K, α^*_H, and α^*_M are constants that are non-linear functions of the output elasticities, $P_{K^{RD}_t}$ and P_{Kt} are the user costs of R&D and other capital in period *t*, respectively. We will return to the specification of the user cost of R&D capital below and analyze explicitly how R&D policy may impact the user cost. W_t is the unit cost of labor in period *t* and P_{Mt} is the price index for material inputs in period t. We show in Appendix A how the price index for other material inputs is determined. The symbol TFP_t denotes the total factor productivity in period *t*. A contribution of the current paper is to endogenize the TFP_t variables for a selection of the industries present in the model. We will come back to this augmentation below.

Investment (*J*) by asset type is determined by the capital accumulation equation

(3) $$J_t = \Delta K_t + DEP_t,$$

where depreciation, *DEP*, is geometric and depreciation rates vary across investment categories and industries (Barth et al., 2016) and Δ is the difference operator ($\Delta K_t = K_t - K_{t-1}$). In most industries the model separates between buildings, machinery, transport equipment and R&D, but we focus on R&D capital and other tangible capital types as an aggregate in this paper.

2.2. Total factor productivity and R&D

There seems to be a consensus in the literature that R&D is a key determinant of economic growth. For example, Coe et al. (2009) concluded that both domestic and foreign R&D capital have measurable impacts on productivity even after controlling for human capital. Based on industry data for many OECD countries, but not including Norway, Bournakis, Christopoulos, and Mallick (2018) found that international spillovers is an important driver of labor productivity and that countries with stronger protection of intellectual property rights experience a larger increase in the effectiveness of spillovers. Griffith et al. (2004) studied international R&D spillovers in a panel of 12 OECD countries, including Norway, and found that roughly half of the growth effects of higher R&D and skill intensity in TFP in Norwegian manufacturing is due to their proxy for technology transfer. In this section, we outline the theoretical framework we apply to model total factor productivity and R&D.

[2] We assume constant return to scale, i.e. $\alpha_{K^{RD}} + \alpha_K + \alpha_H + \alpha_M = 1$.

In line with Griffith et al. (2004) total factor productivity (TFP) by industry is assumed to depend on the R&D knowledge stock. This stock is modelled as a function of both the domestic and the international knowledge stock. In the literature following Coe and Helpman (1995) there is much discussion on the relative importance of domestic versus international spillovers from external R&D. The domestic spillovers, $K^{RD}_{OTHj,t}$, $j \in J$, are assumed to depend on a weighted sum of the R&D capital stocks in other domestic industries. They are weighted sums of R&D capital in other domestic industries and included to pick up domestic spillover effects affecting the industries considered. In addition, TFP by industry may also depend on the skill composition of the labor force by industry.

When constructing the variables $K^{RD}_{OTH\,j,t}$, ($j \in J$), we pay attention both to the industries as receivers and suppliers of intermediate inputs. Whereas the former activity is indicated by the upper-case letter *A*, the latter is indicated by the upper-case letter *B*. The spillover capital stocks attached to the two activities are given by, respectively,

(4) $$K^{RD}_{OTHA\,j,t} = \sum_{i \in I} w_{ji} * K^{RD}_{it}, \text{ where } 0 \le w_{ji} \le 1 \text{ and } \sum_{i \in I} w_{ji} = 1 \forall j \in J,$$

(5) $$K^{RD}_{OTHB\,j,t} = \sum_{m \in I^*} ww_{jm} * K^{RD}_{mt}, \text{ where } 0 \le ww_{jm} \le 1 \text{ and } \sum_{m \in I^*} ww_{jm} = 1 \forall j \in J,$$

with $w_{jj} = ww_{jj} = 0 \forall j \in J$.

The last set of restrictions mean that the own R&D capital stock, K^{RD}_{jt}, does not enter the capital stocks $K^{RD}_{OTHA\,j,t}$ and $K^{RD}_{OTHB\,j,t}$. The reason is that it is present in the production function from which the *TFP*-values have been derived. In Eqs. (8) and (9), *I* and I^* denote, respectively, a set with all industries and a set with all industries except the one for the government, cf. Table 1 below. Furthermore, recall that the set *J* contains all industries for which the development in TFP has been endogenized. The values of the time-invariant weights, cf. the w_{ji} and ww_{jm} symbols in (4) and (5), are reported in Table C1 and Table C2 in Appendix C.

The final spill-over capital stocks, $K^{RD}_{OTH\,j,t}$ ($j \in J$), are given as a weighted mean of $K^{RD}_{OTHA\,j,t}$ and $K^{RD}_{OTHB\,j,t}$

(6) $$K^{RD}_{OTH\,j,t} = \rho K^{RD}_{OTHA\,j,t} + (1-\rho) K^{RD}_{OTHB\,j,t},\ j \in J.$$

The share parameter ρ may vary from 0 to 1.

2.3. Model specification and long-run properties

Below we present the econometric equations on a form that encompasses the equations for which we report empirical results. The model is a set of 8 dynamic regression equations where the left-hand side variables are the relative change in TFP from one quarter to the next. The equations, in log-transformed variables, may be viewed as (non-linear) error-correction equations. They contain three main explanatory variables that possibly influence the relative change in TFP, i.e., the spill-over capital stock from other domestic industries, $K^{RD}_{OTH\,j,t-1}$, the index for the development of *TFP* in the US, $TFP_{US,t-1}$ and the share of skilled workers in the industry, $SK_{j,t-1}$. Since it seems to be a robust finding in the literature that many of the industries in the USA either represent the tehnological frontier, or is close to the technological frontier, we let the variable $TFP_{US,t-1}$ be a proxy for the international knowledge stock. It is interacted with the knowledge capital stock of the own industry, i.e., $K^{RD}_{OTH\,j,t-1}$, to capture the absorption effect, i.e., the more an industry spends on R&D the more it will it be able to absorb the international knowledge. Note that all four variables mentioned above are lagged one quarter and that the two capital stocks are measured at the end of the quarter. The lagged relative change in the TFP is also included in the model specification. Before ending up with the specification given by (7) we have also considered other specifications, among others specifications involving longer lag lengths and interaction effects between $K^{RD}_{OTH\,j,t-1}$ and $SK_{j,t-1}$, which did not produce results that were easy to interpret.

(7) $$\begin{aligned}&\Delta \ln(TFP_{j,t}) = \text{determinstic terms} + \gamma_j \Delta \ln(TFP_{j,t-1}) + \\ &\lambda_j \ln(TFP_{j,t-1}) + \eta_j \ln(K^{RD}_{OTH\,j,t-1}) + \phi_j \ln(K^{RD}_{j,t-1}) \ln(TFP_{US,t-1}) + \kappa_j SK_{j,t-1} + \varepsilon_{j,t},\end{aligned}$$

where ε_{jt} denotes an error term. We assume that $\underline{\varepsilon}_t = [\varepsilon_{1,t}, \ \ \varepsilon_{2,t}, \ \ ..., \ \ \varepsilon_{8,t}]'$, $t = 1, \ldots, T$, are NIID($\underline{0}$, Ω), where $\underline{0}$ is an 8x1 vector of zeros and Ω is a full positive-definite matrix. The right-hand side variables are assumed either to be strictly exogenous or predetermined.

In the partial model given by (7), the long-run relations, neglecting deterministic terms are given by

(8) $$\ln(TFP_{j,t}) = -\frac{\phi_j}{\lambda_j}\ln(K_{j,t}^{RD}) * \ln(TFP_{US,t}) - \frac{\eta_j}{\lambda_j}\ln\left(K_{OTH\ j,t}^{RD}\right) - \frac{\kappa_j}{\lambda_j}SK_{j,t}, \quad j \in J.$$

Eq. (8) is obtained by setting the differenced variables on both the left- and the right-hand side of the equations equal to zero and dropping the error terms.

