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Growth and Innovation Policy in a Small, Open Economy: Should You Stimulate Domestic R&D or Exports?

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Growth and Innovation Policy in a Small, Open Economy: Should You Stimulate Domestic R&D or Exports?*

Brita Bye, Taran Faehn, and Leo A. Grünfeld

Abstract

In small and open economies, absorption of foreign knowledge through international trade often plays a more important role for domestic innovation and growth than investment in domestic R&D. This suggests that trade policies can increase knowledge spillovers from abroad. Public support to R&D can be motivated both by positive internal knowledge externalities and by its ability to expand absorptive capacity. This dynamic, empirical, general equilibrium analysis models these interplays between R&D, trade and productivity. It compares public R&D support and export promotion of R&D based products with respect to long term growth and welfare impacts. We find that export promotion is inferior to R&D support in spurring R&D. However, it is not outperformed in terms of welfare generation. The reason is that existing and politically persistent policy interventions create inefficiencies that can be counteracted by R&D-based export promotion as a second-best policy.

KEYWORDS: absorptive capacity, computable general equilibrium (CGE) model, endogenous growth, research and development, international spillovers

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1 Introduction

A case for growth-enhancing policy arises when the incentives for private firms to invest in technological improvements are insufficient from an economy-wide perspective. The research question of this study is how a small and open economy should form its policy strategies for stimulating long-term productivity growth. The role of research and development (R&D) as an engine for technological progress is well documented (e.g., Nelson and Winter, 1982; Romer, 1990; Griliches, 1995; Jones and Williams, 1998; 2000). The main argument in favour of R&D stimulating policies is that the non-excludable, common features of knowledge suggest external spillover effects, both to other R&D firms, which gain productivity from "standing on the shoulders" of previous findings, and to other industries, which obtain increased technological efficiency (Romer, 1990). These aspects call for stimulating R&D and R&D-based activities.

The empirical literature from the last decade emphasises not only domestic R&D but also the absorption of R&D knowledge from abroad as decisive for the productivity and competitiveness of firms and for 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. Coe and Helpman (1995) and several similar studies find that the level and composition of imports affect learning from abroad. 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.

A positive correlation between exporting and firm performance has long been evident. While the earlier literature found support for the causality going from high productivity to export and stated a selection effect (Clerides et al., 1998; Bernhard and Jensen, 1999), several recent contributions point to the opposite relationship. They show that exporting serves as an important learning channel, particularly for small, open economies (Baldwin and Gu, 2003; Salomon and Shaver, 2005; Aw et al., 2007; Girma et al., 2008). These two theories are not mutually excluding: Not only innovators export more; exporters also innovate more (Andersson and Lööf, 2009).[1] There is evidence of knowledge externalities

[1] Besides trade, foreign direct investment (FDI) stands out as a potential channel for spillovers. However, two studies of Scandinavian economies (Braconier et al., 2001; Grünfeld, 2002) find no significant spillover effects. In the overall literature, the findings are mixed. Pottelsberghe and Lichtenberg (2001) do, for example, identify spillovers on the macro level from outward FDI, while a firm-level study of transition economies in Damijan et al. (2004) finds that spillovers through inward FDI stand out as the most important contributor.

in the learning process. Alvarez and Lopez (2006) find strong spillover effects from exporters to non-exporters in a highly detailed firm-level study for Chile. Additionally, Falvey et al. (2004) indicate that export works as a channel for R&D spillovers and that such spillovers are likely to be a public good.

The observation of a two-way relationship between trade and productivity is consistent with the idea that engaging in domestic innovation activities extends the capacity of firms to absorb knowledge spillovers from abroad. As formulated by Cohen and Levinthal (1989), domestic R&D has two *faces* that affect productivity. First, it spurs own innovation and, second, it increases productivity through better exploitation of the knowledge spillovers from abroad. Empirical research during the last two decades, including the influential work of Griffith et al. (2004), has lent convincing support to this twofold productivity effect of R&D.

