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Brita Bye, Taran Fæhn, and Leo A. Grünfeld

Growth policy in a small, open economy
Domestic innovation and learning from abroad

Abstract:
Research and development (R&D) play a pivotal role for innovation and productivity growth, and knowledge spillovers can make the case for public support to private R&D. In small and open economies, absorption of foreign knowledge through exports and imports can be even more decisive for economic growth than domestic innovation. This macro economic analysis investigates how policies should be formed in order to reap the largest productivity effects, when both these sources of growth interplay. In particular, the firms' capacity to absorb knowledge from abroad depends on domestic R&D, and this reinforces the efficiency arguments for stimulating R&D. We find that from a welfare perspective, export promotion of R&D-based technologies proves slightly more efficient than R&D support.

Keywords: Absorptive capacity, Computable general equilibrium model, Endogenous growth, Research and Development, Spillovers, Two faces of R&D.

JEL classification: C68, E62, H32, O38, O41

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Address: Brita Bye, Statistics Norway, Research Department. E-mail: brita.bye@ssb.no

Taran Fæhn, Statistics Norway, Research Department. E-mail: taran.faehn@ssb.no

Leo A. Grünfeld, Menon Business Economics, Norway. E-mail: leo@menon.no

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1. Introduction

A case for growth-enhancing policy arises when the incentives of private firms to invest in technological improvements are insufficient from an economy-wide perspective. The role of research and development (R&D) as an engine for technological progress is well documented (see e.g. Romer, 1990; Griliches, 1995; Jones and Williams, 1998, 2000). The main argument for public stimulation of R&D is that the non-excludable, common features of knowledge suggest external spillover effects, both to other R&D firms that gain productivity from standing on the shoulders of previous findings and to other industries that obtain increased technological efficiency (Romer, 1990). Patent systems ensure a certain business potential of R&D, but at the same time ownership rights to knowledge hamper competition and economic efficiency. These aspects call for stimulating R&D and R&D-based activities. Some efficiency arguments go the other way around. There will be unnecessary social costs to the extent that R&D firms duplicate their findings or commercialise marginally better innovations that steal markets from already established R&D-based productions, as in the creative destruction model of Aghion and Howitt (1992). However, it is commonly accepted that the balance of evidence suggests too little private R&D and a case for policy intervention (Griliches, 1995; Jones and Williams, 1998).

The empirical literature from the last decade puts emphasis not only on domestic R&D, but also on the absorption of R&D knowledge from abroad as decisive for the productivity and competitiveness of firms, and the efficiency of economies. As a consequence, promoting technological change involves not only domestic R&D stimuli, but also strategies for exploiting the international knowledge stock that is embedded in cross-border flows of persons, ideas, services, and products. These insights form the fundament on which the EU Lisbon strategy is built. Coe and Helpman (1995) and several similar studies in its wake find that the level and composition of imports affect learning from abroad. Recent findings indicate that exports may prove even more important than imports (Alvarez and Lopez, 2006). Not only does the firm's own trade matter; there is evidence of considerable externalities (Delgado et al, 2002; Baldwin and Gu, 2003). Empirical research during the last two decades, including the influential work of Griffith et al. (2004), has also lent convincing support to the twofold productivity effect of investing in domestic R&D; besides spurring domestic innovations, R&D extends the capacity of firms to absorb knowledge spillovers from abroad. This hypothesis of the so-called two *faces* of R&D was first formulated in Cohen and Levinthal (1989). Coe and Helpman (1995) and Keller (2004) document that the international spillover channels for technological growth are particularly important to small and open economies, as their domestic knowledge pools and capacities for creating novel patents, products, and processes, are limited.

The research question of this paper is how small and open economies should form their policy strategies for stimulating productivity growth. Though a vast growth policy literature exist, the last decades' increased research knowledge on the magnitude and determinants of international spillovers gives reason to revisit the insight from previous, applied policy studies, particularly in the case of small, open economies. While the vast majority of earlier studies have treated technological change as exogenous, the endogenous growth models' introduction of the role of R&D policy represented a considerable leap forward. Numerical contributions include Diao et al. (1999), Ghosh (2007)[1], Russo (2004), Alvarez-Palaez and Groth (2005), and Steger (2005).[2] Typically, they find large productivity gains from stimulating R&D. However, only the two first mentioned analyses introduce the small, open economy perspective and a role for international knowledge absorption. They also allow for some endogeneity of absorption, by linking the productivity of R&D to the economy-wide capital import. These studies do, however, find only minor effects of trade policy on growth and economic efficiency. In light of the novel findings on determinants of knowledge absorption summarised above and surveyed more thoroughly in section 2, there is a need to re-examine the policy impacts, in particular, the potential of R&D and trade policies.

The main contribution of our study is to examine the policy implications refining the specifications of absorption mechanisms in a small, open economy in accordance with the recent literature. In particular, we look at how the export channel for technology spillovers can be exploited. We also allow for the observed variation among industries with respect to absorption and absorptive capacity. While Diao et al. (1999) channel all spillovers through the R&D industry we have put effort into representing how international knowledge affects the productivity of final goods producers differently, according to industry-specific trade intensities and absorptive capacities.

First, we look at the impact of directing a general subsidy to R&D when both faces of R&D are accounted for, i.e. the industry-specific absorptive capacity effects as well as direct productivity effects through innovation. In practical policy, R&D support takes on various forms. A more and more widespread measure is general tax credits and/or transfers according to firms' R&D expenses (Warda, 2005). We compare this R&D measure with a similar amount devoted to promoting trade. While Diao et al. (1999) and Ghosh (2007) find only small economy-wide productivity gains of trade policies, the new evidence have led us to study export promotion, rather than import liberalisation, which appears

[1] Ghosh (2007) applies the same absorption model as Diao et al. (1999).

[2] Diao et al (2006) incorporate spillovers between export and productivity in a model for Thailand, but absorptive capacity is not included.

as an, á priori, more potent trade policy instrument, especially if directed towards R&D-based production. Even though direct export subsidies are strictly regulated within the EU/EEA and the WTO agreements, there exist various more acceptable export promotion instruments for newly developed products, like grants, loans, guarantees, and marketing arrangements to promote internationalisation. The EU Lisbon strategy focuses explicitly on such measures to enhance productivity and competitiveness in the EU. Greenaway and Keller (2007) survey the literature covering the effects of such measures on exports. Although a significant number of export promotion instruments appear to have no effect on export volumes, several are found to have strong impact.

In presence of the dynamics of absorption, as well as R&D-based innovation and of the various externalities involved in these processes, the relative performance of R&D and export measures for growth and efficiency is not obvious. Moreover, other market imperfections and existing public interventions will also affect outcomes. To evaluate the effects of the policy incentives, we therefore use a computable general equilibrium (CGE) model that is calibrated to the small, open Norwegian economy. It includes R&D-based growth of the Romer (1990) type, as well as trade and R&D-sensitive absorption that affects the total factor productivity of firms. In spite of the included endogeneities of growth, the dominant growth impulses are still driven by external factors, in accordance with the findings for small, open countries.

The main conclusion from our study is that stimuli directed to R&D-based technology exports perform slightly better than R&D support in terms of improving economic efficiency. However, in light of the efficacious international regulations of strategic trade instruments, legal and more politically acceptable R&D support stands out as an almost equivalently good alternative. We find that the economic setting in which the productivity processes and the policy interventions take place, affect the efficiency outcomes notably. Even though the R&D subsidy responds better to the external effects of domestic innovation and absorption, the directed export measure has more favourable interaction effects with existing policy instruments and market imperfections. This demonstrates the value added of placing the modelling of growth processes within a realistic, empirically based CGE framework. A significant contribution to the efficiency superiority of the directed export measure is its ability to divert resources away from politically favoured, traditional export industries with lower rates of return. In addition, the export measure is more successful in counteracting imperfections in the markets for R&D-based technology and dampening the market stealing effects of R&D.

2. International knowledge spillovers

The idea that knowledge and technology have public goods features is by no means new. Marshall (1891) pointed to the free exchange of knowledge between agents as one of the key forces behind industrial development. Gerschenkron (1962) and Abramowitz (1986) stress the importance of learning and diffusion of knowledge as engines behind long-term growth, and Romer (1986) and Lucas (1988) show how analytical growth models improve their empirical fit when growth is endogenised through knowledge accumulation and externalities. The concept of knowledge spillovers now also plays an important role in industrial organisation (see e.g. d'Aspremont and Jacquemin, 1988 for a central contribution).