In the long-run, the (log of) the TFP-index depends on three terms, i.e., $\ln(K_{j,t}^{RD}) \times \ln(TFP_{US,t})$, $\ln\left(K_{OTH\ j,t}^{RD}\right)$ and $SK_{j,t-1}$. It is convenient for later use to define $\xi_{j,1} = -\phi_j / \lambda_j$, $\xi_{j,2} = -\eta_j / \lambda_j$ and $\xi_{j,3} = -\kappa_j / \lambda_j$, $j \in J$. From Eq. (8), we derive various long-run elasticities of interest. The long-run elasticities with respect to TFP in the US, and the spillover aggregate are, respectively, given by

(9) $$\frac{\partial \ln(TFP_{j,t})}{\partial \ln(TFP_{US,t})} = \ln(K_{j,t}^{RD})\xi_{j,1},$$

(10) $$\frac{\partial \ln(TFP_{j,t})}{\partial \ln(K_{OTH\ j,t}^{RD})} = \xi_{j,2}, \quad j \in J$$

whereas

(11) $$\frac{\partial \ln(TFP_{j,t})}{\partial SK_{j,t}} = \xi_{j,3}, \quad j \in J.$$

is the semi-elasticity with respect to the skill variable, $SK_{j,t}$. It is also of interest to investigate long-run elasticities of the TFP level in a given industry with respect to the R&D capital stock in another industry. They are given by

(12) $$\frac{\partial \ln(TFP_{j,t})}{\partial \ln(K_{i,t}^{RD})} = \omega_{ji}\left(\frac{K_{i,t}^{RD}}{K_{OTH\ j,t}^{RD}}\right)\xi_{j,2};\ j = 1,...,8; i \in I,$$

where $\omega_{ji} = \rho w_{jt} + (1-\rho)ww_{jt},\ j \in J\ ; i \in I.$

3. Data

Data on R&D, capital, employment, gross production etc. are taken from the Statistics Norway's National Accounts.[3] The international spillover variable, measured using the productivity index TFP for the U.S., is taken from the Conference Board.[4] The domestic gross production productivity index by industry, TFP_t, is constructed by the following formula

$$\Delta \ln TFP_t = \Delta \ln X_t - w_{Ht} \Delta \ln H_t - w_{KKt} \Delta \ln \left(K_t + K_t^{RD} \right) - w_{Mt} \Delta \ln M_t,$$

where $K_t + K_t^{RD}$ is the aggregate capital level. Industry subscripts have been suppressed for notational convenience. Three aspects of the weights by industry merit attention: first, we assume that the underlying production function is characterized by constant returns to scale, i.e., the weights sum to unity. This allows us to identify the total capital share of gross production residually as: $ww_{KKt} = 1 - w_{Ht} - w_{Mt}$. Second, since we construct these series using quarterly data we have chosen a weighting scheme based on nominal shares in gross production from the preceding year. This is consistent with the weighting scheme used in the National Accounts, but differs from the weighting scheme that follows from a superlative index such as the Törnqvist index, see Diewert (1976).[5] Third, labor costs have been calculated based on the assumption that the average wage level of self-employed is the same as that of wage earners in the same industry. Note that TFP by industry is calculated including the effect of the industry's own R&D capital stock. So, any further effects of R&D capital stocks on TFP by industry are evidence of spillovers from R&D. We will sometimes refer to an aggregate industry called "mainland business sector". This aggregate comprises the industries 1 to 9 and 12 in Table 1.

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[3] See Statistics Norway: https://www.ssb.no/en/nasjonalregnskap-og-konjunkturer/statistikker/knr

[4] See the Conference Board: https://www.conference-board.org/data/economydatabase/index.cfm?id=27762

[5]In some instances (quarters) (for examplethe primary industry in the mid 1980s), the nominal value of intermediates and labour costs exceeded the nominal value of gross production. In these cases, the capital weight is set to zero and the weight of labour and intermediates are adjusted so that they sum to unity.

Table 1. Industries in the model and some summary statistics. 2018

Current number	Industry	Employment share	Value added share
1	Agriculture, fishing and forestry	2.3	2.2
2	Manufacturing of consumer goods	3.8	3.6
3	Energy-intensive manufacturing	0.7	0.9
4	Manufacture of machinery	3.4	2.9
5	Power generation	0.5	2.1
6	Wholesale and retail trade	12.9	8.0
7	Other private services	33.7	27.1
8	Real estate activities	1.1	3.2
9	Construction	8.6	6.8
10	International shipping services	0.7	0.9
11	Oil and gas extraction	0.9	15.5
12	Services related to oil and gas extraction	1.0	1.0
13	Government sector	30.4	21.2
14	Housing services	0.0	4.6

4. The estimated TFP-relations and derived results

The unknown first and second order parameters of the relations have been estimated jointly by maximum likelihood. The share parameter ρ has been set to 0.5.[6] We have imposed the following restrictions on the equations in (11): $\gamma_j = 0$ (j = 1,3,5,7); $\lambda_j = \lambda$ (j=1,…,8); $\eta_2 = \eta_3 = 0$; $\eta_j = \eta$ (j=2,4,5,6,7); $\phi_j = \phi$ (j=1,…,8); $\kappa_j = 0$ (j = 1,2,3,4,7,8). Table 2 contains estimates of first-order parameters. Except for some of the deterministic terms, the estimates of the parameters are significant. The estimates of the parameters of the key explanatory variables have the correct sign. Table D1 contains some diagnostics and Table D2 reports the estimated covariance matrix of the error vector. For industry 8 there is some sign of heteroskedasticity in the residuals. From the results reported in Table 2, we may derive elasticities for the long-run parameters. They are reported in Tables D3 and D4 in Appendix D. As seen from Table D3, there is a common estimated long-run effect on the log of the TFP-level of the product between the log of the US TFP-level and the log of the own stock of R&D capital for all the eight industries. The estimate is about 0.05. Table D4 contains estimates of the

[6] These shares could in principle vary both across industries and time. Some effort was carried out to estimate time-inariant industry-specific shares, but it showed up difficult to obtain significant and interpretabkle estimates of the parameters.

elasticity of industry specific TFP level with respect to the US TFP-level. Note that this is not an estimate of a parameter, since it also depends on the level of R&D capital stock of the own industry. The largest estimated effects are found for industry 7, followed by industries 4 and 2. They are, respectively, 0.55, 0.52 and 0.48. For the other industries, the estimates are about in the interval 0.29-0.44.

Table 2. Maximum likelihood estimates for the system of equilibrium-correction equations[a]

Parameter	Related variable(s)	Est.	*t*-value
γ_2	$\Delta\ln\left(TFP_{2,t-1}\right)$	-0.2395	-3.7024
γ_4	$\Delta\ln\left(TFP_{4,t-1}\right)$	-0.3276	-5.2421
γ_6	$\Delta\ln\left(TFP_{6,t-1}\right)$	-0.3449	-11.4826
γ_8	$\Delta\ln\left(TFP_{8,t-1}\right)$	-0.3911	-6.8298
λ	$\ln\left(TFP_{j,t-1}\right)$; j=1,…,8	-0.0728[b]	-6.6664
η	$\ln(K^{RD}_{OTH\,j,t-1})$; j=1,4,5,6,7	0.0041	2.2064
η_8	$\ln(K^{RD}_{OTH\,8,t-1})$	0.0137	2.3820
ϕ	$\ln\left(TFP_{US,t-1}\right)*\ln(K^{RD}_{j,t-1})$; j=1,…,8	0.0038	3.7537
κ_5	$SK_{5,t-1}$	0.1254	2.1607
κ_6	$SK_{6,t-1}$	0.3957	5.8536

[a]The digits in the subscripts indicate industry numbers, cf. Table 1. The model also contains a constant term and seasonal variables, but the estimates of intercepts and seasonal effects are not included in this table

For the industries 1, 4, 5, 6 and 7, there is a significantly estimated elasticity with respect to the spillover capital aggregate of R&D capital in other Norwegian industries of 0.056. Furthermore, one may look at long-run spill-over effects from the single industries to the industries 1, 4, 5, 6 and 7, cf. Table D5. Industry 2 contributes the most to the spillovers for industry 1, whereas industry 7 is the most important one for industries 4, 5, 6 and 8. For industry 7, industry 4 is the most important one.

The SK variable is included in industry 5 and industry 6, whereas it turned out to enter insignificantly for the six other industries. Our significant estimates (at the 5 per cent significance level) of the long-run parameters $\xi_{5,3}$ and $\xi_{6,3}$ are quite high and indicate that an increase in the skill shares amounting to one per centage point yields an increase in the TFP level equal to 1,7 and 5,4 per cent, respectively.

