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Promoting innovation and imitation in a small open economy

The role of human capital, R&D and trade

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Abstract:
For small and open economies, absorption of knowledge spillovers from abroad can play a more important role for domestic growth than domestic innovations. However, there are interrelations between innovation and imitation processes, as they both depend on domestic investments in human capital and R&D, as well as trade. This article explores the implications for the desirable growth policy design when R&D policies, trade promotion and education simultaneously affect both innovation and absorption of knowledge spillovers from abroad. We find that devoting similar public funding to R&D, R&D based export or education all stimulate innovation as well as absorption. But the industrial pattern and the relative roles of imitation and innovation processes for productivity growth and welfare differ between the policy alternatives.

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

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

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1 Introduction

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; Nelson and Winters, 1982). For small and open economies spillover effects of *foreign* R&D appear to be the dominant source of productivity growth (Coe and Helpman; 1995 and Keller; 2004). There is, however, evidence that *domestic* R&D might be crucial for the capacity of firms to absorb the knowledge developed abroad (Griffith et al., 2004; Keller, 2004; Kinoshita, 2000).

Along with R&D investments, a positive productivity effect of human capital investments is also empirically supported (Griliches, 1997; Barro, 1991). However, the evidence is not unambiguous, as pointed out in e.g. the survey of Temple (2001). Benhabib and Spiegel (1994) find more explanatory power in the human capital *level* than in its *change*. While the direct productivity growth from increasing the input of human capital is weak (they find even a negative productivity effect for OECD countries), the human capital level enhances growth. It serves, they argue, as a facilitator of technological dispersion. Similar results appear in Borensztein et al. (1998) and Lutz et al. (2008). This implies that not only accumulation of R&D knowledge, but also that of human capital, has a second face, as originally suggested by Nelson and Phelps (1966) and formally modelled in a general framework by Eicher (1999). This hypothesis is supported by later studies that include both R&D knowledge and human capital as absorptive capacity determinants (Griffith et al., 2004; Crespo et al., 2004).

This applied model analysis explores how a small and open economy, exemplified by Norway, should form its policy strategies regarding education, innovation, and trade for stimulating long-term productivity growth. Previous applied policy studies have included some of the empirically relevant mechanisms and externalities. Russo (2004), Alvarez-Palaez and Groth (2005), and Steger (2005) includes endogenous growth through domestic innovation and R&D externalities as in Romer (1990), but leaves no role for international knowledge absorption, which is an important growth channel for small, open economies. Ambler (1999) is a similar model but which emphasises externalities from domestic accumulation processes of human capital rather than of R&D. Yet other studies model the international spillover processes, but leave out domestic innovation. Diao et al. (2006) model productivity growth through trade, but with no absorptive capacity effects of human capital or R&D. Hübler (2010) accounts for the absorptive capacity effects of human capital. Diao et al. (1999) and Ghosh (2007) adapt the Romer model to the small open economy case by accounting for both innovation and absorption of international spillovers. Lai et al. (2006) supplements by including human capital as an absorptive capacity factor. Bye et al. (2008) rather model R&D knowledge as the absorptive capacity factor. The contribution of the present paper is to study all these mechanisms in interplay, by simultaneously taking into account the two faces of R&D as well as education. First, they are important production factors in the innovation processes of the economy. Second, they act as indirect catalysts for absorbing technological spillovers through international trade.

Contrary to most of the above-mentioned studies we apply a fairly disaggregate numerical model. We thereby account for that industries vary with respect to their capacity to absorb external knowledge according to their specific trade, skill, and R&D intensities.[1] We include import and export activities as indicative for the trade openness.[2] Previous studies have focussed on the import channel, only. However, new empirical evidence also supports exports as a determinant; see Delgado et al. (2002), Baldwin and Gu (2003), Alvarez and Lopez (2006), as well as the survey of Greenaway and Keller (2007) on the economic impacts of export promotion.

We analyse the impact of three different policy instruments. The first is a general subsidy to R&D, which generates external standing on shoulders and productivity effects as in Romer (1990) and increases the absorptive capacity of industries using R&D-intensive technology. In practical policy, R&D support takes on various forms. An increasingly widespread measure is general tax credits/transfers according to firms' R&D expenses (Warda, 2005). We compare such a stimulus with a similar amount of resources devoted to stimulate trade in R&D-intensive technology. This will also affect both domestic innovation and knowledge externalities, as well as spillovers from abroad. The third policy experiment is to devote the similar amount to public investments in education that increase the number of high skilled and the level of human capital. Besides enhancing labour productivity directly, productivity is improved through strengthened absorptive capacity.