Knowledge spillovers require that knowledge is diffused by one agent and absorbed by another. If, for instance, a technology or a competency is highly codified, the potential for spillovers is limited (see e.g. Fagerberg et al, 2004). Similarly, if a firm has a low capacity to absorb external knowledge, spillovers will not play a central role in productivity improvements. Several studies address how investments in knowledge increase the capacity of firms, industries or countries to learn from the frontier; see Abramowitz (1986) and Griffith et al. (2004). The latter study also allows for a counteracting effect, in that growth slows down as you approach the frontier, because the learning gap tightens. Knowledge and technology flow across countries through trade, migration, investment, and media. Keller (2004) provides an excellent survey of the empirical literature on this subject over the last 10 to 15 years.

Imports appear to be one of the most robust channels of international knowledge spillovers. Coe and Helpman (1995) find that the total factor productivity of OECD countries is strongly affected by their openness to R&D-intensive imports. The smaller a country is the more important are imports as a source of overall growth. Similar results are reproduced in a series of studies. Keller (2002) extends the framework of Coe and Helpman and shows that geographical distance has a strong negative effect on spillovers through imports, disclosing that spillovers depend strongly on physical and cultural proximity. Other studies have applied the same approach on more detailed cross-country industry data (e.g. Crespo et al, 2002) and reveal the same strong productivity effects on the industry level of R&D-intensive imports. More recent studies also incorporate absorptive capacity aspects in international learning through imports, showing that more R&D-intensive sectors are able to learn more from R&D-intensive imports than less R&D-intensive sectors, as in Griffith et al (2004). See Grünfeld (2002) for a study of Norwegian data.

Exports as a channel of knowledge spillovers have received less robust support, and the number of studies is more limited. Yet, recent evidence identifies significant spillover effects from exporters to domestic firms. Bernard and Jensen (1999, 2004) give support to the learning-by-exporting effect, showing that exporters have a 0.8 per cent higher productivity growth after controlling for exporter selection. However, it is not clear whether this effect relates to spillovers from other firms in the export market or from scale effects as exporters find new markets. Delgado et al (2002) and Baldwin and Gu (2003) control for the scale effect by focusing on young exporters and find evidence of learning by exporting. Alvarez and Lopez (2006) find strong spillover effects from exporters to non-exporters in a highly detailed firm level study on Chile. In contrast, Clerides et al. (1998) find no such evidence in a dataset for Colombia, Mexico, and Morocco. Surprisingly, no studies apply the Coe and Helpman method to investigate the effects of export on the home country productivity. Neither do there exist any studies of the interaction between spillovers through exports and the absorptive capacity of firms. Another potential channel for spillovers is foreign direct investments (FDI). We exclude FDI as a channel, based on two Scandinavian studies (Grunfeld, 2002; Braconier et al, 2001) that find no significant spillover effects from inward FDI.[3] .

We model import and export intensity of industries as decisive to learning across borders. The idea is that exposure to international competitors provides information about their technology and competency. We explicitly model the capacity of firms to absorb knowledge from abroad as a function of the R&D-intensity of the industry, proxied by its intensity of R&D-based, high-tech capital. The productivity effects of investing in absorptive capacity have decreasing returns to scale, in order to account for catching-up effects.

[3] Pottelsberghe and Lichtenberg (2001) identify spillovers from FDI on the macro level, while Damijan et al. (2004) find that spillovers through inward FDI stands out as the most important contributor to productivity in 10 transition economies, based on firm-level data. In the case of Norway and Sweden, industry data studies show no significant spillover effects from inward FDI (Grünfeld, 2002, Braconier et al. 2001), but firm-level analysis and studies of worker mobility between multinationals and domestic firms show significant spillovers (Karpaty and Lundberg, 2004 and Balsvik, 2006).

3. An open economy CGE model with innovation and absorption effects

3.1. General features

The CGE model is a dynamic growth model with intertemporally optimising firms and households. It gives a detailed description of the empirical tax, production, and final consumption structures. It specifies 15 final goods industries and one R&D industry producing R&D-based capital goods. The final goods industries[4] comprise one public and 14 private industries, which according to the empirical input-output structure deliver to final markets and produce intermediates for each other. The public sector collects taxes, distributes transfers, and purchases goods and services from the industries and from abroad. The model fits a small, open economy and is calibrated for Norway. International prices are determined at the world market, as is the interest rate. Financial savings are endogenously determined, subject to a non-ponzi game restriction that prevents foreign net wealth from exploding in the long term. The exchange rate serves as numeraire.

The model takes into consideration exogenous growth drivers through changes in demography and international conditions, as well as the following endogenous productivity growth mechanisms;
i) Productivity within the R&D industry continuously grows because of dynamic spillovers from the accumulated knowledge induced by previously patented R&D, though with decreasing returns as in Jones (1995). *ii)* New R&D-based capital varieties emerge based on the new patents, and due to love of capital variety, the productivity of R&D-based investments within final goods industries increases with the number of patents. *iii)* The absorption of productivity improvements from abroad depends on the industries' extent of foreign trade and their reliance on R&D-based capital. *iv)* Finally, labour productivity improves through accumulation of several types of real capital, which results from the cash-flow maximisation of rational, forward-looking firms.

The following two subsections, 3.2. and 3.3., provide detailed descriptions of the parts of the model that bring about productivity growth through absorption and domestic innovation, respectively. Subsection 3.4. briefly outlines the remaining model mechanisms, including behavioural relations and equilibrium and balanced-growth conditions. To simplify this model exposition, we disregard policy variables as taxes and subsidies. Appendix B provides a more thorough, aggregated presentation of the equations determining firm and household behaviour, where the relevant policy variables are included.

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[4] See appendix A for a list. The following industries are treated exogenously: the governmental sector, the offshore production of oil, gas and pipeline transport, and ocean transport.

Appendix C gives details on parameter values, as well as calibration and solution procedures. Bye et al. (2006)[5] provides the complete model documentation.

3.2. Productivity growth through absorption of international knowledge

In general terms, the technology of firm *i*, irrespective of industry, can be represented by

(1) $$X_i\left(X_i^H, X_i^W\right) = g_i\left(VF_i\right)$$

X_i^H, X_i^W are production for domestic and export deliveries, respectively, and VF_i is a nested Constant Elasticities of Substitution (CES) function of a number of variable inputs, see figure B.1. in appendix B. There are decreasing returns to scale in all industries.[6] VF_i can be represented by

(2) $$VF_i = f_i\left(L_i\tau, K_i^V\tau, K_i^M\tau, V_i\tau\right).$$

L_i, $K^V{}_i$, $K^M{}_i$, and V_i represent the firm's input of labour, R&D-based capital, other capital, and intermediates, respectively. Factor inputs also depend on a factor-neutral, endogenous productivity variable τ, which is common to all firms in the industry, thus having no subscript. τ reflects the firms' absorbed productivity by learning from abroad

(3) $$\tau = AF^{(\lambda_0+\lambda_1 A+\lambda_2 B)}.$$

τ responds to growth in the productivity level abroad, *AF*, according to an absorption elasticity $\lambda_0 + \lambda_1 A + \lambda_2 B$, where λ_0 ensures an autonomous effect of external productivity growth. The λ_1 and λ_2-parameters determine the relative influence of *A*, an export-dependent term, and *B*, an import-dependent term, defined as follows

(4) $$A = \Omega \cdot \frac{X^W}{X},$$

(5) $$B = \Omega \cdot \frac{I}{X^H}.$$

The term *A* accounts for the absorption elasticity's dependence on the industry's export, X^W, as share of total output, *X*. The term *B* describes the corresponding dependence on industry import, *I*, measured relative to the domestic deliveries of similar products from domestic firms within the industry, X^H. The function *Ω*, represents the *absorptive capacity* of the firm. We model it as a function of the industry's input intensity of R&D-based capital, K^V/VF. The model implies that for industries engaging in foreign trade, the firms' capacities to learn from this interplay with foreign agents expand if the intensity of

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[5] Available at http://www.ssb.no/emner/10/03/doc_200611/doc_200611.pdf.
[6] The scale elasticity is equal for all industries, see also appendix B and C.