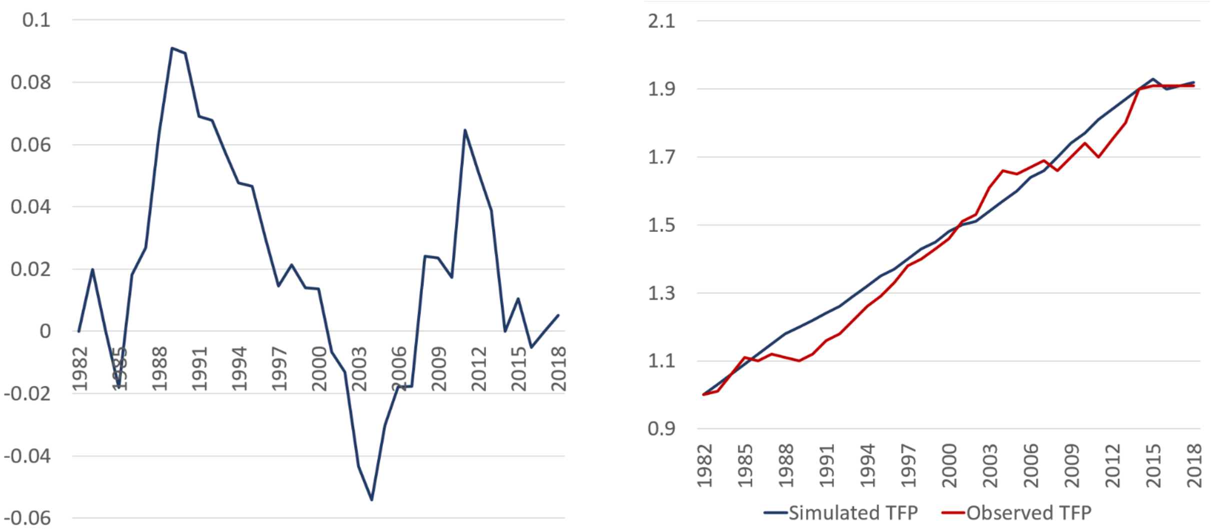
The estimate of the common adjustment parameter, λ, is -0.073. In four of the industries, i.e., industries 2, 4, 6 and 8 there is a significant and negative estimate of the parameter of the lagged left-hand side variable, $\Delta\ln\left(TFP_{j,t-1}\right)$. However, transforming the equations back to level form, one might infer that both the first and the second lag of the response variable, i.e., $\ln\left(TFP_{j,t-1}\right)$ and $\ln\left(TFP_{j,t-2}\right)$, enter with positive values.

Based on the estimated model, we can decompose the growth of TFP at an aggregate level for Norway during a period (1982-2018) where historical data are available. We aggregate TFP by industry using the Domar-index, see also Balk (2009):

$$\Delta\ln TFP = \sum_{j\in J}\left(P_j X_j / P_Q Q\right)\Delta\ln TFP_j,$$

where the weights are the value of gross output in industry *j* divided by the sum of value added across all industries. Note that the weights exceed unity, which implies that productivity growth at the aggregate level amounts to more than a weighted average of industry-level productivity growth. This reflects that productivity gains in the production of intermediate inputs lead to reduced input prices in downstream industries and thus a higher level of aggregate productivity. Figure 1 compares historical TFP data for mainland business sectores with the simulated results (using dynamic simulation).

Figure 1. Estimated errors (left panel) and simulated and actual TFP (right panel). 1982-2018



First, we note that the estimated model tracks the actual TFP quite well in sample. There is, however, a period around 1990 where the model overpredicts TFP which we think is due to the severe economic (banking) crises that took place in Norway during those years. During the last 20 years the residual in aggregate TFP is less than 0.03 and less than 0.01 in 2018. Our level of aggregation corresponds to the mainland business sector in the Norwegian economy excluding Construction and Services related to oil and gas extraction. The average growth rate in TFP during the simulation periode is 1.8 per cent annually using the Domar-index and 0.7 per cent annually using gross output volumes as weights. This implies that the ratio between gross output and value added for our aggregate is roughly 2.5.

In the following we decompose how the various expanatory factors of TFP by industry have contributed to aggregate TFP growth by conducting several counterfactual simulations.[7] First, we construct a baseline simulation where all explanatory variables in the TFP-equations shown in Table 2 are kept at their initial 1981 values. The value of the Domar-index is then almost constant from 1982 to 2018. We then let TFP in the US follow its historical development instead of being constant as in the baseline simulation and compare the Domar-index in this simulation with the baseline. In Table 3 we see that this partial effect of higher TFP in the US has resulted in 35 per cent higher TFP in 2018. Next, we let the Norwegian R&D capital stocks follow their historical developments and estimate their effects on the Domar-index by comparing with the baseline. Finally, we do the same with the skill ratios (*SK*) to estimate the effect ont aggregate TFP of their historical increase. The results from these two simulations compared to the baseline are shown as line one and two in Table 3. Because the model is non-linear, cf. Eq. (7), there are interaction effects of these partial changes in the explanatory variables that we need to include as well. We therefore end up with three partial effects and three interaction effects. Their contribution to the overall growth in TFP as measurued by the Domar-index is shown in Table 3. The total increase in TFP according to the Domar-index is 91 per cent over the whole sample period which implies that the factors specified have contributed to 1.8 per cent annual growth in aggregate TFP in Norway from 1982 until 2018.

Table 3. Decomposition of increase in total TFP 1982-2018

Source	Per cent
Increase due to domestic R&D capital	16
Increase due to domestic skill-ratio	19
Increase due to higher TFP_{US}	35
Combined effect of TFP_{US} and R&D capital	8
Combined effect of TFP_{US} and skill-ratio	9
Combined effect of R&D capital and skill-ratio	5
Total	92

[7] To be explicit, consider the function y=f(x,z). The direct contribution to the change in y (dy) from the change in x (dx) is given by f(x+dx,z) and the direct contribution to the change in y from the change in z (dz) is given by f(x, z+dz). The change in y (dy) not stemming from the direct changes in x or z is labelled combined effect, i.e. dy-f(x+dx,z)-f(x, z+dz), see also Benedictow and Boug (2017, appendix 2).

We can compare some of these results with those in Table 3 in Griffith et al. (2004) who conducted a similar analysis. They found that roughly half of the growth effects of higher R&D and skill intensity in TFP in Norwegian manufacturing is due to their proxy for technology transfer. Our results for the Norwegian business sector as a whole, are slightly smaller. The total growth effect of higher skills is 19 + 9 percentage points, so the technology transfer effect is roughly one third. A similar effect applies for R&D capital (16 + 8 percentage points) and the technology tranfers amount to one third of the total effect also in this case. There is an additional interaction effect between the two domestic sources of TFP growth, R&D capital and skill intensity, but this is small. The "partial" domestic effect on TFP growth amounts to (16+19+5)/92=0.435 while the partial international transfer effect is 35/92=0.38 (or 38 per cent). The remaining interaction effects between domestic sources and international transfers are 17/92=0.185 out of total TFP growth. These results are also in line with Coe et al. (2009) who concluded that both domestic and foreign R&D capital have measurable impacts on TFP even after controlling for human capital. The importance of skill for innovation is also highlighted by Bye and Fæhn (2012) in a CGE analysis for Norway.

5. Policy simulations

The econometric model presented in the previous section specifies two policy instruments available to policy makers. The government can increase their own R&D-investment and/or they can stimulate private R&D activities by reducing the user cost of R&D capital. An increase in government R&D-investment involves a fiscal stimulus (an increase in government expenditures) that builds up the government R&D capital base. According to our estimates in Section 4 this will lead to spill-over effects to total factor productivity in the private sector. For such a policy not to be also a fiscal stimulus package one could reduce other components of government investment to balance the budget.

A stimulus to the user cost of R&D capital can be implemented or interpreted in two ways. The first uses changes to the existing tax credit for R&D while the second focuses on the highly generous depreciation allowances that are built into the Norwegian tax code for R&D investment expenditures. Norway introduced a tax credit system for R&D in 2002 (SkatteFUNN) to stimulate R&D investments in the business sector, cf. Cappelen et al. (2010). The basic idea was that the Norwegian business sector did not invest enough in R&D at the time compared to other OECD-countries. Stimulating R&D using government subsidies in addition to existing support through grants from the Research Council of Norway was expected to stimulate productivity growth in the economy. The R&D capital stock in each industry depends on the user cost of R&D capital as well as other factor prices, TFP and gross output. A useful way to capture a system of tax credits to R&D investments in a user cost of capital framework is given by Warda (2001).[8] In the case of a tax credit system where there is a 100 per cent write off of R&D investments (which approximates the Norwegian tax code) and tax credits are not taxable, the rental rate of R&D capital becomes P_K^{RD} *B-index, where P_K^{RD} is the user cost of capital, cf. Sandmo (1974). The *B*-index is equal to $(1 - s - s_c)/(1-s)$ where s is the corporate tax rate and s_C is the rate of the tax credit for R&D investment. The *B*-index is equal to one when there is no tax credit. In the case of Norway in 2019, s = 0.22 while s_c= 0.18 for a large firm (0.20 for SMEs) so B_{2019} = 0.77 (0.74 for SMEs). Eliminating the tax credit for R&D in Norway in 2019 would consequently lead to an increase in the rental rate of R&D of 30 per cent (1/0.77=1.30). Note however, that this effect on the user cost is only relevant for firms that have R&D investment below the upper limit or cap in the system. Although most firms do in fact belong to this group there are large firms with large R&D expenditures that spend more than the cap every year. For these firms the user cost is unchanged.