While the vast majority of earlier applied studies have treated technological change as exogenous, endogenous growth models now dominate the field. Diao et al. (1999), Russo (2004), Alvarez-Pelaez and Groth (2005), Steger (2005), and Ghosh (2007)[2] find large productivity gains from stimulating R&D. Only the first two studies introduce the small, open economy perspective and a role for international knowledge absorption. In light of the new findings on the determinants of knowledge absorption summarised above, there is a need to re-examine the growth effects of R&D and trade policies, particularly for small, open economies. The aim of this analysis is to account for the two faces of R&D while taking into account new evidence on the magnitude and determinants of international knowledge spillovers. We extend the previous endogenous growth model frameworks by introducing the two-way relationship between export and productivity and a role for export-promoting policy instruments.[3] A relatively detailed computable general equilibrium (CGE) model is applied to capture how final goods industries vary in their absorption of international knowledge spillovers depending on their respective trade and R&D intensities. This model is a refinement compared to Diao et al. (1999), where all spillovers are channelled through the (single) R&D industry. Our small, open economy case is Norway.

As R&D and trade drive the endogenous growth processes, we analyse policies directed towards these activities. We compare the growth and welfare impacts of an R&D subsidy, an export-promoting instrument directed towards R&D-based products and a general export-promoting instrument directed towards all goods. In practice, R&D subsidies take on various forms. An increasingly widespread measure being used is general tax credits/transfers according to firms' R&D expenses (Warda, 2005). We compare this type of R&D support with a

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

[3] Diao et al. (2006) incorporate spillovers between international trade and productivity in a model for Thailand but do not include any role for R&D either as an internal growth engine or as an absorptive capacity factor.

similar number of resources devoted to promoting trade. New empirical evidence has led us to study export promotion rather than import liberalisation, which appears to provide limited economy-wide productivity gains even if absorption is accounted for; see Diao et al. (1999) and Ghosh (2007).[4] Recently, Alvarez (2004), Tomiura (2007), and Gil et al. (2008) have identified the significant effects of export promotion. Greenaway and Kneller (2007) have surveyed the literature on export-promoting measures and conclude that although the picture is mixed, several instruments have a strong economic impact. Our export-promoting instrument directed towards R&D-based products better reflects practical and relevant policies than does the generally directed instrument, as direct export subsidies are highly regulated within the agreements of the European Economic Area[5] and the World Trade Organisation. Most accepted export promotion instruments – such as grants, loans, guarantees, and marketing arrangements to promote internationalisation – apply exclusively to newly developed products. [6]

The impact of R&D support and export promotion on growth and efficiency is not obvious. In a real economy, several market imperfections and government interventions coexist. Particularly relevant are distortions due to favourable policies directed towards traditional industries, which tend to hamper productivity growth and economic efficiency. A vast political economy literature exists on the tendency of governments to conserve traditional industrial patterns through protectionist measures (Hufbauer and Rosen, 1986; Ray, 1991; Baldwin and Robert-Nicoud, 2007; Hawkins, 2009). As Tovar (2009) points out, these results are relevant not only for direct trade protection but also for other supportive policy instruments, such as production subsidies and tax breaks. In the wake of globalisation, the scope of available instruments has narrowed. Nevertheless, active lobbyists have succeeded in preserving beneficial policy arrangements up to the present day, primarily through a low-priced energy supply, access to natural resources, and regional policy instruments (Ekins and Speck, 1999; OECD, 2001; 2007; 2008). Traditional Norwegian export industries are no exception (Bye and Nyborg, 2003; Bjertnæs and Fæhn, 2008; Bye and Holmøy, 2010; Gullberg and Skodvin, 2011).

Our analysis indicates that promoting the export of R&D-based products enables the government to kill three birds with one stone. This policy alternative stimulates domestic spillovers from R&D, and it enhances absorption of knowledge spillovers from abroad. Both these results can also be obtained even

[4] Second, the Norwegian import hindrances are already few, even when non-tariff barriers are accounted for, with agriculture as the main exception (Fæhn, 2002).
[5] Though outside the European Union, Norway is regulated by the same competition rules through participation in the European Economic Area.
[6] Such export-promoting instruments are used within the European Economic Area; see ECON (2001).

more effectively with direct R&D support. However, export promotion outperforms R&D support in its ability to counteract inefficiencies caused by already existing policy measures. In the Norwegian economy the documented interventions in favour of traditional manufacturing contribute to direct resources to that industry. Our results show that promoting R&D-based industries associated with positive externalities has the effect of diverting resources out of the traditional manufacturing industry, and this is likely to be one of the reasons why export promotion turns out to be slightly welfare-superior to R&D support. In an economy distorted by several policy interventions, there is a lack of general rules of welfare effects of policy reforms (Auerbach, 1985; Dixit, 1985). The result illustrates the value added of placing the modelling of growth processes within a realistic, empirically based CGE framework.