R&D-based capital of the industry increases. There is decreasing returns to the R&D-based capital intensity, which we ensure by the following specification

(6) $$\Omega = \frac{\varphi\left(\frac{K^V/VF}{K_0^V/VF_0}\right)}{\frac{\varphi}{2}+\frac{K^V/VF}{K_0^V/VF_0}}, \qquad \varphi>0,\ \Omega'>0,\ \Omega''<0.$$

We assume equal λ-values for all industries, see appendix B.6. Their values are chosen in accordance with estimates found in the literature. In particular, facing international competition in foreign markets proves somewhat more influential than competing with importers in the home markets. All firms are symmetric, and we implicitly assume that they do not consider the strategic effects on their absorbed productivity of adjusting their trade or R&D-based capital intensity, since firms are small. Thus, the absorbed productivity effects are external.[7] Appendix C provides more details on the calibration.

3.3. Productivity growth through domestic innovation

Domestic innovation takes place within the R&D industry, which provides R&D-based technologies. The process involves two distinct activities within each firm: R&D that develops patents and capital production based on these patents. The industry output of patents, X_R, benefits from endogenous domestic productivity spillovers that originate from the accumulated stock of knowledge, *R*, and are freely accessible, thus

(7) $$X_R = R^{s_1} VF^{s}$$

and $R = R_{-1} + X_R$. The parameter s_1 denotes the elasticity with respect to the domestic spillovers. As suggested in Jones (1995), it is less than unity. This productivity growth dynamics generated by R&D is external to the individual patent producer, who is too small to consider the effect of its own output on the accumulated stock of patented knowledge. $s<1$ is the scale elasticity of the variable input factors used for production of R&D. The development of a patent represents a fixed establishment cost for a new firm in the R&D industry before entering the market for R&D-based capital goods with a new and distinct variety, K^V. The production of R&D-based capital varieties also involves variable factor input costs. We assume identical factor input cost structures for all R&D firms both in their patent and capital production.

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[7] Note that defining absorptive capacity in terms of R&D-based capital investments excludes absorptive capacity effects in the R&D industry; confer also footnote 5.

The R&D-based capital varieties are partly exported and partly delivered to domestic final goods industries. The input of each capital variety, K_i^V, is represented by so-called Spence-Dixit-Stiglitz (love-of-variety) preferences for a composite of the varieties, K^V

(8) $$K^V = \left[\sum_{i=1}^{R} \left(K_i^V \right)^{(\sigma_{KV}-1)/\sigma_{KV}} \right]^{\sigma_{KV}/(\sigma_{KV}-1)}.$$

R is the accumulated stock of patents (or number of firms producing R&D-based capital varieties), and σ_{KV} is the uniform elasticity of substitution applying to all pairs of capital varieties. The more varieties, the higher is the productivity of the R&D-based capital within final goods industries. This love-of-variety effect represents a second external productivity growth mechanism stemming from R&D. Again, the R&D-firms are too small to consider their impact on the productivity of the aggregated composite, K^V. The input intensity of the R&D-based capital composite within final good industry j, K_j^V / VF_j, varies with j and reflects its degree of absorptive capacity.[8]

3.4. Market behaviour, equilibrium and balanced growth

Market behaviour of firms:

Production is allocated to the foreign and domestic markets, which are segmented through a Constant-Elasticity- of-Transformation (CET) technology. All firms within an industry are identical, and firm notation is suppressed.

(9) $$X = \left[\left(X^H \right)^\rho + \left(X^W \right)^\rho \right]^{1/\rho}$$

The transformation elasticity ρ >0 implies costs of diverting deliveries between the two markets.[9] By assuming $\rho=1/s$ we obtain separability between the export and home market supplies;, see Holmøy and Hægeland (1997). Each firm has perfect foresight and maximises the present value of the after-tax cash flow. Except for the domestic market for R&D-based capital, many domestic firms ensure perfect competition, and the first-order conditions equate prices with marginal costs within the two, segmented markets. The CET technology implies that the ratio of export to domestic market deliveries is determined by the relative price between them.

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[8] In the R&D industry, input of K^V is per definition zero both in R&D activity and the R&D-based capital production, in order to avoid cumulative love-of-variety multiplicators.

[9] This, together with decreasing returns to scale of total factor use, so that s < 1, avoids complete specialisation of production of tradables.

The R&D firms have market power in the domestic market for R&D-based capital. Maximisation of the present value of the after-tax cash flow gives the following first-order conditions for deliveries to the home market X_{Ki}^{H}

(10) $$P_{Ki}^{H} = m_{Ki} \frac{c}{s} \left(X_{Ki}^{H} \right)^{\frac{1-s}{s}} .$$

The monopoly price of R&D-based capital variety *i*, P_{Ki}^{H}, is set as a mark- up, m_{Ki}, on costs.

$m_{Ki} = \frac{\varepsilon_{Ki}}{\varepsilon_{Ki} - 1}$, where ε_{Ki} is the domestic demand elasticity for R&D-based capital varieties equal to σ_{KV}. The price in the domestic market is equal for all the R&D-based capital varieties, and each variety is produced in equal quantities.

From the value maximisation of the representative firm, and using the fact that profit is equal for all firms, the entry condition for each R&D firm in the capital variety markets can be deduced

(11) $$P_{R0} = \int_{0}^{\infty} e^{-rt} (\overline{\pi}_t) dt .$$

P_{R0} is the fixed entry cost in period 0, or the shadow price of developing a patent in advance of variety production. Firms are entering until the representative firm's discounted net profits $\overline{\pi}_t$ equal the entry cost. In each period, new patents are produced and new firms will enter the R&D industry. Given that a firm has entered, the first-order condition in eq. (10) determines the domestic price of the R&D-based capital variety for given marginal costs and demand.

Except for labour and R&D-based capital, the factors of production are importable. An Armington type CES aggregate of imported and homemade varieties of the same investment or intermediate good defines them as imperfect substitutes, implying the following purchaser price, *P*, of a composite good:

(12) $$P = \left((1-\upsilon)(P^{H})^{(1-\sigma_{HI})} + \upsilon (P^{I})^{(1-\sigma_{HI})} \right)^{\frac{1}{1-\sigma_{HI}}} .$$

P^{H} is the price of the domestic variety, P^{I} is the respective, exogenous, import price, ν is the initial import share, while σ_{HI} is the substitution elasticity (Armington elasticity) between the two varieties. The Armington assumption implies that the shares of imports to home deliveries are determined by the ratio of the domestic to the import prices.

Consumer behaviour

Consumption and savings result from the decision of an infinitely lived, perfectly foresighted representative consumer that maximises intertemporal utility. The consumer chooses a consumption path subject to an intertemporal budget constraint that requires the present value of consumption not to exceed total wealth (current non-human wealth plus the present value of labour income and net transfers). Labour supply is exogenous. We assume that the consumer's rate of time preferences equals the exogenously given nominal interest rate for the entire time path. Total consumption is allocated across 10 different goods and services according to a nested CES structure. The structure is given in figure B.2 in appendix B. Each consumer good also consists of one imported and one domestically produced variety according to an Armington function as in eq. (12).

Equilibrium conditions

The model is characterised by equilibrium in each period in all product markets and the labour market. Intertemporal equilibrium requires fulfilment of two transversality conditions: the limit values of the total discounted values of net foreign debt and of real capital, respectively, must both be zero. The model is characterised by a path-dependent balanced growth path solution (or steady state solution), see Sen and Turnovsky (1989) for a theoretical exposition. This implies that both the path and the long-run stationary solution differ between simulated scenarios.

To ensure a long-run *balanced growth path*, the following conditions must be fulfilled: *1)* The rate of technological change for each input factor in each industry must converge to the same rate, g, so that each industry grows at the same rate. *2)* Growth in per capita consumption equals the same rate, g. *3)* Population growth rate is constant. Along the transitional path the growth rate may vary. Bye et al. (2006) give further details.