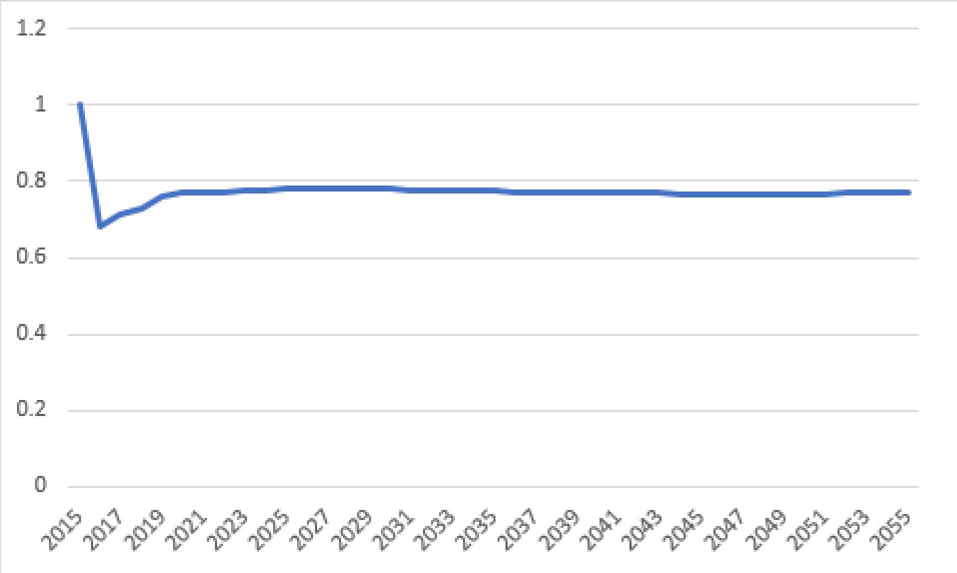
The alternative interpretation of this policy change instead focuses on depreciation allowances for R&D investments in the Norwegian tax code. The tax code allows for R&D investment to be immediately deductible as operating expenditure. To be explicit, in our model the user cost of R&D capital p_K^{RD} is given by $P_K^{RD} = (i + \delta_{RD} + \frac{\tau}{1-\tau}(\delta_{RD} - tdr) + \mu)q_{RD}$, where i is the nominal interest rate, δ_{RD} is the actual depreciation rate, tdr is the tax depreciation rate, τ is the corporate income tax, μ includes other factors such risk premium, inflation expectations etc. and q_{RD} is the investment price. This type of user cost formula is based on a representative firm optimizing after-tax profits by solving a dynamic optimization problem with geometric depreciation (Sandmo, 1974). While the actual depreciation rate represents the gradual decrease in the value of the capital stock, the tax depreciation rate represents the decrease in value of the capital stock as it is reported to the tax authorities based on domestic accounting principles (Barth *et al.*, 2016). If the actual depreciation rate is lower than the tax-depreciation rate, i.e. $\delta_{RD} < tdr$, it is beneficial for the firm to hold capital from a tax perspective. The actual depreciation of R&D is assumed to be δ_{RD} = 15 per cent which is used in the literature, see e.g. Hall (2005). In Norwegian tax law, R&D activities can be classified as operating costs and be expensed immediately, which implies a tax depreciation rate of tdr =100 per cent. If this tax-benefit is reduced, i.e. tdr is lowered, the user cost of R&D increases.[9] It is standard in the literature to study

[8] OECD (2018) provides a detailed discussion of the *B*-index for various tax credit systems and presents estimates for Norwegian firms (large and SMEs) for 2017. Note that we ignore the cap of the tax credit in this discussion.

[9] For example, lowering the tax depreciation rate from 100 per cent to 88 per cent would increase the user cost of capital by about 30 per cent.

effects of R&D promoting policies. Because *tdr* = 1 in the Norwegian case, we simulate the effects of reducing *tdr* but use the results from this simulation as the reference simulation and the current policy rate as the policy scenario. In Figure 2 the user cost of R&D capital in the policy scenario is compared to the reference.

Figure 2. The user cost of R&D capital in the policy scenario compared to the reference



Note: Simulated change in user cost of R&D due to an increase in the tax deductability rate (*tdr*) by 10 percentage points.

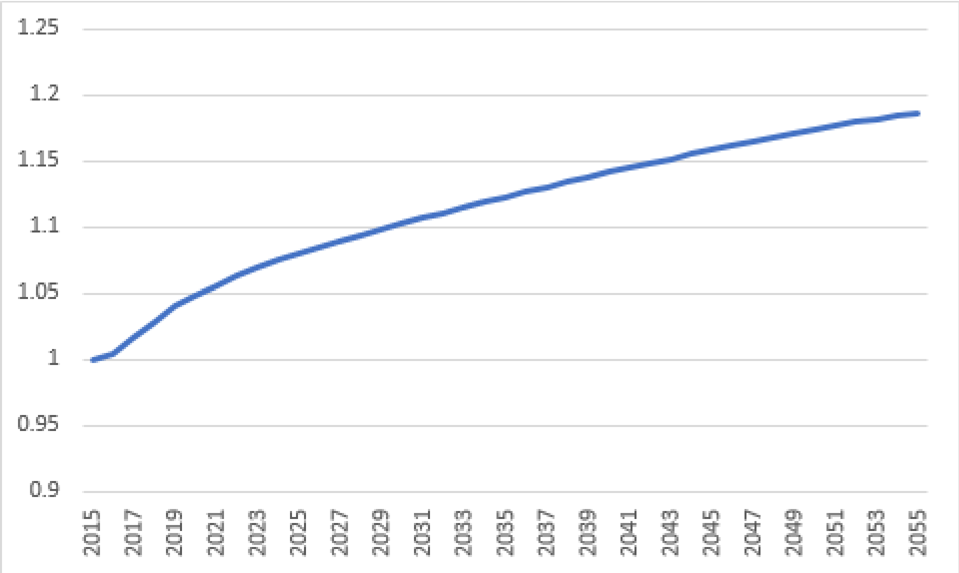
The next question we need to address is the financing of the tax credit. An increase in tax deductions for R&D increases profits that is taxed using the corporate tax rate of 0.22. But tax deductions are larger so corporate income tax revenue is reduced. After a few years the revenue loss is roughly 2 billion Norwegian kroner or 200 million Euros according to our model simulations. To finance this revenue loss, we reduce government transfers by a similar amount. The reason we say “similar” and “same” is that there will be indirect effects of the change. We do not balance total government budget in each year in the same way in both simulations. Instead we focus on the long run balance and government net assets as share of nominal GDP. In this way the two policies will have the same long run fiscal balance but allows the budget balance to differ in the short and medium run. This is in line with the Norwegian fiscal policy rule. Our choice to use transfers to households is motivated by utilizing a variable with little effects on incentives such as income tax rates.

The permanent reduction in the user cost of R&D capital will gradually increase the R&D capital stock in the private mainland economy.[10] This is shown in Figure 3. Because of the sluggish response

[10] This is defined as all industries except petroleum exploration, international shipping services and government.

of the capital stock to changes in the user cost, the increase in the capital stock will be very gradual. Also, there will be some increase in the capital stock and more investment as a second-round effect of the initial reduction in the user cost. We shall come back to this feature below. We study the policy shift over a 40-year horizon to illustrate the slow response of the spillover effects and the repercussions of these spillovers to the rest of the economy.

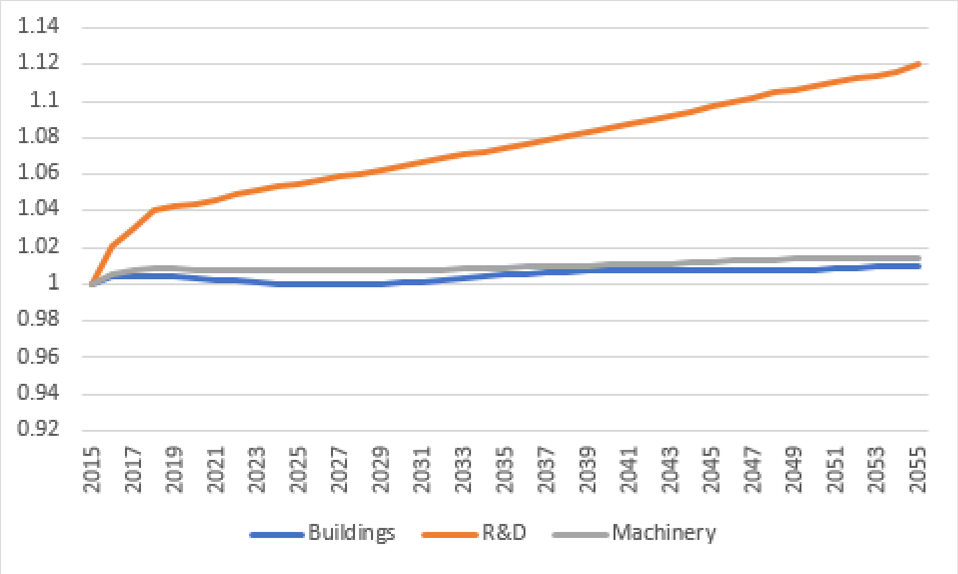
Figure 3. The effect on the R&D capital stock in mainland non-oil industries



Note: Model simulations of a negative shift in the user cost of R&D of 25 per cent compared to baseline.