The paper is organised as follows; in Section 2, we describe the CGE model with innovation and absorption effects, in Section 3, the policy shifts and analyses are presented, and Section 4 concludes.

2 An open economy 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 fits a small, open economy and is calibrated to the Norwegian economy. The model 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[7] deliver to final goods markets and produce intermediates for each other according to the empirical input-output structure of the 2002 National Accounts. The public sector collects taxes, distributes transfers, and purchases goods and services from the industries and from abroad. 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 a numéraire.

The model specifies the following endogenous productivity growth mechanisms: *i) The standing on shoulders effect*, which refers to the continuous productivity growth within the R&D industry caused by dynamic spillovers from the accumulated R&D knowledge stock. We assume decreasing returns as in

[7] See appendix A for a list. The following industries are treated exogenously: the public sector, the offshore production of crude oil, natural gas and related services and pipeline transport, and overseas transport.

Jones (1995). *ii) The love of variety effect* in the demand for R&D-based capital, which implies that the productivity of R&D-based investments within final goods industries increases with the number of patents/varieties. *iii) Endogenous absorption* of spillovers from abroad, as absorbed productivity improvements depend on each industry's extent of foreign trade and input share of R&D-based capital. The latter strengthens their absorptive capacity. *iv) Real capital accumulation*, which results from the cash flow maximisation of rational, forward-looking firms improves labour productivity.

The next two subsections (2.2 and 2.3) provide detailed descriptions of the parts of the model that bring about productivity growth through international spillovers and domestic innovation, respectively. Subsection 2.4 briefly outlines the remaining model mechanisms, including behavioural relations and equilibrium and balanced growth conditions. Transfer, tax, and subsidy wedges are represented in detail in the model, but apart from the growth policy instruments applied in this study, these are suppressed in the present exposition. Appendix B provides a more thorough, aggregated presentation of the equations that determine firm and household behaviour and document parameter values. Appendix C outlines details on the reference path dynamics, as well as calibration and solution procedures. Bye et al. (2006)[8] 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

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

X_i^H and 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.[9] VF_i can be represented by

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

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-

8 Confer http://www.ssb.no/english/subjects/10/90/doc_200611_en/doc_200611_en.pdf for a model documentation.

9 The scale elasticity is equal for all industries; see also appendices B and C.

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, such that

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

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, which are defined as follows

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

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

The term A accounts for the absorption elasticity's dependence on the industry's export, X^W, as share of total output, X.[10] The term B describes the corresponding dependence on industry import, I, which is measured relative to the domestic deliveries of similar products from domestic firms within the industry, X^H.[11] 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, $\kappa = K^V \big/ VF$.[12] 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, in line with the findings in Bernard and Jensen (1999). There are decreasing returns to the R&D-based capital intensity, which we ensure by the following specification[13]

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

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[10] This formulation is chosen to account for the finding of Baldwin and Gu (2003) that the export intensity is important for the knowledge spillovers.

[11] Modelling industry-specific import shares as determinants is inspired by Griffith et al. (2004).

[12] κ is normalised to the base year level.

[13] This characteristic harmonises with empirical findings of decreasing domestic growth rates as productivity increases and approaches the productivity (frontier) abroad; see e.g., Griffith et al. (2004).

We assume equal λ-values (see eq. (3)) 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 or R&D-based capital intensity, as the firms are small. Thus, the absorbed productivity effects are external. Appendix C provides more details on the calibration. Section 3.4 presents a sensitivity analysis of the chosen parameters.

2.3 Productivity growth through domestic innovation

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

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

where *R* grows according to $R = R_{-1} + X_R$. The parameter s_1 denotes the elasticity with respect to the domestic spillovers. As suggested in Jones (1995), its value is less than unity. These productivity growth dynamics generated by the accumulated stock of R&D knowledge, *R*, are external to the individual patent producer, who is too small to consider the effect of 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_i^V. The production of R&D-based capital varieties also involves variable factor input costs with decreasing returns to scale.[14] We assume identical factor input cost structures for all R&D firms, both in their patents and R&D-based capital production.