A CGE approach can simultaneously grasp the many direct and indirect interdependencies of R&D, education, and trade. It will also account for these activities' interplays with other market imperfections and existing government interventions. The model is calibrated to the small, open Norwegian economy.

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[1] Only Bye et al. (2008) use a similar level of detail in the absorptive capacity representation.

[2] Another potential channel for spillovers is foreign direct investments. We exclude FDI as a channel, based on two Scandinavian studies (Grünfeld, 2002, Braconier et al, 2001) that find no significant spillover effects from inward FDI. However, the findings in the literature are mixed. Pottelsberghe and Lichtenberg (2001) do, for example, 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.

We find approximately similar welfare effects of all the policy alternatives. But the industrial pattern and the relative roles of imitation and innovation processes for productivity growth and welfare differ. An R&D subsidy causes the R&D activity to expand considerably. This brings about positive externalities both through internal knowledge spillovers and productivity gains for users of R&D based capital. Absorption of spillovers from international technological development is also facilitated by the dispersion of R&D based capital domestically. Human capital has less absorptive capacity effects for most industries. Many final goods industries reduce their use of high skills as a result of the expansion of the R&D industry. The export promotion policy has the intended outcome of increasing absorption of knowledge across borders in the R&D industry more. However, this comes at the expense of absorption in most other industries. Education policies have a direct positive effect on R&D activity because this sector is the far most human capital intensive. The R&D expansion comes less at the expense of other human capital intensive industries compared to the other policy alternatives.

2 A CGE model with innovation and absorption effects

2.1 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[3] deliver to final markets and produce intermediates for each other according to an empirical input-output structure. Labour is a composite of high and low skilled workers. 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, educational composition, natural resources, and international conditions. In addition, it includes

[3] 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.

several endogenous productivity growth mechanisms: *i)* Productivity within the R&D industry grows continuously 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 and high-skilled labour. *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 next two subsections (3.2. and 3.3.), provide detailed descriptions of the parts of the model that bring about productivity growth through international spillovers and domestic innovation, respectively. Subsection 3.4. briefly outlines the remaining model mechanisms, including behavioural relations and equilibrium and balanced-growth conditions. Transfers, tax and subsidy wedges are represented in detail in the model, but apart from the policy instruments applied in this study, these are suppressed in the present exposition. Appendix B provides a more thorough, aggregated presentation of the equations determining firm and household behaviour, where the relevant policy variables are included. Appendix C gives details on parameter values, as well as calibration and solution procedures. Bye et al. (2006)[4] provides the complete model documentation.

2.2 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.[5] VF_i can be represented by

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

L_i^H, L_i^L $K^V{}_i$, $K^M{}_i$, and V_i represent the firm's input of high-skilled labour, low-skilled 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

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

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

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

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 functions Ω^R and Ω^H represent the *absorptive capacity* of the firm from R&D-based capital and human capital respectively. We model Ω^R as a function of the industry's input intensity of R&D-based capital $\kappa^R = K^V/VF$ and Ω^H as a function of the industry's input of high-skilled labour, L^H.

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 R&D-based capital of the industry increases and/or if their use of high skilled labour increases. There is decreasing returns to the R&D-based capital intensity and the use of high-skilled labour, which we ensure by the following specifications

(6a) $$\Omega^R = \frac{\varphi\kappa^R}{\frac{\varphi}{2} + \kappa^R}, \qquad \varphi>0,\ \Omega^{R'} > 0,\ \Omega^{R''} < 0.$$

(6b) $$\Omega^H = \frac{\varphi L^H}{\frac{\varphi}{2} + L^H}, \qquad \varphi>0,\ \Omega^{H'} > 0,\ \Omega^{H''} < 0.$$

We assume equal λ-values for all industries. Their values are chosen in accordance with estimates found in the literature, see appendix C. All firms are symmetric, and we implicitly assume that they do not consider the strategic effects on their absorbed productivity of adjusting their trade, R&D-based

capital intensity or input of high-skilled, since firms are small. Thus, the absorbed productivity effects are external.[6] Appendix C provides more details on the calibration.

2.3 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.

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

[6] Note that defining absorptive capacity in terms of R&D-based capital investments excludes absorptive capacity effects in the R&D industry in our model.

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.[7]

2.4 Market behaviour, equilibrium and balanced growth

2.4.1 Market behaviour of firms

Production for each identical firm is allocated to the foreign and domestic markets, which are segmented through a Constant-Elasticity- of-Transformation (CET) technology.