Figure 3 shows the effects on gross investments for three main asset types. The effects on R&D investment is substantial while the effects on the other two major categories are quite moderate. Consequently, the aggregate capital stocks of buildings and machinery will not change much either. Besides the effect of changes in the user cost of R&D capital, capital stocks by industry are affected by gross output and TFP. Output increases following the decline in user costs leading to an increase in demand for capital of all categories in line with Eq. (2), while the increase in TFP will lower the demand for capital cet. par. The net effect of these two elements is what we see on Figure 3.

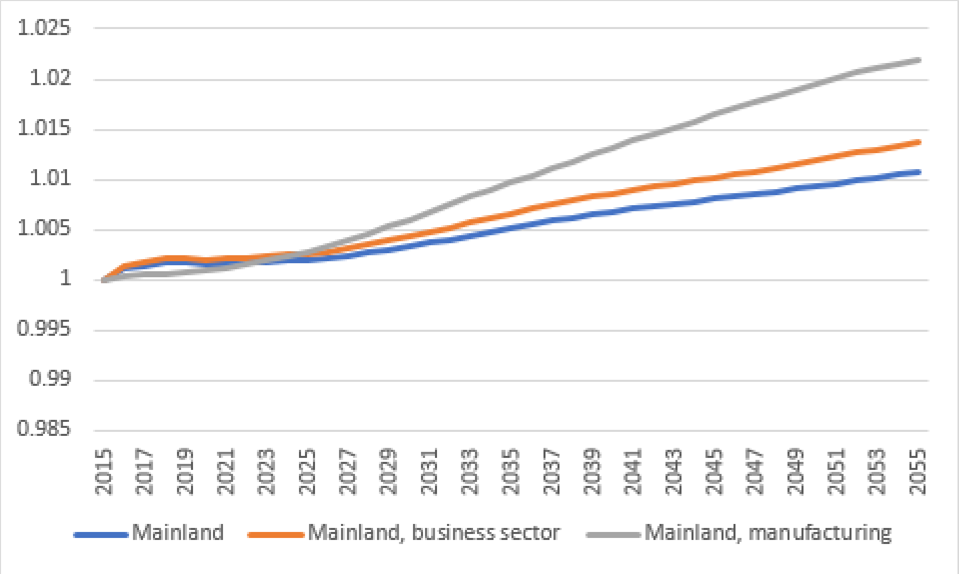
Figure 4. The effects on gross investment. Buildings, R&D and Machinery



Note: Model simulation of a negative shift in the user cost of R&D.

The effects on value added for two aggregates are shown on Figure 5. For Mainland GDP (total GDP excl. petroleum extraction and international shipping services) we notice that the cut in the user cost takes a long time to affect output. One reason is due to the balanced budget policy assumption whereby cutting transfers to households, consumption is reduced. The other reason for the sluggish response is that it takes time to increase the R&D capital stock enough for it to have productivity and spillover effects. This explains why there is almost no aggregate effect on GDP during the first decade following the cut in the user cost of capital. The effect on the mainland business sector is somewhat larger since there by assumption are no changes in government employment or investment. After the first decade there are steadily larger aggregate output effects. Notice also that these effects are not moving towards a new equilibrium level but increase during the entire simulation period. Thus, the growth rate of the economy is affected by the stimulus to R&D in line with some models of endogenous growth.

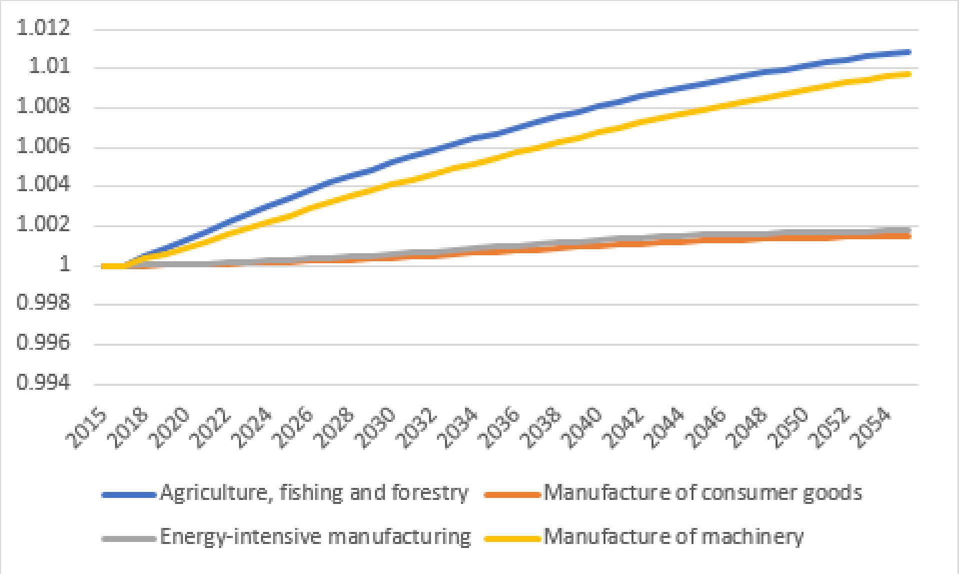
Figure 5. Effects on mainland GDP and manufacturing



Note: Model simulation of a negative shift in the user cost of R&D.

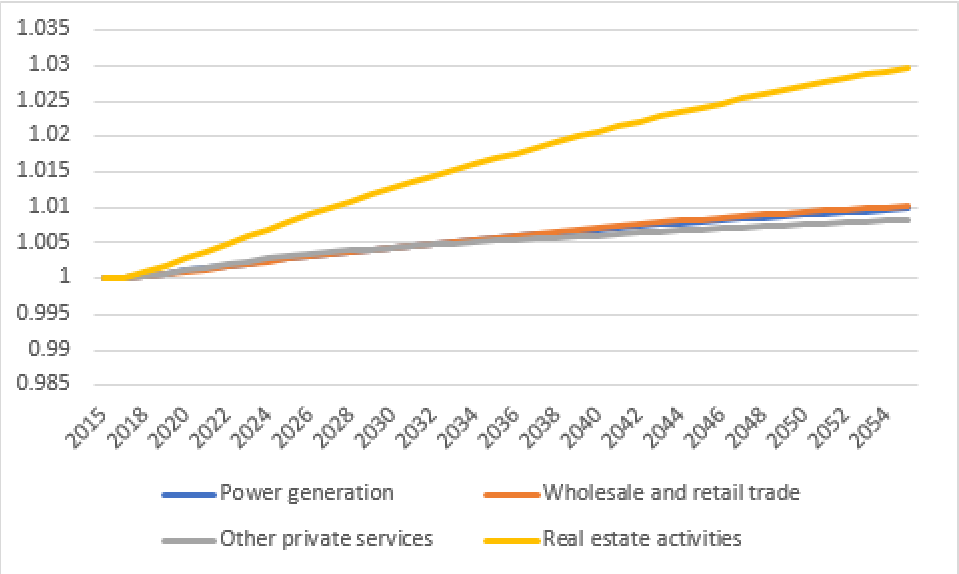
The main reason for the growth effect on GDP is the change in TFP in various industries. This is shown on Figures 6 and 7 which display changes in TFP for three manufacturing industries and for various other private industries. For most industries TFP increases by around one per cent. This is only due to the spillover effect of higher R&D capital in Norway. From the presentation of the model in Section 2 we noticed that R&D capital by industry is included in the total capital stock by industry with standard "neoclassical" effects. In addition, R&D affects industry TFP through spillovers from R&D capital in other industries. Looking at the macroeconomic effects in Table 4, we see that total employment declines while the total capital stock increases due to this policy shift. The increase in the capital stock is a result of the increase in gross investment as shown on Figure 4. According to Figure 6 it is the industry "Production of machinery and transport equipment" that enjoys most spillover within the manufacturing sector. The reason why the two other manufacturing industries (Production of food etc. and Production of semi manufactures (metals, fertilizers, and paper and pulp)) are not much affected is due to the low estimated spillover effect from domestic sources (cf. Table 2 and Table D3 in Appendix D).

Figure 6. Effects on total factor productivity



Note: Model simulation of a negative shift in the user cost of R&D.