A balanced growth path also requires that the following equation is fulfilled

(13) $$\left[\frac{(1+\theta)}{(1+r)/(1+p)}\right] = (1+g)^{-1/\sigma_d} \ .$$

θ is the rate of time preferences, r is the nominal interest rate, p is the growth rate of the consumer price index, and σ_d is the intertemporal elasticity of substitution. Together with equation (13), the transversality condition regarding net foreign debt is fulfilled when the consumer finds the optimal level of consumption, given the intertemporal budget constraint and the transversality condition.

Correspondingly, the transversality condition for the value of real capital is a restriction on the determination of net investments by firms. In an infinite time horizon, growth in our model will only depend on exogenous drivers. For technical reasons, we have set all exogenous and endogenous growth drivers to zero in the far future (after about 100 years). This ensures that the economy is eventually on a balanced growth path (steady state) and that this growth path, with zero growth both in consumption and in the consumer price index, satisfies these transversality conditions. In particular, equation (13) then implies that $r=\theta$ at all points in time.

4. Effects of growth policy

4.1. The policy schemes

We compare two different policy alternatives, both designed to stimulate the productivity of firms. The first, an R&D subsidy, directly affects domestic innovation as well as the capacity of firms to absorb technological progress from abroad. The second policy is a support for promotion of exporting R&D-based capital goods. It is primarily motivated by the absorption externalities related to trading and, in particular, to exporting. The policy instruments are dimensioned so that they involve the same discounted government expenditures. Each year the governmental budgets are balanced by reduced VAT rates.

We ask what policies perform better when it comes to stimulating economic growth and national welfare. In presence of many channels and externalities, it is difficult, *á priori*, to predict outcomes of policies. Thus, we use CGE model simulations to quantify the simultaneous effects on the innovation and absorption processes. We identify important interaction effects through other markets and imperfections in the economy. In table 2 we report the long-run effects of policies 70 years from now, after the economy has reached stable growth rates and before the endogenous growth is emptied out. The effects are measured as per cent changes from a reference path, see appendix C for more details.

4.2 R&D support

We introduce a constant 5.0 per cent ad valorem subsidy to the development of new patents through R&D. It corresponds to approximately 1.5 times the value of today's Norwegian R&D tax credit system.[10] The direct effect is to shift marginal costs of R&D downwards. The marginal willingness to invest in R&D is determined by the discounted future profit from sales of R&D-based capital for the

[10] This approximates a support of € 250 in annuity terms.

last new firm entering the R&D industry, and it falls along with entry, as the market share and profit of each capital variety producer fall. The marginal costs of R&D will perpetually shift downwards as a result of dynamic, positive spillover effects from the accumulated knowledge stock. In long-run equilibrium, R&D increases considerably, by 18.7 per cent, while the shadow price of patents falls by 6.9 per cent compared to the baseline; see table 2. Total deliveries of R&D-based capital increase by 6.7 per cent, while the number of capital varieties increases by 13.5 per cent. The output of each variety falls because the demand for each variety shifts downwards when their number increase. The output of each variety is further downscaled in response to increased factor prices. For instance, wages increase by 2.5 per cent.

The factor price increases reflect higher scarcity. Increased factor demand from the newcomers in the R&D industry is part of this picture, but the main pressure comes from other final goods producers. Their increased factor demand reflects two productivity effects. First, the productivity of the R&D-based capital they use increases with the number of varieties because of love of variety. This is reflected in a fall in the capital price per efficiency unit of 5.5 per cent, despite a slight rise in the price of each variety of 0.4 per cent. Second, increased R&D intensity through investments in R&D-based capital, measured in efficiency terms, increases the R&D intensity. This improves the absorptive capacity of the final goods producers.

The absorption effects are most prominent within the trade-intensive final goods industries, and in particular the export-intensive ones since the export engine is empirically the strongest. Absorption effects through export are self-enforcing before emptying out: In isolation, higher export increases absorption, which again feeds back into higher export by improving the productivity and competitiveness of domestic firms. The most exposed and R&D-intensive final goods firms, represented by those in *Traditional manufacturing*[11], face a 1.6 per cent increase in their long-run, absorbed productivity level. In other, less exposed and less R&D-intensive industries, smaller or no effects occur on productivity absorbed from abroad. The R&D production industry even faces a slight reduction in absorbed productivity, because the share of export in total output of R&D-based capital goods falls.

In the long run, total export increases by 3.1 per cent and the rise in GDP is 1.7 per cent. The long run GDP growth rate increases by 0.04 percentage points due to the stimulation of the productivity growth processes. Welfare measured as total discounted utility of consumption rises by 0.8 per cent.

[11] This industry includes manufacturing of metals, industrial chemicals, pulp, and paper.

4.3. Export promotion

In this policy alternative we represent export-promoting instruments by a subsidy to exports of R&D-based capital. For a small, open economy without market power in the export markets and without noteworthy influence on world market prices, policy stimulation of export would normally not be recommendable from an efficiency point of view. However, as export positively affects spillovers from abroad, and is a stronger impetus than import in this respect, there could still be efficiency arguments for strategically promoting export in small, open countries. In particular, promoting sales of R&D-based products would have a welfare increasing potential. [12]

The constant export support rate amounts to 1.3 per cent of the export value. It serves to increase export of R&D-based capital by 10.3 per cent in the long run; see table 1. This is approximately 40 per cent more than the increase in the R&D subsidy case. The absorption of international spillovers in the R&D industry increases in every period, and in the long run the increase is 0.2 percent, as compared to a fall of 0.1 per cent in the R&D subsidy case.

However, this comes at the expense of absorption in other industries. The support to export in the R&D industry results in a downscaling of their home market deliveries of R&D-based capital compared with the R&D support case. Also, the productivity of the capital is lower, because new patents develop at a slower pace. In the long run, the number of varieties available in the market increases by only 9.1 per cent in the export support case, as compared to 13.5 per cent in the R&D support case. As a consequence of these changes, the absorptive capacity falls in most final goods industries relative to the previous policy case.

In addition, productivity through absorption depends on foreign trade intensities. Because the export policy scheme is biased towards one industry, only, it crowds out other exports from, for instance, traditional manufacturing. In aggregate, gross trade increases slightly more under the export support scheme than the R&D support scheme. However, most of this stems from more import, which has weaker absorption effects. In addition, the trade increase tends to come within industries with relatively small potentials for interaction effects with absorptive capacity, as in the retail markets for

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[12] Albeit being subject to heavy international regulations, we have simulated a *general* export-promoting stimulus in order to de-emphasise the R&D effects and cultivate the general absorption effects of export. This policy results in an efficiency loss of 0.1 per cent compared to the reference and shows that the absorption argument, alone, is not empirically strong enough to defend export promotion. Unless accompanied by R&D promotion, the absorptive capacity of firms gradually deteriorates. We find a long run fall in the average absorption, competitiveness, and over-all export. Thus, economic as well as legal arguments weigh against pursuing this policy instrument any further.

consumer goods. In sum, absorbed productivity falls slightly in this alternative compared with the R&D subsidy, contributing to lower welfare.

Table 1. Policy alternatives, percentage deviations from the reference, long run

Policy alternative	R&D support	Export promotion
Ad val. rate of support*	5.0	1.3
The R&D industry		
No. of firms/patents/varieties	13.5	9.1
R&D/Production of patents	18.7	15.3
Patent shadow price	-6.9	-0.4
Production of R&D-based capital	6.9	9.2
- for export deliveries	6.4	10.3
- for home market deliveries	8.5	5.5
- for export per firm	-6.2	1.1
- for home markets per firm	-4.4	-3.3
- home market price per unit	0.4	0.4
- home market price per effective unit	-5.5	-3.7
Absorbed productivity		
- level	-0.1	0.2
- growth rate**	-0.00	0.00
The traditional manufacturing industry		
Export	3.1	0.9
Absorbed productivity		
- level	1.6	1.1
- growth rate**	0.03	0.03
GDP	1.7	1.6
GDP growth**	0.04	0.04
Average absorbed productivity		
- level	0.9	0.8
- growth rate**	0.03	0.03
Wage rate	2.5	2.3
Export	3.1	3.2
Import	2.5	2.6
Welfare***	0.7	0.9

* constant ad val. rate
** absolute deviation from the reference (in the long run)
*** percentage change in discounted value

As already explained, the export promotion is also less stimulating to domestic innovation through R&D than what we saw in the R&D subsidy case. Less R&D reduces productivity within R&D, as there is less knowledge spilling over from previous and concurrent R&D. In addition to the indirect absorptive capacity effect already explained, a direct productivity effect also occurs in the final goods industries when fewer varieties of R&D-based capital emerge. On the other hand, other distortions are counteracted in the wake of lower R&D. The increased supply of R&D-based capital goods partly stems from higher production in already established firms than in the other policy case. This effect contributes to increase welfare, as larger production scales within each firm counteract the inefficiencies related to the existing market imperfections. In addition, fewer patents imply less R&D costs behind the sales from the R&D industry. This does, in isolation, save social costs. A third positive contribution to welfare relates to the crowding out of traditional manufacturing. This industry enjoys various lenient indirect taxes and other favourable input cost terms designed to keep up its competitiveness.[13] Thus, its contraction brings about welfare improvements.