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

The transformation elasticity ρ >0 implies costs of diverting deliveries between the two markets.[8] 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.

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 and export market

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

(11) $$P_K^W = \frac{c}{(1+\alpha_3)s} \left(X_{Ki}^W \right)^{\frac{1-s}{s}}.$$

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

$m_{Ki} = \dfrac{\varepsilon_{Ki}}{\varepsilon_{Ki} - 1}$, 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

[7] 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.

variety is produced in equal quantities. The marginal costs of export deliveries equals the exogenous world market price of capital varieties P_K^W . α_3 is an ad valorem subsidy rate on export deliveries.

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

(12) $$(1+\alpha_1)P_{R0} = \int_0^\infty e^{-rt}(\overline{\pi}_t)dt .$$

P_{R0} is the fixed entry cost in period 0, or the shadow price of developing a patent in advance of variety production. α_1 is an ad valorem subsidy rate on patent 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:

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

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.

2.4.2 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). The representative consumer supplies a composite of high skilled and low skilled labour. 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

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

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. (13).

2.4.3 Market equilibrium

The model is characterised by equilibrium in each period in all product markets and labour markets. There are two labour markets, for high skilled labour (man years provided by persons with more than 4 years education after high school) and low skilled labour (rest of the labour force), respectively. The intensity of high-skilled differs among the industries, with the R&D-industry as the most high skill intensive. Equilibrium in the two labour markets for high and low skilled determines their respective wage rates. Supply of both skill types is exogenous, but education policies can exogenously affect the composition at a public cost.

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

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

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 (14), 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 (14) then implies that $r=\theta$ at all points in time.

3 Effects of growth policy

We study three different policy scenarios, all designed to stimulate the productivity of firms. The first, an R&D subsidy (see eq. (12)), directly stimulates domestic innovation. However, it will also facilitate increased knowledge absorption to the extent that domestic firms increase their R&D intensity. The second policy promotes exports of R&D-based capital goods, see eq. (11). As compared with the R&D support, this second policy puts more emphasis on the absorption externalities, as it stimulates trading. Since R&D-intensive export is promoted we do, however, obtain considerable growth through domestic R&D and internal knowledge spillovers, too. The third policy is directed towards human capital investments. The government provides higher education and, thus, a higher share of high-skilled in the economy. This policy is motivated by both the direct productivity gains and the indirect absorptive capacity effects of higher intensity of high skilled labour. The direct effects will first of all gain skill intensive industries, As the R&D industry is highly skill intensive, the educational policy will also bring about domestic innovation and knowledge externalities. On top of these productivity gains, the absorptive capacity effects of human capital will stimulate industries with high trade exposure.

In order to identify the role of human capital for the growth processes and for the effects of growth policy, we compare the policy results within two different regimes, one main regime (the HC regime), where labour is split into two skill types: high skilled and low skilled with both direct and indirect productivity effects of human capital, and one alternative regime (the NON-HC regime), where both these productivity effects of human capital are coupled out.

In the HC regime, the substitution elasticity between the skill types is set to 2. In an economy free from distortions, the split would ensure a more flexible economy, where labour is more efficiently allocated among industries according to differences in high and low skill intensities. In addition, distinguishing between the two skill types enables us to account for the indirect absorptive capacity effects of human capital, which are allowed to be industry specific. In addition to these two obvious differences between the HC and the NON-HC regime, other allocation effects can produce efficiency differences between the regimes. The model accounts for several externalities, market imperfections, and public interventions. Particularly relevant is what happens to the R&D activity as well as to other determinants for the degree of knowledge absorption across borders.[9]

In the NON-HC regime the direct productivity effects are eliminated by keeping the industry-specific use of high-skilled labour proportional to the use of low-skilled. Absorption of knowledge spillovers from abroad is assumed insensitive to the use of high-skilled, and is only dependent on the industry's intensities of R&D and international trading.[10]

3.1 Effects of R&D support

In this scenario we analyse the impacts of 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.[11] The first column in Table 1 reports the long-run effects (70 years from now) in the main regime (the HC regime), after the economy has reached stable growth rates and before the endogenous growth is emptied out.

The direct effect of the R&D support 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 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 the long-run the R&D industry expands considerably. In the main regime, its patent production increases by 20.1 per cent and its supply of R&D based capital increases by 8.2 per cent. Both home and export deliveries increase, by 7.6 and 9.8 per cent, respectively.