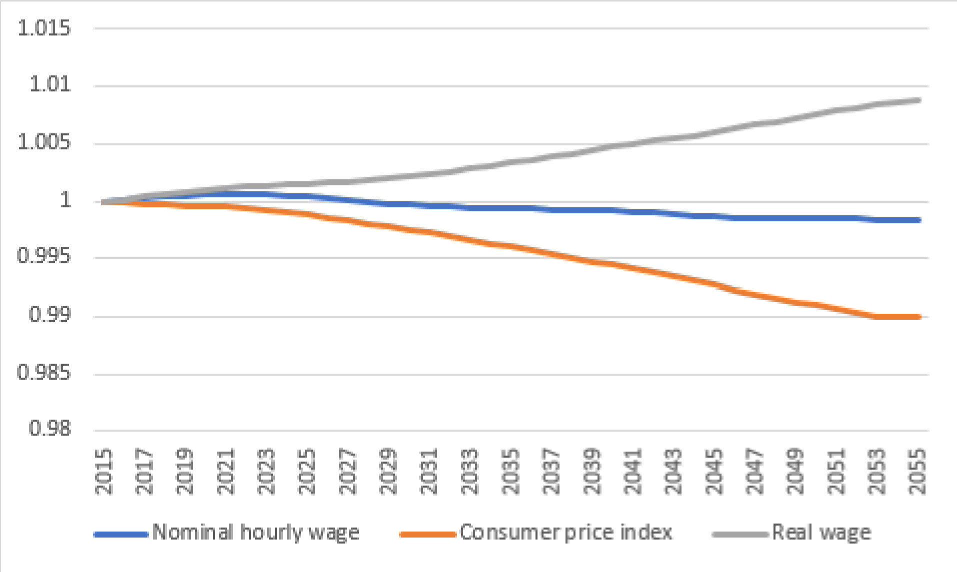
Figure 7. Effects on total factor productivity



Note: Model simulation of a negative shift in the user cost of R&D.

For other private industries in the model, see Figure 7, the effects on TFP are roughly similar. The increase in TFP in these industries is also the main reason why output prices and the consumer price index fall, see Figure 8. The consumer price falls roughly in line with the increase in TPF. The nominal wage does not change much at all on average so the consumer real wage increases. This is one factor behind the increase in household incomes that leads to higher consumption. On the other hand, total employment falls due to higher TFP and counteracts the increase in real wages. The reason why consumption still increases is that transfers to households (mostly pensions) increase in real terms because pensions per pensioner are linked to the wage rate (a policy rule in Norway) and the number of pensioners is not reduced even if employment is.

Figure 8. Effects nominal and real wages and the consumer price index



Note: Model simulation of a negative shift in the user cost of R&D.

From Table 4 we see that the increases in TFP by industry lead to lower employment and higher unemployment. This is due to how wage bargaining is modelled where the hourly wage rate does not clear the labor market with constant unemployment in the long run as is often the case in CGE/AGE-models. This result has to do with which industries that are most significantly affected by the increase in TFP. From Figure 5 we see that only one of the manufacturing industries has a TFP effect that resembles those in the industries on Figure 6. Wage bargaining in Norway follows what is called "pattern bargaining" where bargaining in manufacturing sets a norm for wage growth that other industries follow. In manufacturing it is profitability that is the main factor driving wages and the product real wage cost follows labor productivity in manufacturing. The level of unemployment matters also while the consumer real wage does not matter in the long run. In our simulation there is a larger productivity increase outside manufacturing. Thus, with wage changes mostly related to what happens to manufacturing and not the whole economy, this rigidity leads to wages not falling enough in order to bring unemployment back to its level in the reference scenario.

Table 4. Macroeconomic effects of a permanent reduction in the user cost of R&D capital. Changes in per cent unless otherwise stated

	5th year	10th year	15th year	20th year	25th year	30th year	35th year	40th year
Household consumption	0.0	0.1	0.2	0.3	0.5	0.6	0.8	1.0
Gross investment	1.0	1.0	1.3	1.7	2.0	2.2	2.5	2.8
- R&D investment	4.3	5.4	6.5	7.6	8.7	9.8	10.9	12.1
Exports, non-oil	0.0	0.1	0.2	0.4	0.5	0.7	0.8	0.9
Imports	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7
GDP mainland	0.2	0.2	0.3	0.5	0.7	0.8	0.9	1.1
- Manufacturing	0.1	0.3	06	1.0	1.3	1.6	2.0	2,2
Employment mainland	0.0	-0.1	-0.2	-0.2	-0.3	-0.3	-0.4	-0.6
Unemployment rate, pp.	-0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2
Real wage	0.0	0.1	0.2	0.3	0.5	0.6	0.8	0.9
Interest rate pp.	0.0	-0.1	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3

Note: Model simulation of a negative shift in the user cost of R&D.

6. Conclusions

In this paper we have analyzed macroeconomic effects of tax policies related to R&D investment when there are spillovers from domestic as well as foreign sources of knowledge. We have done this by specifying a general dynamic econometric model of total factor productivity (TFP) by industry. The foreign source of spillover is proxied by TFP in the US where the idea is that the US economy represents the frontier of knowledge. But the spillover to a Norwegian industry is not a “free lunch”. It is also assumed to depend on the industry’s own knowledge as measured by its R&D capital stock. Domestic spillovers are measured by a weighted sum of private and public R&D capital stocks. We estimate the effects of these spillovers using quarterly National Accounts data for Norway and found that both foreign and domestic sources of spillovers matter for TFP in most industries. At anaggregate level we have found that domestic R&D spillovers and increased skill intensity contributed with 44 per cent of the total growth in TFP over the period 1982 to 2018. The impact from international spillovers through technology adoption amounted to 38 per cent. The remaining 18 percentage points are due to interaction effects.

Next, we extended a large scale macro-econometric model by including these econometric TFP equations in the model and simulated the effects of a more R&D friendly tax system. The policy change consists of a more generous depreciation allowance for R&D in the tax code leading to a 30 per cent decline in the user cost of R&D capital. To counteract the loss in government revenues, estimated to be around 200 million Euros or somewhat less than 0,1 percent of mainland GDP, we assume a cut in government transfers to households. We found that these policy changes lead to a substantial increase in R&D investments in the economy. As the R&D capital stocks gradually increase in various industries, they enjoy a spillover effect both from abroad and from domestic sources. In the short and medium term, the effects on aggregate output is very small simply because the changes in capital stocks by industry are modest. However, after a decade output in the economy increases and continues to grow so that the level of GDP increases steadily. This implies that the growth rate of output is permanently higher due to the policy shift. Thus, the balanced budget multiplier is positive and increasing over time due to supply side effects from stimulating R&D. After roughly 40 years the level of output, real wages and consumption are around one percentage point higher in our R&D tax policy scenario compared to baseline. The productivity gain leads to higher real wages and consumption but also to more exports. The size of these changes are small but taking into account the modest policy change, the results show an important potential of certain R&D policies. We have not calculated the potential welfare effects of the policy.

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Appendix A. A description of other blocks in the macro model KVARTS

The macroeconomic model has an extensive input–output structure based on the National Accounts. All blocks in the model are determined simultaneously, which implies that a change in one industry will affect all the other industries. For each of the 38 products, there is a supply and use equation which, slightly simplified, is given by

(A1) $$X + I = A + \sum_k d_{Ck} C_k + \sum_k d_{Jr} J_r + \sum_k d_{Mj} M_j + DS = A + D,$$

where X is gross production, I is imports, A is exports, C_k is consumer category k, J_r is gross investment category r, M_j is category j of material input and DS is changes in total stocks. Total domestic demand, D, is thus the sum of consumption, gross investment, other material inputs and changes in total stocks. The indices k, r and j run over 15 consumer categories, 8 investment categories and 16 industries, respectively.

Each impoted good is assumed to be a variety of a composite domestically produced goods. Each user minimizes the costs of consuming composite good as in Dixit and Stiglitz (1977). Thus, the import share for each user of a composite commodity is a constant elasticity of substitution (CES) function of the domestic price (P_D) and the corresponding import price (P_I) for each commodity. Hence, total imports of each commodity equal the import share multiplied by domestic demand

(A2) $$I = CES(P_I / P_D) \times D,$$

where we have dropped commodity subscripts for notational convenience, and I denotes import. Note that Eq. (A2) is slightly simplified compared with the actual model, as the structure of imports varies among domestic users. Hence, it is a weighted sum of the various components in Eq. (A1) that is inserted into Eq. (A2). The weights are taken from the most recent final National Accounts. For non-competitive imports, domestic production is zero or negligible and imports are given by demand. Exports (A) are also assumed to be variants of the corresponding domestically produced goods and are modeled using the Armington approach[11]

[11] For exports of crude oil and natural gas, gross domestic production is exogenous, and exports are determined by Eq. (A1).