To sum up the efficiency effects, the export promoting scheme fosters less productivity spillovers both from domestic innovation and absorption than does the R&D support. However, there are positive contributions from counteracted distortions elsewhere in the economy, including less total R&D investment costs, increased scales within firms with mark-ups and reduced activity within industries facing favourable and inefficient policies. All in all, the total welfare is marginally higher with support to R&D-based export than with R&D subsidies.

4.4 Sensitivity analysis of the absorption elasticities

The econometric foundation for quantifying absorption effects is still debateable and insufficiently tested, in particular when it comes to the trade sensitivities and the externalities of absorption. We have, therefore, simulated the sensitivity of our policy results to different strengths of the absorption elasticity; see table 2. In the regime labelled *none*, the parameters λ_1 and λ_2 in eq. (3) are set to zero. This removes absorption endogeneities both through trade and absorptive capacity effects of R&D, and renders the productivity growth through cross-border learning exogenous. The main regime is denoted *moderate* in table 2, while a *strong* absorption regime is constructed by increasing λ_1 and λ_2 with 1/3.[14]

The main conclusion above that export promotion is slightly welfare superior, is insensitive to the variations of λ_1 and λ_2. The explanations for the ranking of the policy schemes are also robust to the changes in the absorption assumptions. In all regimes, a change from R&D subsidy to export

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[13] These include relatively lower taxes on electricity, CO_2 emissions, and labour, as well as favourable energy contracts.

[14] The model framework relies on strictly positive outputs and is unsuitable for simulating with substantially higher absorption elasticities, because activities in the sheltered sector, including R&D, will be crowded out.

promotion implies lower R&D and accumulated knowledge. In the regimes with moderate and strong absorption we also obtain a slightly lower average factor productivity level absorbed from abroad, except in the R&D industry where it increases. Thus, when R&D support is replaced by export promotion, both less domestic innovation and less absorption contribute negatively to economic efficiency. However, positive effects more than offset these losses. These are joint contributions from the reallocation of resources from the inefficient traditional manufacturing industry, higher market shares for each firm when the number of firms in the R&D industry decreases, and larger outputs within each of the variety firms with market power.

Although the main conclusions from the policy comparison hold in regimes with both weaker and stronger absorption, one should not conclude that absorption does not matter. Removing absorption effects from the main scenarios approximately halves the welfare effects of policies, because important externalities are left out.[15] Even in the comparison of policies we can see effects of absorption, in that promotion of R&D-based export stimulates production in the R&D sector at the expense of traditional manufacturing export. The superiority of the export promotion in terms of welfare is, therefore, somewhat more marked when absorption effects are allowed. The same is true for GDP growth.

Table 2: Relative performance of export promotion vs. R&D support under different absorption regimes

Strength of absorption effects:	**none**	**moderate (main)**	**Strong**
The R&D industry			
No. of firms/patents/varieties	**-6.2**	**-3.9**	**-3.1**
R&D	**-8.2**	**-2.3**	**-0.8**
Export of R&D-based capital	**0.1**	**3.6**	**5.2**
Home deliveries per firm	**2.5**	**1.2**	**1.0**
Absorbed productivity level	**0**	**0.3**	**0.5**
The traditional manufacturing industry			
Export	**0.0**	**-2.1**	**-1.9**
Absorbed productivity level	**0**	**-0.5**	**-0.4**
GDP growth*	**-0.01**	**0.00**	**0.01**
Average absorbed productivity level	**0**	**-0.1**	**-0.2**
Welfare**	**0.1**	**0.2**	**0.2**

* absolute deviation from the R&D support case (in the long run)

** percentage change in discounted value from the R&D support case

[15] Bye et. al (2007) is a comparable policy study within a setting without endogenous absorption effects.

5. Conclusions

Recent empirical studies find that a country's level of R&D affects productivity and competitiveness of national firms, not only through developing new and better products and processes, but also through increasing the firms' capacity to learn from abroad. For small countries, the international channel is of high importance, as they necessarily rely heavily on technological change induced abroad. This fact brings up the question on how national efforts can enhance the exploitation of this common good.

In this study we examine the policy implications of refining the specifications of absorption mechanisms in a small open economy. Especially, we introduce a role for the export channel, which is novel when compared to earlier macroeconomic studies. We combine the modelling of innovation processes with the modelling of absorption within an empirical setting, to grasp quantitatively the interplay between domestic innovation and spillovers of productivity growth from abroad. The processes are modelled in a CGE framework that also accounts for indirect interdependencies via resource restraints and behavioural responses. The disaggregate approach also allows us to study industrial differences and variations in growth prospects.

Our study finds that directed support to R&D-based technology export promotion performs slightly better than R&D support in terms of economic efficiency. However, as strategic export promotion is likely to run counter with international competition rules, direct R&D support is a good substitute in terms of effects on economic efficiency and growth. While the R&D subsidy performs better in meeting the externalities both related to domestic innovations and absorption, the directed export measure has more favourable interaction effects with existing policy instruments and market imperfections. In our case these effects include diverting resources away from the politically favoured traditionally manufacturing export industries, counteracting imperfections and dampening the market stealing effects in the markets for R&D-based technology.

We find a relatively large welfare impact from trade policy compared to the existing literature. The difference is mainly related to our introduction of the export-driven impetus for absorption effects that is not accounted for in other analyses. Also, relative to the R&D subsidy, the export measure performs better than in previous studies. Our sensitivity analysis reveals that this feature is not explained by the introduction of absorption effects, but comes as a consequence of export promotion counteracting market imperfections elsewhere in the economy. As such, the effects are fairly case specific and reflect Norwegian tax systems and market characteristics. Nevertheless, we claim that lessons of more general interest can be learned, as the inclination of governments to favour its traditional export industries at the expense of economic efficiency is widespread.

There are several potentials for adding features into the model that are empirically significant and relevant from a growth and welfare perspective. Human capital is an important growth engine and a factor that is crucial for the economy's capacity to absorb knowledge from abroad. Accumulation of human capital and education policies will interact with innovation policies in ways that are crucial to understand in order to choose optimal growth promoting policies. Such interactions are left for future research, as are interlinkages between private and governmental R&D.

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Production activities

Other Products and Services
Traditional Manufacturing
Polluting Transport Services
Non Polluting Transport Services
Research and development (R&D)
R&D based Capital
Transport Oils
Heating Fuels
Other Ordinary Machinery
Building of Ships, Oil Drilling Rigs, Oil Production Platforms etc.
Construction, excl. of Oil Well Drilling
Ocean Transport - Foreign, Services in Oil and Gas Exploration
Crude Oil
Natural Gas
Pipeline Transport of Oil and Gas
Production of Electricity
Wholesale and Retail Trade
Government Input Activities

The model structure of firm and household behaviour

When firm notation *i* is suppressed all variables in the equation apply to firm *i*. Subscripts denoting industry is also suppressed for most variables. Subscript 0, -1, or *t* denote period. When period specification is absent, all variables apply to the same period. Compared to the exposition in Section 3, we disregard inputs of intermediate goods. In consumption, *i* denotes good *i*, *j* denotes CES composite *j*. We include the relevant subsidy policy variables in this presentation, but for simplicity reasons the rest of the policy variables are disregarded.