The R&D-based capital varieties are partly exported and partly delivered to domestic final goods industries.[15] The input of each R&D-based capital variety

[14] The common scale elasticity also applies to the R&D activity; see more details in appendices B and C.
[15] In the R&D industry, input of K^v is per definition zero both in the R&D activity and the R&D-based capital production in order to avoid cumulative love of variety multiplicators.

in the final goods industries is represented by so-called Spence Dixit Stiglitz (love of variety) preferences for a composite of the varieties, K^V

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

The accumulated stock of R&D knowledge, *R,* also represents the number of firms in the R&D industry and available patented varieties. σ_{KV} is the elasticity of substitution, which is applied to all pairs of capital varieties. It is common to all final good industries. The more varieties there are, the higher 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 the final good industry j, K_j^V / VF_j, varies with j and reflects its degree of absorptive capacity. [16]

2.4 Market behaviour, equilibrium, and balanced growth

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.

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

The transformation elasticity ρ >0 implies costs of diverting deliveries between the two markets.[17] 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. For the final goods industries, we assume perfect competition among numerous firms within each industry, and the first order conditions equate prices with marginal

[16] Note that in our model defining absorptive capacity in terms of R&D-based capital investments excludes absorptive capacity effects in the R&D industry because the R&D-industry does not use own-produced R&D-based capital as input.

[17] This, together with decreasing returns to scale of total factor use in each industry, avoids complete specialisation in production of tradables.

costs within the two segmented markets. The CET technology implies that the ratio of export to domestic market deliveries is determined by their relative prices.

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

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

$$P_{K}^{W} = \frac{c}{(1+\alpha)s}\left(X_{Ki}^{W}\right)^{\frac{1-s}{s}}. \tag{11}$$

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. The marginal costs of export deliveries equal the exogenous world market price of capital varieties, P_{K}^{W}. α 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 as

$$\left(1+\beta\right)P_{R0} = \int_{0}^{\infty} e^{-rt}\left(\overline{\pi}_{t}\right)dt. \tag{12}$$

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

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

P^H is the price of the domestic variety, P^I is the respective, exogenous, import price, ν is the initial import share, and σ_{HI} is the substitution elasticity (Armington elasticity) between the two varieties. The Armington assumption implies that the ratio of imports to home deliveries is 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 equal 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 analogous to eq. (13).

Equilibrium conditions

The model is characterised by equilibrium in each period in all product markets and in 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 must both be zero. The model is characterised by a path dependent balanced growth path solution; see Sen and Turnovsky (1989) for a theoretical exposition. This implies that the balanced growth paths, as well as the transitional paths, differ among 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)* The 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

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

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. 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 fulfilment of eq. (14). Correspondingly, the transversality condition for the value of real capital is a restriction on the determination of net investments by firms. The endogenous growth effects of innovation will asymptotically approach zero, in line with the non-scale growth assumption (s_I<1 in eq. (7)). The endogenous absorptive capacity effects also asymptotically approach zero, according to the decreasing effect of absorptive capacity; see eq. (6). In an infinite time horizon, growth in our model will therefore 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), to ensure that a balanced growth path is reached within a limited number of periods.[18] This induces a balanced growth path with zero growth in both consumption and the consumer price index. Thus, the transversality conditions are satisfied. In particular, eq. (14) then implies that $r=\theta$.

3 Effects of growth policy

3.1 The policy schemes

We analyse two main policy alternatives, both designed to stimulate the productivity of firms. The first, R&D support (represented by β in eq. (12)), directly affects domestic R&D, which has dynamic spillover effects within the industry. Increased R&D also indirectly spurs the efficient use of R&D-based capital domestically and, thereby, generates both love of variety gains and increased capacity of firms to absorb technological progress from abroad. The second policy is export promotion of R&D-based capital goods (represented by α in eq. (11)). It is primarily motivated by the absorption externalities related to trading and, in particular, to exporting. It will encourage R&D activity indirectly

[18] Tests show that the growth dynamics and rates in the transition period are not sensitive to the year in which the growth is driven to zero. Appendix C elaborates more on these issues.

and have analogous R&D-related spillovers to the first policy. In addition, we briefly report results from a *general* export-promoting instrument used for all goods. This exercise is performed to de-emphasise the R&D effects and to cultivate the general absorption effects of export.[19] The policy instruments are dimensioned so that they involve the same discounted government expenditures. Each year, the governmental budgets are balanced by increased value added tax (VAT) rates. The balancing ensures public revenue neutrality, so we can compare welfare effects of the policy reforms.