Virtually all industries face increased productivity through absorption. The spillover absorption of an industry is determined by its human capital, its intensity of R&D based technology, as well as its international trading activity. Subsidising R&D has two main, counteracting effects: The human

[9] We have identified the isolated effect of splitting the labour market in a growing economy, while leaving out absorptive capacity effects of human capital input. Simulations show that the economy becomes more efficient. This also benefits the R&D industry, which expands and contributes to increased GDP growth and welfare.

[10] In these preliminary simulations, the effects of trading are not completely comparable, but decomposition analysis reveals that the differences hardly influence the policy results.

[11] This approximates a support of 250 € in annuity terms, while the subsidy is zero in the reference path.

capital level diminishes in several industries, because of the pressure on this resource when the R&D industry expands. On the other hand, more R&D reduces the costs of investing in R&D based capital. This takes place in all industries and more than offsets the adverse absorptive capacity effects in many industries from less use of human capital. At the aggregate level, the economy also faces higher trade volumes as shares of GDP that can stimulate absorption. In the long run, total export increases by 3.7 per cent, import by 3.2 per cent, and GDP by 2.1 per cent. The trade intensity changes do, however, vary among industries.

The wage rate of high skilled workers increases sharper than that of the low skilled; in the long run by 5.0 and 2.7 per cent, respectively. This encourages all industries to substitute low skilled for high skilled labour. The factor price increases reflect higher factor scarcity, particularly in the market for skilled workers. Increased factor demand from the newcomers in the R&D industry is part of this picture. Pressure also originates from higher productivity within most final goods industries that is brought about and which increases the international competitiveness of domestic firms. Besides higher absorbed productivity, as described above, also another, more direct productivity externality favours those investing in R&D based technology. As they are characterised by love of variety, the higher number of varieties increase the productivity of the R&D-based capital.[12]

The long run GDP growth rate increases by 0.05 percentage points due to the stimulation of the innovation and absorption processes. As these largely involve external productivity growth, the policy intervention is welfare improving. The economy obtains a welfare gain of 0.9 per cent. Two implications of the reallocations contribute negatively: First, as the R&D firms exhibit some market power in the home market, their production scales are sub-optimally low. The R&D subsidy causes home market deliveries to fall to even lower levels. Second, the traditional manufacturing industry enjoys beneficial tax and subvention policies that render their resource input at sub-optimally high levels. [13] This inefficiency is also reinforced by the R&D support.

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[12] This is reflected in a fall in the capital price per efficiency unit, despite a slight rise in the price of each variety.

[13] These include relatively lower taxes on electricity, CO_2 emissions, and labour, as well as favourable energy contracts. Manufacturing industries in several countries often make use of favourable policies as subsidised energy prices and exemptions from energy and environmental taxes, see e.g. OECD (2008).

Table 1. Effects of a 5% R&D subsidy, percentage deviations from the reference, long run

Regime	With human capital (HC regime)	Without human capital (NON-HC regime)
Ad val. rate of support*	5.0	5.0
The R&D industry		
No. of firms/patents/varieties	14.7	13.5
R&D/Production of patents	20.1	18.7
Patent shadow price	-6.2	-6.9
Production of R&D-based capital	8.2	6.9
- for export deliveries	7.6	6.4
- for home market deliveries	9.8	8.5
- for export per firm	-6.2	-6.2
- for home markets per firm	-4.3	-4.4
- home market price per unit	0.4	0.4
- home market price per effective unit	-5.5	-5.5
Absorbed productivity		
- level	0.2	-0.1
The traditional manufacturing industry		
Export	3.3	3.1
Absorbed productivity		
- level	1.8	1.6
GDP	2.1	1.7
GDP growth**	0.05	0.04
Average absorbed productivity		
- level	0.8	0.8
Wage rate high skilled	5.0	2.5****
Wage rate low skilled	2.7	
Export	3.7	3.1
Import	3.2	2.5
Welfare***	0.9	0.7

* constant ad val. rate

** absolute deviation from the reference (in the long run)

*** percentage change in discounted value

**** only one labour market

Table 1 compares the effects in the HC regime with those in the NON-HC regime. [14]The output changes within the R&D industry are between 1 and 2 percentage points larger than in the NON-HC regime. Even if dividing the labour market into two skills improves the economy's efficiency, it is uncertain whether this flexibility contributes to enhance or dampen the R&D activity. The reason is that labour costs rise significantly for the R&D industry, due to its high skill intensity. This modifies the positive effect on R&D production. (See also the sensitivity analyses below.)