B.1. Final goods industries

(B.1) $$PV_0 = \int_0^{\infty} e^{-rt}\left(\pi_t - P_t^J J_t\right)dt = \int_0^{\infty} e^{-rt}\left(\pi_t - P_t^K K_t\right)dt + P_0^J K_0$$

(B.2) $$\pi = P^H X^H + P^W X^W - wL$$

(B.3) $$\left[\left(X^H\right)^{\rho} + \left(X^W\right)^{\rho}\right]^{1/\rho} = \left[f\left(L\tau, K\tau\right)\right]^s$$

(B.4) $$\tau = AF^{(\lambda_0 + \lambda_1 A + \lambda_2 B)}$$

(B.5) $$A = \Omega\left(\frac{K^V}{VF}\right)\frac{X^W}{X},$$

(B.6) $$B = \Omega\left(\frac{K^V}{VF}\right)\frac{I}{X^H}$$

(B.7) $$\Omega = \frac{\varphi\left(\dfrac{K^V/VF}{K_0^V/VF_0}\right)}{\dfrac{\varphi}{2} + \dfrac{K^V/VF}{K_0^V/VF_0}}, \qquad \Omega' > 0 \ , \ \Omega'' < 0$$

(B.8) $$C = c\left[\left(X^W\right)^{1/s} + \left(X^H\right)^{1/s}\right]$$

(B.9) $$\bar{\pi} = P^H X^H - c\left(X^H\right)^{1/s} + P^W\left(1 + \alpha_2\right)X^W - c\left(X^W\right)^{1/s}$$

(B.10) $$P^H = \frac{c}{s}\left(X^H\right)^{\frac{1-s}{s}}$$

(B.11) $$P^{W} = \frac{c}{(1+\alpha_2)s}\left(X^{W}\right)^{\frac{1-s}{s}}$$

(B.12) $$s = 1/\rho$$

(B.13) $$K = \left[\delta_{KM}\left(\frac{K^{M}}{\delta_{KM}}\right)^{\left((\sigma_K-1)/\sigma_K\right)} + (1-\delta_{KM})\left(\frac{K^{V}}{(1-\delta_{KM})}\right)^{\left((\sigma_K-1)/\sigma_K\right)}\right]^{\left(\sigma_K/(\sigma_K-1)\right)}$$

(B.14) $$K^{V} = \left[\sum_{i=1}^{R}\left(K_i^{V}\right)^{(\sigma_{KV}-1)/\sigma_{KV}}\right]^{\sigma_{KV}/(\sigma_{KV}-1)}$$

(B.15) $$P^{KV} = \left[\sum_{i=1}^{R}\left(P_i^{KV}\right)^{(1-\sigma_{KV})}\right]^{1/(1-\sigma_{KV})}$$

B.2. R&D industry

Eq. (B.1) applies to the R&D activity. In addition, the following structure describes the R&D/patent production:

(B.2') $$\pi = P_R X_R - wL$$

(B.3') $$X_R = [R]^{s_1}\left[f\left(L\tau, K^{M}\tau\right)\right]^{s}$$

(B.8') $$C = \frac{c}{(R)^{s_1/s}}\left[X_R\right]^{1/s}$$

(B.16) $$R = R_{-1} + X_R$$

(B.9') $$\overline{\pi} = P_R(1+\alpha_1)X_R - \frac{c}{(R)^{s_1/s}}\left(X_R\right)^{1/s}$$

(B.10') $$P_R = \frac{c}{(1+\alpha_1)s(R)^{s_1/s}}\left(X_R\right)^{\frac{1-s}{s}}$$

Each R&D-based capital variety is delivered both to the home and export market, in quantities X_{Ki}^{H} and X_{Ki}^{W}, respectively, in each period. For each variety, equations as (B.2) and (B.12) apply, in addition to the following:

(B.1'') $$PV_{i0} = \int_0^{\infty} e^{-rt}\left(\pi_{it} - P_t^{K}K_{it}\right)dt - P_{R0} + P_0^{J}K_{i0}$$

(B.3'') $\left[\left(X_{Ki}^{H}\right)^{\rho}+\left(X_{Ki}^{W}\right)^{\rho}\right]^{1/\rho}=\left[f\left(L_{i}\tau,K_{i}^{M}\tau\right)\right]^{s}$

(B.8'') $C_{i}=c\left[\left(X_{Ki}^{W}\right)^{1/s}+\left(X_{Ki}^{H}\right)^{1/s}\right]$

(B.9'') $\bar{\pi}_{i}=P_{Ki}^{H}\left(X_{Ki}^{H}\right)X_{Ki}^{H}-c\cdot\left(X_{Ki}^{H}\right)^{1/s}+P_{K}^{W}(1+\alpha_{3})X_{Ki}^{W}-c\cdot\left(X_{Ki}^{W}\right)^{1/s}$

(B.10'') $P_{Ki}^{H}=m_{Ki}\frac{c}{s}\left(X_{Ki}^{H}\right)^{\frac{1-s}{s}}$

(B.17) $\varepsilon_{Ki}=-\frac{\partial X_{Ki}^{H}}{\partial P_{Ki}^{H}}\frac{P_{Ki}^{H}}{X_{Ki}^{H}}$

(B.18) $m_{Ki}=\frac{\varepsilon_{Ki}}{\varepsilon_{Ki}-1}=\frac{\sigma_{KV}}{\sigma_{KV}-1}$

(B.11'') $P_{K}^{W}=\frac{c}{(1+\alpha_{3})s}\left(X_{Ki}^{W}\right)^{\frac{1-s}{s}}$

(B.19) $P_{R0}^{H}=\int_{0}^{\infty}e^{-rt}\left(\bar{\pi}_{t}\right)dt$

B.3. Consumer behaviour

(B.20) $U_{0}=\int_{0}^{\infty}u\left(d_{t}\right)e^{-\rho t}dt$

(B.21) $u(d_{t})=\frac{\sigma_{d}}{\sigma_{d}-1}d^{\left(\frac{\sigma_{d}-1}{\sigma_{d}}\right)}$

(B.22) $W_{0}=\int_{0}^{\infty}P_{t}^{D}d_{t}e^{-rt}dt$

(B.23) $d_{t}=\left[\mu\cdot P_{t}^{D}\right]^{-\sigma_{d}}$

(B.24) $D_{t}=d_{t}(1+n)^{t}$

(B.25) $D_{it}=\omega_{i.0}\left(\frac{P_{jt}^{D}}{P_{it}^{D}}\right)^{\sigma_{j}}\frac{VD_{jt}}{P_{jt}^{D}}$

(B.26) $P_{i}^{D}=\left((1-\upsilon_{i})(P_{i}^{H})^{(1-\sigma_{HI})}+\upsilon_{i}(P_{i}^{I})^{(1-\sigma_{HI})}\right)^{\frac{1}{1-\sigma_{HI}}}$

(B.27) $\frac{D_{t+1}}{D_{t}}=(1+n)(1+g)$

B.4. Variables

PV_0	The present value of the representative firm
π	Operating profit
P^J	Price index of the investment good composite
J	Gross investment
P^K	User cost index of capital composite
K	Capital composite
X^H	Output of final good firm delivered to the domestic market
X^W	Output of final good firm delivered to the export market
X	Total industry output
P^H	Domestic market price index of final good
P^W	World market price index of final good
w	Wage rate
L	Labour
τ	Endogenous factor productivity change through absorption of international spillovers
K^V	R&D-based capital
K^M	Other ordinary capital
C	The variable cost function
c	Price index of the CES-aggregate of production factors
$\overline{\pi}$	Modified profit (the period-internal maximand of firms)
R	Accumulated number of patents/R&D-based capital varieties
X_R	Production of patents
K_i^V	R&D-based capital variety *i*
P_i^{KV}	User cost of R&D-based capital variety *i*
P_R^H	Shadow price of the patent
X_{Ki}^H	Output of R&D-based capital variety firm *i* delivered to the domestic market