The policy instruments are chosen because they directly target the modelled external effects in the growth processes: the standing on shoulders, love of variety, and absorption externalities. The policy instruments are, therefore, likely to promote social efficiency, measured as total welfare equal to the discounted utility of household consumption, as well as growth. While we do quantitatively compare their macroeconomic outcomes, we are more concerned with identifying the qualitative differences in how their welfare and growth impacts are channelled. By cultivating one instrument at a time, we will be able to distinguish between their externality-correcting effects and compare their effectiveness. The focus on qualitative aspects has generic relevance irrespective of the scaling of the policy measures and the particularities of countries.

In the presence of many channels and externalities, it is difficult to predict, *á priori*, the outcomes of policies. Thus, we use CGE model simulations to identify and quantify the effects on the innovation and absorption processes that simultaneously take place. We identify important interaction effects through other markets and imperfections in the economy. We focus on both transitional effects and the balanced growth path that is reached in the long run.

3.2 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.[20] Table 1 reports long-run effects. The effects are measured as percentage changes from a reference path that is described in more detail in appendix C. The direct effect of the R&D support is to shift marginal costs of R&D downwards. The marginal costs of R&D will perpetually shift downwards as a result of dynamic, positive spillover effects from the accumulated knowledge stock. Therefore, R&D increases gradually until the increase stabilises in the late part of the transitional path and remains 18.8 per cent above the reference path in the long run.

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[19] This policy shift involves increases in α as well as α_2; see eq. (11) as well as eq. (B.11) in appendix B.
[20] Our subsidy approximates a support of 250 € in annuity terms.

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	15.5	12.2
R&D/Production of patents	18.8	19.2
Patent shadow price	-7.5	-0.8
Production of R&D-based capital	6.9	10.5
- for export deliveries	6.3	11.4
- for home market deliveries	9.3	6.9
- for export per firm	-7.9	-0.7
- for home markets per firm	-5.3	-4.7
- home market price per unit	0.6	0.4
- home market price per effective unit	-6.1	-4.9
Absorbed productivity	-0.2	0.2
The traditional manufacturing industry		
Export	4.3	2.4
Absorbed productivity	2.1	1.7
Macroeconomic variables		
GDP	2.4	2.5
Average absorbed productivity	1.5	1.2
Wage rate	3.0	3.0
Export	4.2	4.5
Import	3.0	3.3
Consumption	0.7	0.8
Gross investment	2.9	2.1
Welfare**	0.7	0.9

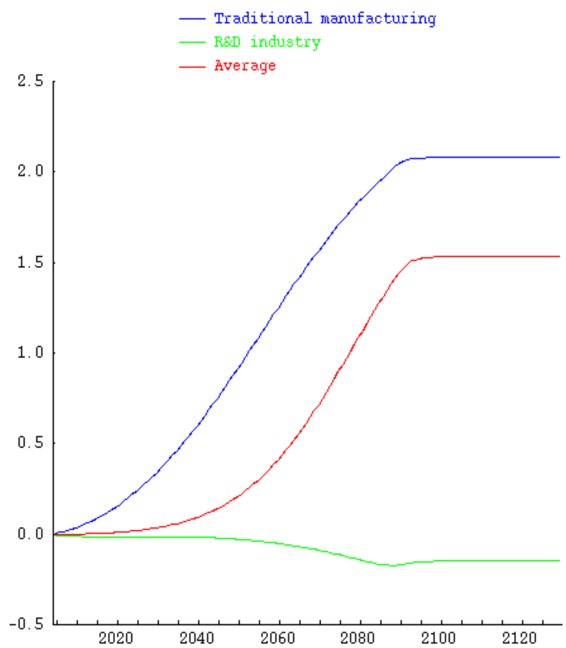
* constant ad valorem rate
** percentage change in discounted value

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. In the long run, the shadow price of patents has fallen by 7.5 per cent compared to the reference. Total deliveries of R&D-based capital increase gradually to 6.9 per cent above the reference in the long run, while the number of capital varieties increases by 15.5 per cent. The output of each variety falls because the demand for each variety shifts downwards when the number of varieties increases. The output of each variety is further downscaled in response to increased factor prices, as reflected by the long-run wage increase of 3.0 per cent.