Another and unambiguously positive impulse to the R&D industry of accounting for human capital is that its absorbed productivity increases compared to the NON-HC regime. High skilled labour is largely drawn from production of consumer goods and services, which supplies a high share of services that are fairly high skilled intensive. Production of R&D based capital requires low skilled labour to a larger extent. This is primarily reallocated from the traditional manufacturing industry[15]. Compared with the NON-HC regime the more flexible labour market implies more labour drawn from the traditional manufacturing industry and less from production of consumer goods and services.

The HC and the NON-HC regime differ significantly in their absorption effects, particularly in how productivity growth through cross border spillovers varies among industries. As most industries involved in international trading, apart from the R&D based capital producers, give up high skilled workers in the HC regime, their absorptive capacity become lower than in the NON-HC regime. Only the R&D industry strengthens its absorptive capacity and cross border productivity spillovers compared with the NON-HC case. This is strengthened by the fact that its absorption effects are self-enforcing: In isolation, higher human capital/skills increase absorption, which again stimulates R&D based export, which increases absorption externalities further. Its level of absorbed productivity increases by 0.2 per cent as compared with a fall of 0.1 per cent in the NON-HC regime; the latter explained by a negative self-enforcing spiral that caused exports within each firm to fall sharper in the NON-HC regime.

The welfare gain is 0.2 percentage point higher than in the NON-HC regime. A more efficient resource allocation is obtained because of a more flexible labour market, stronger external effects from knowledge spillovers internally and across borders, as well as fewer resources allocated to the traditional manufacturing industry.

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[14] The effects are measured as per cent changes from their respective reference paths, reflecting the HC and NON-HC regimes, respectively. The reference paths are described in Appendix C.

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

3.2 Export promotion

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 is a channel for absorbing spillovers from abroad, there could still be strategic to promote export in small, open countries.[16] Promoting sales of R&D-based products will be particularly promising, because of the direct, as well as absorptive capacity-induced productivity externalities. Therefore, we simulate promotion of R&D-based capital export, implemented as an export subsidy.[17]

We have imposed a constant export support rate of 1.3 per cent of the export value. The export promotion serves to increase the export from the R&D industry by 10.1 per cent in the long run; see table 2. The absorption of international spillovers in the R&D industry increases in every period, and in the long run the increase is 0.3 percent. Compared with the NON-HC case, the absorption effect is stronger, and the explanations are as in the R&D subsidy alternative: The reallocation of high skilled workers from other final goods industries to the R&D industry implies that the R&D industry strengthens its absorptive capacity and cross border productivity spillovers compared with the NON-HC case, while most others reduce.

Increased export of R&D based capital can either come from new firms, which will require increased patent production, or from already existing firms. R&D increases by 14.7 per cent while each firm exports 1.3 per cent more. Compared to the NON-HC case, export from each firm increases more while the number of firms increases less. This is due to the high skill intensity in patent production, which makes it relatively more costly. The overall welfare gain of the export promotion is of approximately the same magnitude within the HC and NON-HC regimes. A more efficient resource allocation is obtained because of a more flexible labour market. However, the productivity externalities related to domestic innovation – both through standing on shoulders effects in R&D and through love of variety - are weaker.

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[16] Although a significant number of export promotion instruments appear to have no effect on export volumes, several are also found to have a strong impact. ECON (2001) surveys the size and composition of such instruments in the Scandinavian countries and finds that Norway spends less resources on export promotion than Sweden and Denmark. Hence, there is a significant potential for increased export promotion in terms of government support.

[17] We have also simulated a *general* export-promoting stimulus in order to de-emphasise the R&D effects and be able to cultivate the general absorption effects of export. Besides being subject to heavy international regulations and of small policy relevance, our exercise shows that it is neither recommendable from the national point of view: efficiency drops by 0.1 per cent compared to the reference. This 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.

Table 2. Effects of a 1.3% export subsidy for R&D based capital, percentage deviations from the reference, long run

Regime	**With human capital (HC regime)**	**Without human capital (NON-HC regime)**
Ad val. rate of support*	1.3	1.3
The R&D industry		
R&D/Production of patents	14.7	15.3
Patent shadow price	0.1	-0.4
Production of R&D-based capital	9.4	9.2
- for export deliveries	10.3	10.3
- for home market deliveries	6.9	5.5
- for export per firm	1.3	1.1
- for home markets per firm	-2.4	-3.3
- home market price per unit	-0.9	0.4
- home market price per effective unit		-3.7
Absorbed productivity	0.3	0.2
The traditional manufacturing industry		
Export	0.5	0.9
Absorbed productivity	1.3	1.1
GDP	1.4	1.6
GDP growth**	0.04	0.04
Wage rate high skilled	3.9	2.3****
Wage rate low skilled	2.1	
Export	2.7	3.2
Import	2.6	2.6
Welfare***	0.9	0.9

* constant ad val. rate

** absolute deviation from the reference (in the long run)

*** percentage change in discounted value

**** only one labour market

As the two policy analyses involve approximately equal public expenses, we gain insight by comparing their effects.[18] Directly stimulating R&D activity will, as expected, boost R&D more than supporting the export activity of the industry. The export promotion, on the other hand, has the intended outcome of increasing absorption of knowledge across borders in the R&D industry more.