X_{Ki}^{W}	Output of R&D-based capital variety firm *i* delivered to the export market
P_{Ki}^{H}	Domestic market price index of R&D-based capital variety *i*
P_{K}^{W}	World market price index of R&D-based capital varieties
P^{KV}	User cost index of the R&D-based capital composite
U_0	Discounted period utilities of a representative consumer
d	Consumption of a representative consumer
P^{D}	Consumer price index
r	Nominal interest rate
W_0	Consumer's current non-human wealth + present value of labour income + net transfers
μ	Marginal utility of wealth
D	Aggregate consumption
n	Annual population growth rate
D_i	Demand for consumer good *i*
VD_j	Aggregate expenditure on CES aggregate *j*
g	Growth rate
I	Import
P^{I}	Import price
P	Purchaser price, Armington composite good
A	The absorption elasticity’s export-dependent term
B	The absorption elasticity’s import-dependent term
Ω	The absorptive capacity wrt. spillovers from abroad
AF	Productivity level abroad

B.5. Parameters

		Value
s	Scale elasticity	0.83
ρ	Transformation parameter between deliveries to the domestic and the foreign market	1.2
σ_K	Elasticity of substitution between variety-capital and ordinary capital	1.5
δ_{KM}	Calibrated share of other ordinary capital in the capital composite	industry-specific
σ_{KV}	Uniform elasticity of substitution applying to all pairs of capital varieties	3.0
s_1	Elasticity of domestic spillovers	0.5
ε_{Ki}	Domestic demand elasticity for capital variety i	3.0
m_{Ki}	Mark-up factor for variety firm i	1.5
θ	Consumer's rate of time preferences	0.04
σ_d	Intertemporal elasticity of substitution	0.3
$\omega_{i.0}$	Calibrated budget share of good i in CES aggregate j in period 0	good-specific
σ_i	Elasticity of substitution between the two consumer goods in CES aggregate j	0.5 for all j
σ_{HI}	Armington elasticity between imported and domestic produced varieties	4.0
v	Initial import share in the Armington aggregate	good and user-specific
λ_0	Autonomous absorption effect	0.25
λ_1	Influence of the export term on absorption	0.15
λ_2	Influence of the import term on absorption	0.075
φ	Parameter in the Ω - function	4.0
α_1	R&D subsidy	scenario-specific
α_2	General subsidy to all export deliveries	scenario-specific
α_3	Subsidy to export deliveries of R&D-based capital	scenario-specific

Figure B.1. The nested structure of the production technology

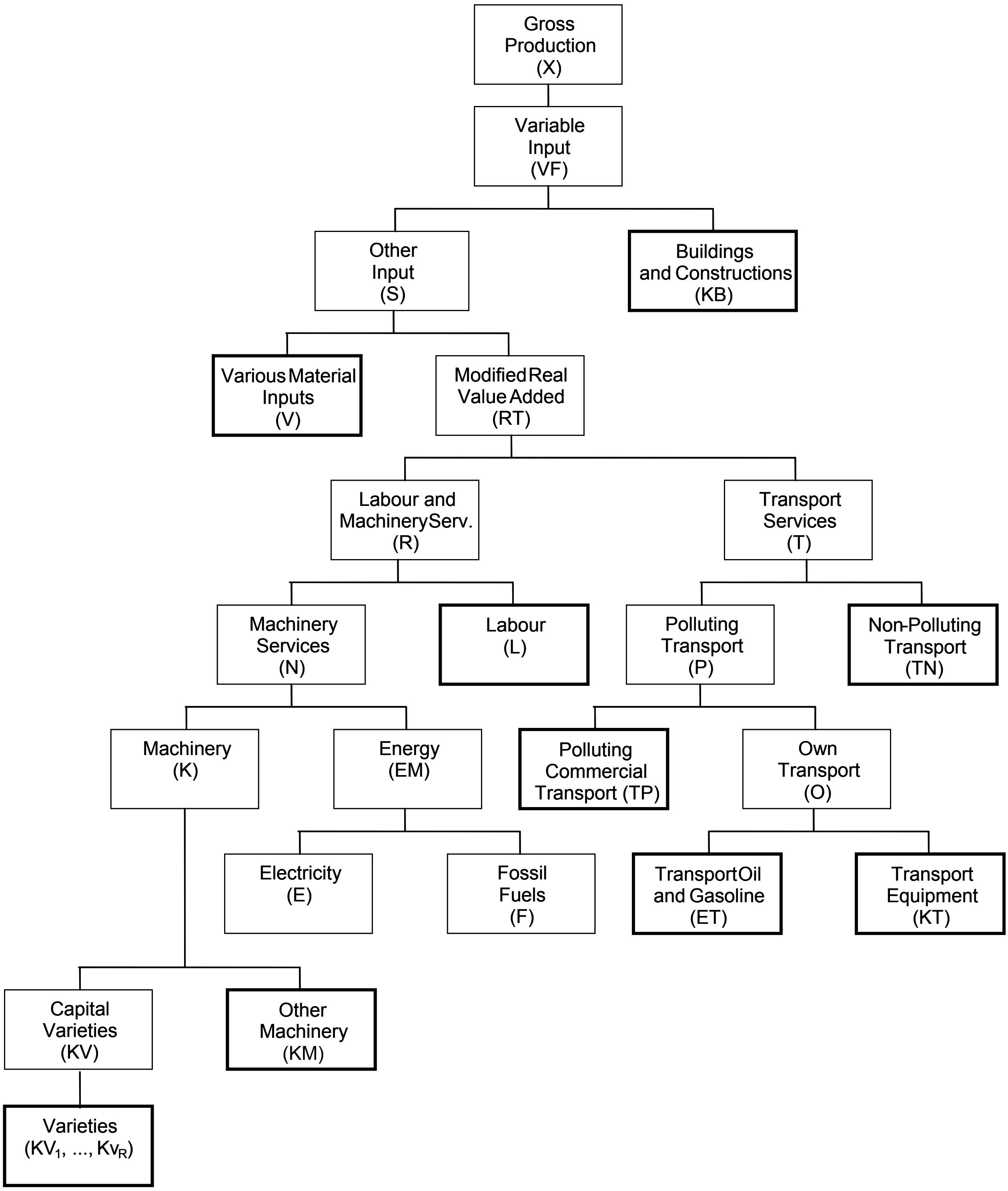
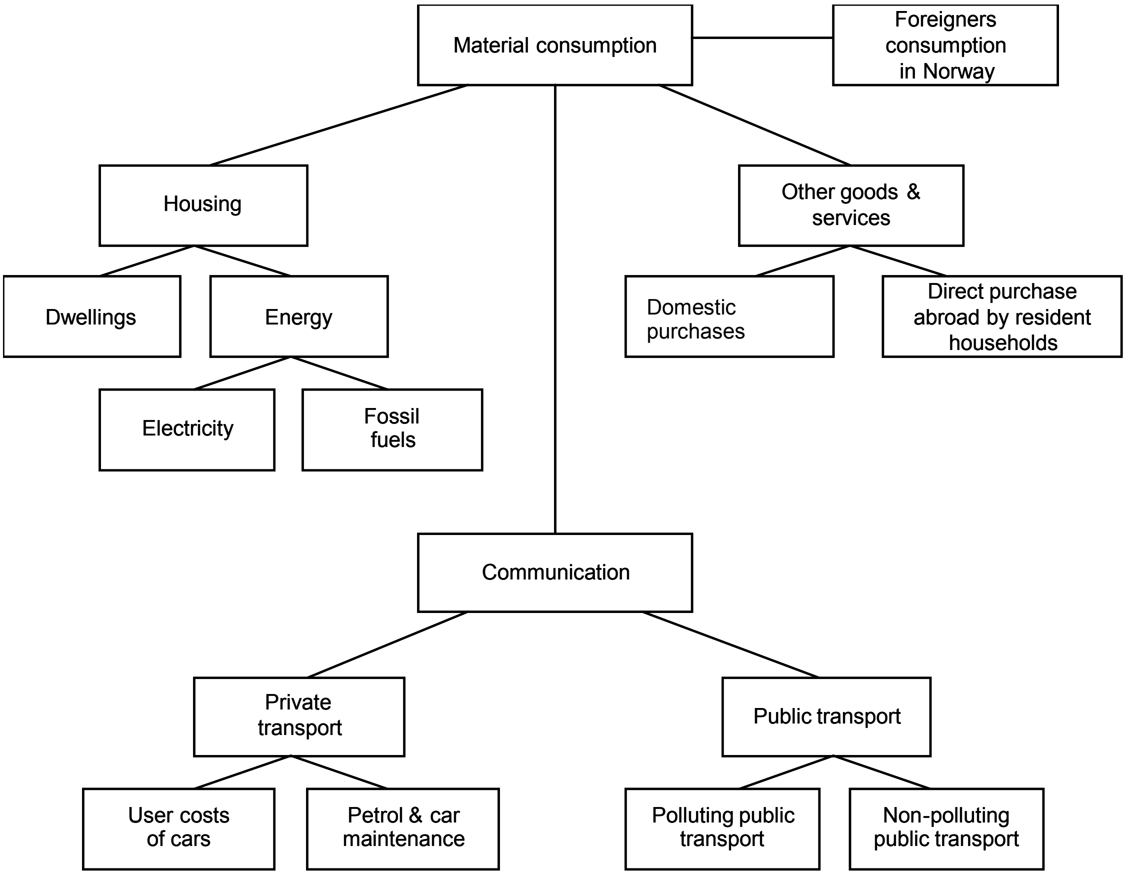