The factor price increases reflect higher factor scarcity, which increases over time. 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.[21] 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 related to knowledge from abroad are strongest within the trade-intensive final goods industries and, in particular, the export-intensive ones, because the export engine is empirically the strongest. Absorption effects through export are self-enforcing: 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[22], face a gradual increase in their absorbed productivity level that ends up 2.1 per cent higher than in the reference in the long run. The two-way causality between productivity and export results in a long-run increase in the export from this industry of 4.3 per cent.

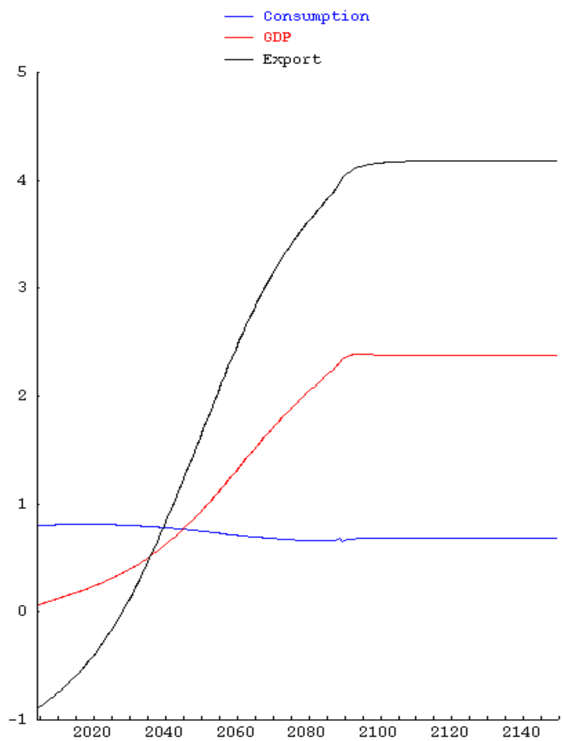
Figure 1. Absorbed productivity; percentage change from reference



[21] This is reflected in a long run fall in the capital price per efficiency unit of 6.1 per cent, despite a slight rise in the price of each variety of 0.6 per cent.
[22] This industry includes manufacturing of metals, industrial chemicals, pulp, and paper.

All other industries face less absorbed productivity effects than does the traditional manufacturing, and the average for the industries increases by 1.5 per cent in the long run. In the R&D industry, even a slight *reduction* of 0.2 per cent occurs in the long run because its share of export in total output of R&D-based capital goods falls. The percentage change from the reference in the absorbed productivity along the path for the traditional manufacturing and the R&D industry, along with the economy-wide average, is depicted in figure 1.

Figure 2. Macroeconomic development in the transition path; percentage change from reference



While the long run percentage changes in main macroeconomic variables are reported in table 1, figure 2 shows their development along the transitional path. The productivity gains of the R&D support translate into increased gross domestic product (GDP) over time (red curve). GDP stabilises at 2.4 per cent above the reference in the long run. Consumption (blue curve) is smoothed relatively evenly throughout the path; the long-run increase is 0.7 per cent. In the early part of the transitional period, where GDP is still relatively low, higher consumption is facilitated by reducing export (black curve). Later on, export gradually increases towards a long-run level 4.2 per cent above the reference to satisfy the non-Ponzi game condition that prevents debt from exploding. There will also be higher investment activity. Necessary reinvestments in the long run render the gross investment 2.9 per cent higher than in the reference.

Along the transitional path, the GDP growth rate increases compared to the reference path, and it is 0.04 percentage points higher than the reference in the last, and stable, part of the transitional period. Table 2 reports changes in key growth rates for this period.[23] The increase in the GDP growth partly reflects endogenous domestic technological progress. Higher R&D causes the growth rate of the R&D knowledge stock to increase by 0.14 percentage points. The higher GDP growth also reflects that absorbed productivity increases through the entire transition path. The absorption dynamics relies on the domestic innovation dynamics through the development of absorptive capacities of firms. The growth rate of absorbed productivity strengthens through time along with the increased home market deliveries of R&D-based capital, and stabilises at an average rate of 0.04 percentage points above the reference in the transitional path. The industrial effects vary significantly.