[18] For more conclusive results, we should balance public budgets by letting other transfers vary, e.g. by adjusting the VAT rate. In these preliminary simulations, balancing is yet not perfect.

However, this comes at the expense of absorption in most 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 subvention case. There is less pressure on the high skilled labour, but the reallocations still go from the final goods industries (particularly production of consumer goods and services) to the R&D industry. These effects result in reduced absorptive capacity in the final goods industries. Also, trade in these industries, particularly exports of traditional manufacturers, falls, contributing to less productivity spillovers from abroad. While the economy absorbs approximately the same productivity spillovers, on average, the bias towards the R&D industry is even more pronounced in the export promotion than in the R&D support case.

The two subsidy alternatives turn out to give approximately equivalent welfare gains. While the spillover externalities from abroad are exploited to more or less the same degree, the export promotion generates less productivity gain from domestic innovation, as the economy invests less in R&D. In the opposite direction comes that other existing distortions are counteracted more in the case of export promotion. In the wake of lower R&D, production scales within each firm expand and counteract the inefficiencies related to the existing market imperfections. In addition, we find a more pronounced crowding out of traditional manufacturing. Because of the various favourable arrangements enjoyed by this industry, this will, in isolation, bring about welfare improvements.

3.3 Education policy

An increase in the share of high skilled labour reduces the high-skilled wage rate and boosts the R&D industry. Low-skilled labour are substituted by high skilled in several industries which contribute to dampen a wage increase for low-skilled. Costs of R&D production falls and R&D production increase. More high-skilled and higher R&D-production improves productivity and strengthens the absorptive capacity through the high-tech- and human capital channels. Increased availability of high-skilled has similarities with the R&D subsidy case since more (and cheaper) high-skilled has a direct positive effect on R&D activity.

4 Sensitivity analyses

4.1.1 Elasticity of substitution

The higher the elasticity of substitution between the two skills the more high skilled is demanded by other industries than the R&D industry and the high skilled wage rate increase. The cost increase is especially large for the R&D industry and R&D production falls. Other industries increase their activity. If the elasticity of substitution is low the wage gap between high and low skilled can be negative.

4.1.2 Absorptive capacity effects of human capital

In a sensitivity analysis we have simulated the R&D subsidy alternative in a model with divided labour market and no human capital effects in the absorptive capacity. The R&D subsidy boosts the R&D industry and the demand for high-skilled and their wage rate. This cost increase modifies slightly the positive effect on R&D production of the R&D subsidy. The effects on R&D production, GDP and welfare are approximately equal to the NON-HC case. Introducing absorptive capacity effects of human capital (high-skilled intensity) enhance the welfare effects of the R&D subsidy, while increased flexibility in the labour market may pull in both directions.

5 Conclusions

Empirical studies find that a country's level of R&D and human capital 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.

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.

We analyse three different policies; direct R&D support, support to export of R&D based capital and investment in education of high skilled. We find approximately similar welfare effects of all the policy alternatives. But the industrial pattern and the relative roles of imitation and innovation processes for productivity growth and welfare differ. An R&D subsidy causes the R&D activity to expand considerably. This brings about positive externalities both through internal knowledge spillovers and productivity gains for users of R&D based capital. Absorption of spillovers from international technological development is also facilitated by the dispersion of R&D based capital domestically.

Human capital has less absorptive capacity effects for most industries. Many final goods industries reduce their use of high skills as a result of the expansion of the R&D industry.

A decomposition analysis shows that accounting for human capital ambiguously influences welfare. While it in a first best world would increase flexibility and efficiency, its allocation effects within sectors with externalities and market distortions will be of crucial importance and ex ante give ambiguous effects. We find that the absorptive capacity effect of human capital stimulates the R&D industry, but negatively affects the other industries. Stimulating R&D is however important for welfare.