(A3) $A = G[(P_A / P_W) \times E, D_W]$,

where the export price, P_A, relative to world market prices for similar goods (P_W) in domestic currency captures price effects and where E is an aggregate of the main exchange rates of relevance for Norwegian exports. The function G is log-linear and homogeneous of degree zero in export and world market prices measured in a common currency. The indicator of world demand (D_W), measured by aggregating the imports of Norway's main trading partners, captures income effects; see Boug and Fagereng (2010).

Consumption (C) is modeled in a three-step procedure. At the highest level, aggregate consumption in the long run is a log-linear function of disposable income, DY, wealth, W, and the after-tax real interest rate, r,

(A4) $\ln(C) = 0.85 \times \ln(DY) + 0.15 \times \ln(W) - 0.7 \times r.$

Note that the coefficients of income and wealth sum to unity, i.e., consumption is homogeneous of degree 1 in income and wealth. The estimated aggregate consumption function is obtained from a cointegrated VAR system; see Jansen (2013) and Boug et al. (2020). At the next level, consumption is spread over non-durable consumption, transportation vehicles and other durable consumer goods using a dynamic linear expenditure system based on the Stone-Geary utility function. At the lower level, expenditure on non-durable consumer goods is spread further in accordance with the Almost Ideal Demand System; see Deaton and Muellbauer (1980).

Prices are determined as mark-ups over marginal costs where the latter is derived from the production function. The producer price in every industry is determined by maximizing real profits, given that producers face a downward declining demand curve for their products both on the domestic and export markets. Products are generally assumed to be imperfect substitutes; hence the Norwegian product prices may differ from prices set by foreign competitors. Norwegian producers take foreign prices into account in their price setting in line with theories of monopolistic competition. In each industry, producer prices for domestic goods and exports (excl. taxes) are the product of mark-up (MU) and marginal cost (MC). Hence, producer prices excl. taxes *(P)* are determined as

$$P = MU \times MC$$

Standard theory (cf. for instance Rødseth, 2000, p. 266) tells us that the mark-up is a function of relative prices and total expenditure. We simplify and let each industry mark-up be a function of the relative price P_F/P:

$$MU = m_0 \times \left(P_F / P\right)^m .$$

where P_F is the competing foreign price and m_0 and m are parameters. In the base year, when all price indices are one, MU equals m_0. So, this parameter is the mark-up in the base year.

Inserting the expression for the mark-up in the price equation gives

(A5) $$P = m_0^{1/(1+m)} P_F^{m/(1+m)} MC^{1/(1+m)} .$$

If m=0, the mark-up is constant. In this case, price equals marginal cost multiplied by m_0. If, on the other hand, the export price or the price in domestic markets ($m \to \infty$) for each good equal the competitor's price, P_F, there is price-taking behavior and output (gross production) is determined by supply (small open economy case). Such price-taking behavior is the case in the petroleum industry where the crude oil price is exogenous in the model and all prices are equal (except for some short-run differences). In the standard case with mark-up pricing, output in each industry is determined by a weighted sum of demand categories in the model. The empirical properties of the price equations are outlined in Boug *et al.* (2017). In addition to domestic price setting, foreign prices and taxes are essential in determining consumer prices. For each component of demand, there is a purchasing price index that is determined according to the structure in the National Accounts. The price index for other material inputs (P_M) by industry is used below as an example of how purchasing prices are determined

$$P_M = \sum_i c_i (1 + VAT_i)[(1 - IS_i) P_{Hi} + IS_i P_{Fi} + b_i ET_i + c_{tm} P_{TM}].$$

The price index is a weighted sum of domestic (P_H) and foreign (P_F) basic prices, a trade margin (P_{TM}) and excise taxes (ET_i), where the weights (denoted by lower case letters) are calibrated constants based on the National Accounts. The P_H variables are determined according to the mark-up pricing model outlined above. IS_i is the import share for product i and VAT is the value-added tax rate, which varies according to uses.[12] The price indices for various consumer goods as well as investment categories are determined in the same way. Import prices are mostly exogenous in foreign currency, although for some goods there are pricing-to-market effects; see Benedictow and Boug (2013).

The model also contains an exchange rate equation based on a combination of purchasing power parity and uncovered interest rate parity linking the Norwegian krone to the euro. The interest rate setting of the central bank is captured by a Taylor rule type of equation based on unemployment and inflation.

The employment 'block' of the macro-econometric model consists of labor demand by industry which can be aggregated to total labor demand, noting that employment in the three government sectors is exogenous. Total labor supply, *LS*, is disaggregated by five age groups and gender since participation rates vary a lot between groups and over time. For each group, we specify a logit function relating labor supply in terms of the participation rate for each group to the (marginal) real after-tax wage as well as the unemployment rate to capture discouraged worker effects. The logit function by age groups and gender generally reads as

$$\ln\left(\frac{YP}{1-YP}\right) = g\left[W \times (1-TMW)/CPI, UR\right],$$

where *YP* is the participation rate, *TMW* is the (average) marginal tax rate on wage income, *CPI* is the consumer price index and *UR* is the unemployment rate. The implied aggregated supply elasticity is in line with micro-econometric results in Dagsvik *et al*. (2013) as well as Dagsvik and Strøm (2006). Aggregate labor supply is found by multiplying the various participation rates with the size of the population in the corresponding group. Unemployment is merely the difference between the labor force (supply) and employment.[13]

The labor market is further characterized by large wage setters that negotiate on wages given the price-setting behavior of firms (Layard *et al*., 2005). Unions are assumed to have preference for both wages and employment. Therefore, the bargaining power of unions increases with low levels of

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[12] Some services have a low rate, and some even have a rate equal to zero, but the standard VAT rate is 25 per cent. Food has a low rate of 15 per cent. Excise tax rates vary considerably across products; fuels, electricity, alcohol, tobacco and nearly all cars are heavily taxed. Most goods and consumer categories are hardly taxed at all, however. Both VAT rates and excise tax rates are exogenous variables in the model and are not changed in any of the simulations in our study compared to actual historical values.

[13] The model separates between hours worked and employment, but we abstract from this distinction in the general overview.

unemployment, implying that the wage response is higher for a low level of unemployment compared to a high level of unemployment. This non-linearity is captured in the specification of the wage curve:

$$\ln(W) + \ln(H) - \ln(P_Y) - \ln(Y) = f(UR),$$

where Y is the volume of value added and P_Y is the value-added price index. The left-hand side of the equality sign thus represents the wage share. The wage curve above mimics the wage bargaining process in manufacturing. In Norway, wage growth in the manufacturing sector leads wage growth in other sectors of the economy; see Aukrust (1977). This institutional setting is captured in KVARTS and wages in the other sectors depends on the wage growth in manufacturing, see Gjelsvik et al. (2019).

Appendix B. Definition of symbols

Table B1. List of symbols

Symbol	Interpretation
X	Gross production
I	Imports
A	Exports
C_k	Consumer category
J_r	Gross investment category
M_j	Category of material input
DS	Changes in total stocks
D	Total domestic demand
d_{Ck}	Coefficient related to consumption category in supply and use equation
d_{Jr}	Coefficient related to investment category in supply and use equation
d_{Mj}	Coefficient related to material input in supply and use equation
Z	Technology level
P_D	Domestic price of product that also is imported
P_I	Import price
P_A	Export price in domestic currency
P_W	World price of product of the same type as the export product
E	Exchange rate index
D_W	Indicator of world demand
C	Total private consumption
DY	Total real income of the households
Y	Value added, volume index
P_Y	Value added, price index
W	Total real wealth of the households
R	After-tax real interest rate
J	Investment (with unspecified cateory)
K	Capital stock at the end of the year (with unspecified cateory)
DEP	Capital depreciation (with unspecified cateory)
K_t^{RD}	R&D capital stock at the end of period *t* (with unspecified category)
TFP_t	TFP-level in period *t* (with unspecified category)
P_{Kt}	User cost of an ordinary capital in period *t* (with unspecified category)
$P_{K^{RD}t}$	User cost of R&D capital in period *t*
H_t	Labour input in period *t* (with unspecified industry)
SK	Share of skilled worker (with unspecified industry)

Table B1. (Continued)