Figure B.2. The nested structure of consumption activities



Appendix C

Calibration and parameters

The model is calibrated to the 2002 Norwegian National Accounts. The elasticities of substitution in the production technology range from 0.15 at the upper part of the nested tree to 0.5 further down in the nested tree structure, see appendix B, figure B.1, and are in the range of empirical findings (Andreassen and Bjertnæs, 2006). We have less empirical foundation for the substitution possibilities within the composite of R&D-based capital and other machinery capital. We assume a relatively high substitution elasticity of 1.5, while the elasticity between the different R&D-based capital varieties is expected to be even higher and set to 3.0, giving a mark-up factor of 1.5 for the domestic price of R&D-based capital varieties.[16]

The elasticities of scale are equal to 0.83 in all industries and fit econometric findings of moderate decreasing returns to scale in Norwegian firms (Klette, 1999). The scale elasticity is at the lower end of the estimates by Klette (1999), but is chosen in order to avoid unrealistic industrial specialisation patterns.[17] This implies that the elasticities of transformation between domestic and foreign deliveries are equal to 4.9. The elasticities of substitution between domestic products and imported goods are assumed equal to 4. The elasticity of scale related to previous knowledge is equal to 0.5, in order to ensure decreasing spillover effects of the knowledge base, supported by both theoretical and empirical findings (see Jones, 1995; 1999; Leahy and Neary, 1999).

In the scenarios, the exogenous growth factors are assumed to grow at constant rates. In most cases, rates are set in accordance with the average annual growth estimates in the baseline scenario of Norwegian Ministry of Finance (2004) that reports the governmental economic perspectives until 2050. The population growth is set to 0.4 per cent annually, in accordance with the expectations in Norwegian Ministry of Finance (2004). Exogenous activities, like public consumption and output, are also set in accordance with the governmental perspectives. The exogenous levels of offshore investments and oil and gas exports result from a smoothing of their expected present values in the

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[16] This is in line with the Jones and Williams (2000) computations that exclude creative destruction (similarly to our model). Numerical specifications of Romer's Cobb Douglas production functions, as in Diao et al. (1999), Lin and Russo (2002), and Steger (2005), result in far larger mark-ups. Mark-ups of 1.5 are nevertheless in the upper bound of econometric estimates (Norrbin, 1993; Basu, 1996). Our main motivation for staying in the upper bound area is that we model industrial R&D as outsourced to a separate high-tech industry. Thus, R&D costs are ascribed to this industry, whereas the marginal costs of final goods industries exclude this part of the costs. This deviates from typical regressions of mark-ups, where marginal costs include all observed costs, including industrial R&D costs.

[17] Because $\rho=1/s$, a larger elasticity of scale will imply a larger elasticity of transformation between domestic and foreign deliveries, $1/(1-\rho)$. If the elasticity of scale is close to 1 (constant returns to scale), the elasticity of transformation will be very high, implying practically no dispersion between domestic and foreign deliveries.

governmental perspectives. The smoothing is made to account for the economic significance of the Norwegian oil and gas resources without introducing another source of dynamics into the growth path.

World market prices are assumed to increase 1.4 per cent annually. This is in the lower range of exogenous price growth estimates in the governmental perspectives, and is chosen so that exogenous inflationary impulses are more in line with internal impulses, which are dampened by the consumption-smoothing features of the model. This provides us with endogenous developments of the delivery ratios between the export and domestic markets that are more in line with those of the governmental perspectives. The international nominal interest rate is 4 per cent. All policy variables are constant in real terms at their 2002 levels.

In the governmental perspectives, total factor productivity growth is entirely exogenous and valued at, on average, 1 per cent annually. Our model distinguishes between exogenous and endogenous components. In line with empirical findings; see e.g. Coe and Helpman (1995) and Keller (2004), we calibrate 5 per cent of the long-run domestic growth to stem from domestic innovation.[18] The long run in this context is 50-70 years from now, where the reference path obtains a stable growth period. The assumed 5 per cent growth resulting from domestic innovation in this period forms a basis for calibrating the 2002 level of accumulated knowledge, R_0, which together with the remaining parameters of the model determines the productivity growth from domestic knowledge accumulation.

The relative influences of exogenous and endogenous absorption factors are quantified by synthesising available models and estimates from the econometric literature, see equation (3). Based on Grünfeld (2002), estimated for Norwegian industries, we set the parameter determining the absorption through the import channel, λ_2, to 0.075. This is also fairly in line with Griffith et al. (2004). We do not represent the relative gap with the international technology frontier explicitly as in Griffith et al. (2004), but as in Grünfeld (2002) we assume decreasing effect of domestic absorptive capacity to account for effects of approaching the frontier. We ensure this by specifying the following Ω-functions in eq. (4) and (5):

C.1 $$\Omega = \frac{\varphi\left(\dfrac{K^V/VF}{K_0^V/VF_0}\right)}{\dfrac{\varphi}{2} + \dfrac{K^V/VF}{K_0^V/VF_0}},$$

[18] This lies in lower bound of estimates for small, open countries like the Norwegian. We choose that, as several mechanisms believed to drive domestic innovations are excluded from the model, like basic, governmental research, endogenous education, and learning-by doing.

where subscript *0* refers to values in the first year of the reference path, 2002. The historical import channel impact in Coe and Helpman (1995) is also in the range of our estimate for λ_2, when we adjust for that they have not specified the influence of innovativeness.

Neither of the studies reported above include export as a channel of spillovers. Our main sources w.r.t export effects are Alvarez and Lopez (2006), Delgado et al (2002) and Baldwin and Gu (2003). Even when using conservative estimates, it is reasonable to assume that export is a considerably more effective channel for spillovers than import. We include absorptive capacity effects in this term, too, and use a λ_1- parameter of 0.15, which is a doubling compared to the parameter for the import channel.

In addition to effects from imports and exports, the absorbed productivity equation, eqn. (3), includes the influence on productivity from unexplained, exogenous drivers. These are captured through the λ_0 parameter, which is set to 0.25. The autonomous contribution to growth is lower than in Coe and Helpman (1995), since we regard more of the productivity effects as explained (through changes in export and absorptive capacity). Some of our sources report industry-specific parameters, but we have assumed common elasticities for all. The productivity level abroad, *AF*, is calibrated (dependent on R_0) so that long-run TFP growth arrives at levels comparable with the projections in Norwegian Ministry of Finance (2004).

In the long run, i.e. 50-70 years from now, the stable GDP growth rate of the reference path amounts to 1.6 per cent annually. The endogenous growth effects of innovation will asymptotically approach zero, in line with the non-scale growth assumption (Jones, 1995). The endogenous absorptive capacity effects also asymptotically approach zero, according to the decreasing effect of absorptive capacity. In an infinite time horizon, growth will thus only depend on exogenous drivers. For technical reasons, we have set all exogenous and endogenous growth drivers to zero in the far future (after about 100 years). This ensures that the economy is eventually on a balanced growth path (steady state) and that this growth path, with zero growth, satisfies the transversality conditions described in section 3.4. In particular, equation (13) then implies that $r=\theta$ at all points in time.[19]

[19] We have tested the significance of this assumption by varying at what time the zero growth is imposed. The relative effects of the different policy analyses appear independent of this timing, as do the growth rates within the stable period. Only the durability of the stable period is affected.