The export promotion policy has the intended outcome of increasing absorption of knowledge across borders in the R&D industry more. However, this comes at the expense of absorption in most other industries. On average, the two policies generate about the same absorption, but the bias towards the R&D industry is even more pronounced in the export promotion than in the R&D support case. Export promotion also fosters less domestic R&D, i.e. more export takes place from already existing firms. This implies less productivity spillovers from domestic R&D-driven innovation. However, there are positive contributions from counteracted distortions elsewhere in the economy, including increased scale effects within firms with mark-ups and reduced activity within industries facing favourable and nationally costly policies. All in all, the total welfare gains are of the same magnitude in the two policy cases.

Education policies have a direct positive effect on R&D activity because this sector is the far most human capital intensive (Rybscinsky effect). The R&D expansion comes less at the expense of other human capital intensive industries. However, the share of labour with lower skills decreases with opposite implications for low skill intensive industries.

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Appendix A. 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

Appendix B. The model structure of firm and household behaviour

(Preliminary - Not including the heterogeneous labour market model)

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

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

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

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

(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'') $\overline{\pi}_i=P_{Ki}^{H}\left(X_{Ki}^{H}\right)X_{Ki}^{H}-c\cdot\left(X_{Ki}^{H}\right)^{1/s}+P_{K}^{W}(1+\alpha_3)X_{Ki}^{W}-c\cdot\left(X_{Ki}^{W}\right)^{1/s}$

(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) $\left(1+\alpha_1\right)P_{R0}=\int_0^{\infty}e^{-rt}\left(\overline{\pi}_t\right)dt$

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) $W_0=\int_0^{\infty}P_t^{D}d_te^{-rt}dt$

(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	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
ν	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 final goods 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