M_t	Material input in period *t* (with unsp. industry and material category)
$\alpha_{K^{RD}}$	R&D capital elasticity (output elasticity in unspecified industry)
α_K	Ordinary capital elasticity (output elasticity in unsp. industry and cat.)
α_H	Labor elasticity (output elasticity in unspecified industry)
α_M	Material elasticity (output elasticity for unsp. material type and ind.)
P	Producer price exclusive of taxes (with unspecified product)
MU	Mark-up (with unspecified product)
MC	Marginal cost (with unspecified product)
m_0	Parameter in mark-up equation (with unspecified product)
m	Parameter in mark-up equation (with unspecified product)
P_F	Competing foreign price (with unspecified product)
P_{Hi}	Domestic price of product *i*
IS_i	Import share of product *i*
VAT_i	Value added tax for product *i*
ET_i	Excise taxe for product *i*
b_i	Coefficient attached to ET_i
YP	Participation rate (unspecified group)
TMW	Marginal rate on tax income
CPI	Consumer price index
UR	Unemployment rate
LS	Total labor supply
γ_j	*j*=1,…,8; adjustment parameters in equations for relative change in TFP
λ_j	*j*=1,…,8; short-run parameters in equations for relative change in TFP
η_j	*j*=1,…,8; slope parameters related to domestic spillover effects
ϕ_j	*j*=1,…,8; slope parameters related to foreign spillover effects
κ_j	*j*=1,…,8; slope parameters related to skill share
$TFP_{US,t}$	TFP-level in USA in period *t*
$\varepsilon_{j,t}$	*j*=1,…,8. Error terms in eq. (7) for relative change in TFP
ρ	Share parameters related to domestic spillover aggregates. Set to 0.5.
$K^{RD}_{OTH\,j,t}$	Spillover aggregate relevant for industry *j* in period *t*, j=1,…,8
$K^{RD}_{OTHA\,j,t}$	Component of spillover aggregate (stemming from the industry as a receiver of products) relevant for industry *j* in period *t*, j=1,…,8

Table B1. (Continued)

$K^{RD}_{OTHB\,j,t}$	Component of spillover aggregate (stemming from the industry as a supplier of products) relevant for industry *j* in period *t*, j=1,…,8
w_{ji}	Weight of industry *i* in the construction of $K^{RD}_{OTHA\,j,t}$
ww_{ji}	Weight of industry *i* in the construction of $K^{RD}_{OTHB\,j,t}$
I	Set with all industries specified in the model
I^{*}	Set with all industries specified in the model except the governmental
J	Set with industries, for which TFP is endogenized
$\underline{\varepsilon}_t$	Vector with errors from the TFP equations
Ω	Covariance matrix of $\underline{\varepsilon}_t$
$\xi_{j,1}$	*j*=1,…,8. Long-run parameter related to foreign TFP in endogenized TFP-equations
$\xi_{j,2}$	*j*=1,…,8. Long-run parameter related to domestic spillover aggregates in endogenized TFP-equations
ω_{ji}	Linear combination of w_{ji} and ww_{ji}

Appendix C. Weights used for spillover aggregates

Table C1. Weights used for constructing capital aggregates across industries, w_{ji}

	i						
j	1	2	3	4	5	6	7
1	0	0.4235	0.0471	0.0353	0.0824	0.0824	0.2
2	0.3243	0	0.0541	0.0135	0.0541	0.0946	0.1892
3	0.0172	0.1897	0	0.0862	0.2069	0.1207	0.2759
4	0	0.0492	0.1148	0	0.0656	0.1311	0.5082
5	0	0.0492	0.1148	0	0.0656	0.1311	0.5082
6	0	0.1087	0.0326	0.1413	0.0761	0	0.4348
7	0.0233	0.2093	0.0465	0.186	0.093	0.1395	0
8	0	0.0588	0.0588	0.0235	0.1176	0.0353	0.5176

Table C1 (Continued)

	i					
j	8	9	10	11	12	13
1	0	0.0588	0	0.0706	0	0
2	0.0135	0	0	0.2432	0	0.0135
3	0	0	0	0.069	0.0172	0.0172
4	0.0492	0.0164	0	0.0164	0.0328	0.0164
5	0.0492	0.0164	0	0.0164	0.0328	0.0164
6	0.1957	0.0109	0	0	0	0
7	0.1395	0.0465	0	0	0.0698	0.0465
8	0	0.1529	0	0	0	0.0353

Table C2. Weights used for constructing capital aggregates across industries, *ww_i*

			i			
j	1	2	3	4	5	6
1	0	0.8889	0.037	0	0.037	0
2	0.3186	0	0.0973	0.0265	0.0531	0.0885
3	0.1212	0.1212	0	0.2121	0.0303	0.0909
4	0.0429	0.0143	0.0714	0	0.0571	0.1857
5	0.1111	0.0635	0.1905	0.0635	0	0.1111
6	0.1148	0.1148	0.1148	0.1311	0.0492	0
7	0.0447	0.0368	0.0421	0.0816	0.1895	0.1053
8	0	0.0250	0	0.0750	0.1750	0.4500

Table C2 (Continued)

			i			
j	7	8	9	10	11	12
1	0.0370	0	0	0	0	0
2	0.0796	0.0442	0.177	0.0177	0.0354	0.0619
3	0.0606	0.1515	0.0303	0	0	0.1818
4	0.1143	0.0286	0.1429	0.0143	0.0143	0.3143
5	0.0635	0.1587	0.0794	0	0.0635	0.0952
6	0.0984	0.0492	0.1148	0.0164	0.0164	0.1803
7	0	0.1158	0.0553	0.0737	0.1684	0.0868
8	0.1500	0	0.0500	0	0.0250	0.0500

Appendix D. Estimation results

Table D1. Diagnostics for the estimated equations

Industry	R^2	DW	LM-test for heteroscedasticity[a]
1	0.867	2.391	0.799
2	0.306	2.219	0.480
3	0.283	2.071	0.581
4	0.327	2.148	0.937
5	0.863	2.198	0.650
6	0.823	1.860	0.163
7	0.713	2.551	0.774
8	0.413	1.880	0.032

[a] Significance probability. The null hypothesis implies absence of heteroscedasticity.

Table D2. Scaled estimated covariance matrix of the errors in the system of regression equations[a]

	Industry							
Industry	1	2	3	4	5	6	7	8
1	11.7416							
2	0.0853	0.0714						
3	0.0028	0.0269	0.1575					
4	-0.4513	0.0151	-0.0129	0.1527				
5	-2.0109	-0.0095	0.0061	0.0465	3.2474			
6	-0.3928	0.0259	0.0413	0.0429	0.1648	0.2518		
7	0.5515	0.0314	0.0233	0.0127	-0.1246	0.0296	0.2366	
8	-1.8860	0.0372	0.0093	0.0632	0.0972	0.1231	0.0991	1.8864

[a]The estimated covariance matrix, $\hat{\Omega}$, has been multiplied by 1000.

Table D3. Estimates of derived long-run parameters

Derived long run parameter	Interpretation	Involved equation(s)	Estimate	*t*-value[a]
$\xi_{j,1}; j = 1,\ldots,8$	Foreign spillover effect	1-8	0.0518	4.4329
$\xi_{j,2}; j = 1,4,5,6,7$	Domestic spillover effect	1,4,5,6,7	0.0563	2.4396
$\xi_{8,2}$	Domestic spillover effect	8	0.1886	2.5462

[a]Calculated by the delta method.

Table D4. The long-run elasticity of the TFP-level in industry *j* with respect to the US TFP-level[a]

Industry	Estimate
1	0.3159
2	0.4810
3	0.4415
4	0.5161
5	0.3790
6	0.4273
7	0.5498
8	0.2929

[a]The applied formula is $\ln(K_j^{RD})\xi_{j,1}$. [Evaluation is done at the sample mean of $\ln(K_j^{RD})$]. In all the eight cases the *t*-value is 4.3293.

Table D5. The long-run elasticity of the TFP-level in industry *j* with respect to the R&D capital stock in industry *i*[a]

	i					
j	1	2	3	4	5	6
1	0[a]	0.03018	0.00093	0.00162	0.00040	0.00079
4	0.00004	0.00131	0.00187	0[a]	0.00034	0.00244
5	0.00009	0.00195	0.00152	0.00327	0[a]	0.00085
6	0.00011	0.00430	0.00137	0.01048	0.00034	0[a]
7	0.00016	0.01021	0.00175	0.02205	0.00173	0.00435
8	0.00000	0.00487	0.00166	0.01148	0.00232	0.01063

Table D5 (continued)

				i			
j	7	8	9	10	11	12	13
1	0.02124	0.00000	0.00013	0.00000	0.00099	0.00000	0.00000
4	0.04742	0.00005	0.00030	0.00001	0.00038	0.00026	0.00185
5	0.04681	0.00011	0.00014	0.00000	0.00059	0.00006	0.00088
6	0.03895	0.00015	0.00023	0.00001	0.00019	0.00014	0.00000
7	0[a]	0.00037	0.00042	0.00011	0.00426	0.00028	0.01059
8	0.14440	0[a]	0.00108	0.00000	0.00087	0.00011	0.01122

[a]The applied formula is $\omega_{ji}\left(K_i^{RD}\Big/KOTH_j^{RD}\right)\xi_{j2}$. (Evaluation is done at the sample mean of the capital ratio).

[b]A priori restriction.