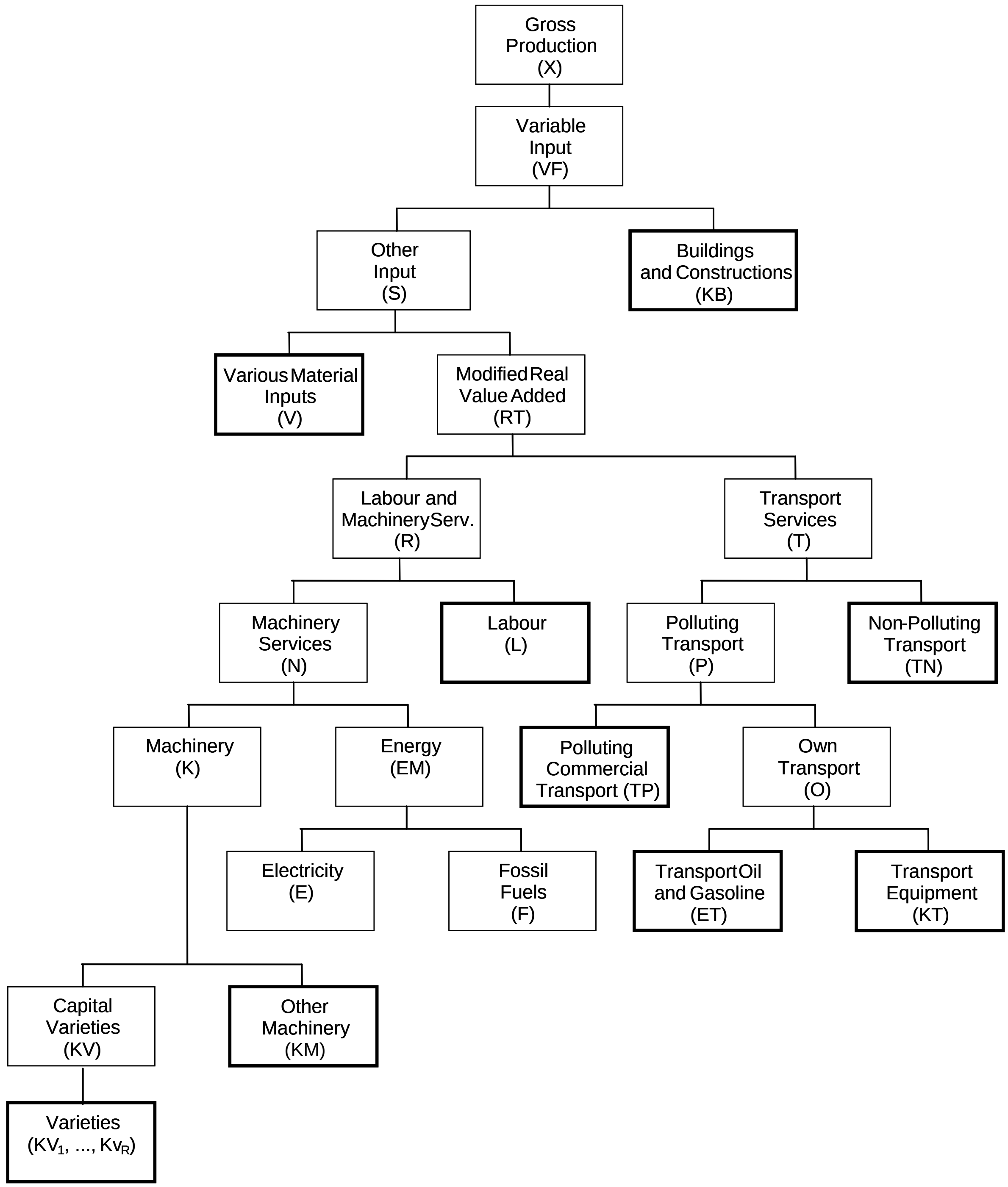
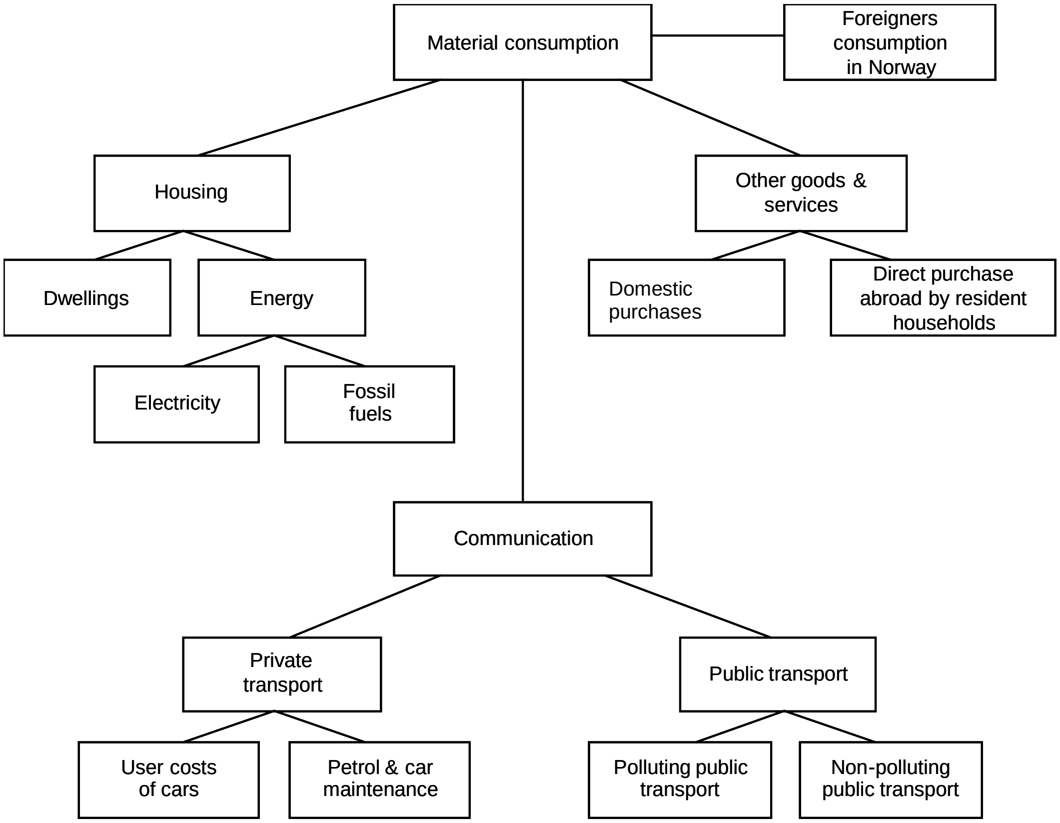


Figure B.2. The nested structure of consumption activities



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.[19]

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.[20] 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 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.

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[19] 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.

[20] 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.

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.[21] 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). 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 $$\Omega = \frac{\varphi\left(\frac{K^V / VF}{K_0^V / VF_0}\right)}{\frac{\varphi}{2} + \frac{K^V / VF}{K_0^V / VF_0}},$$

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), while

[21] 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.

our import estimate is based on Grünfeld (2002), estimated for Norwegian industries. The estimates on absorption through the import or export channels are mixed and we choose identical parameters to be conservative, i.e. $\lambda_1 = \lambda_2$ 0.045. This is also fairly in line with Griffith et al. (2004).

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 (14) then implies that $r=\theta$ at all points in time.[22]

[22] 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.