Table 2: R&D support: Growth rates of key variables in the transitional path, absolute deviation from reference

GDP	0.04
No. of firms/patents/varieties	0.14
Absorbed productivity	
Average	0.04
Traditional manufacturing industry	0.03
R&D industry	-0.00

Welfare rises by 0.8 per cent. The main contributions are the increased absorption in many industries as well as the productivity externalities from increased R&D both within R&D firms, which profit from knowledge spillovers, and final goods firms, which benefit from more capital varieties. On the other hand, reduced home market deliveries of R&D-based capital from each firm will, in isolation, contribute negatively to welfare; see table 1. The reason is that as the firms exhibit some market power, their production scales are sub-optimally low already, and reduced scales reinforce this market imperfection. Another negative contribution to welfare is related to various lenient indirect taxes and other favourable input cost terms, including relatively lower taxes on electricity, CO_2 emissions, and labour, as well as favourable energy contracts, which is enjoyed by the traditional manufacturing industry. Allocating additional resources to this

[23] The GDP growth rate in the reference path is depicted in figure C.1 in appendix C.

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industry, which is a result of the R&D support, has the isolated effect of accentuating the efficiency costs of the existing distortions.[24]

3.3 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 considered a relatively strong impetus for absorbing spillovers from abroad, it could still be strategic to promote export in small, open countries. Promoting sales of R&D-based products will be particularly promising because of the direct and absorptive capacity-induced productivity externalities. Therefore, our main export promotion alternative is directed towards R&D-based capital export, implemented as an export subsidy.

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 11.4 per cent in the long run; see table 1. This is approximately 80 per cent more than the increase in the R&D support 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 per cent, compared to a fall of 0.2 per cent, in the R&D support case.

However, the stronger absorption in the R&D industry comes at the expense of absorption in other industries. The export promotion of R&D-based capital results in a downscaling of the home market deliveries from the R&D industry compared with the R&D support case. Additionally, 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 12.2 per cent in the export promotion case, compared to 15.5 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 R&D support case.

In addition, productivity through absorption depends on foreign trade intensities. Because the export promotion scheme is biased towards one industry only, it crowds out other export from, for instance, traditional manufacturing, compared with the R&D support scheme. Total trade increases slightly more under the export promotion scheme than the R&D support scheme and causes trade intensities to rise on average. However, the stronger effect is seen for import

[24] The adverse welfare impacts of different aspects of the beneficial industrial policy arrangements enjoyed by this industry are analysed and quantified in previous studies; see Holmøy and Hægeland (1999), Bye and Nyborg (2003), Bjertnæs and Fæhn (2008), and Bye and Holmøy (2010). While these studies support inefficiencies caused by the distortions, we know that several coexisting, modelled distortions also affect the industrial pattern. There is, however, no evidence of counteracting distortions strong enough to suspect misallocation of resources the opposite way.

intensities, which have relatively weaker absorption effects. Further, the trade intensities tend to rise more within industries that simultaneously face weak growth in their absorptive capacity (R&D-based capital intensity). In sum, average absorbed productivity falls slightly compared with the R&D support case.

Less absorbed productivity contributes to reducing the welfare gain of export promotion compared to the R&D support alternative. As already mentioned, export promotion is also less stimulating for domestic innovation through less accumulated R&D knowledge. This also weakens the welfare performance of the export promotion instrument.

On the other hand, other existing distortions have less adverse welfare impacts in this policy alternative than in the direct R&D support case. Among the inefficiences that will be more effectively counteracted and, in isolation, yield larger welfare gains in the export promotion case than in the R&D support case are: *(i)* The modelled monopolistic competition in the domestic R&D-based capital market, which implies that a lower number of patents and R&D firms and, thus, larger supply scales within each firm, contributes to larger welfare. *(ii)* The sunk R&D investment costs, which imply that, as an isolated effect, social costs are saved when fewer patents and R&D costs back the sales from the R&D industry. *(iii)* The existing policy interventions in the traditional manufacturing industry, which means that efficiency is likely to improve when export and factor use of the traditional manufacturing industry decline. Though these price wedges are modelled and calibrated, our analyses are not able to compute their isolated welfare impacts and their part of the total welfare outcome.[25]

To sum up, export promotion fosters fewer productivity spillovers both from domestic R&D-driven innovation and from absorption from abroad than does the R&D support. However, there are positive contributions from counteracted distortions elsewhere in the economy, resulting in a marginally larger welfare improvement of the export promotion scheme than of the R&D support scheme (0.9 per cent vs. 0.7 per cent increase from the reference path). Among the positive contributions are less total R&D investment costs, increased scale effects within firms with mark-ups, and reduced activity within manufacturing industries facing favourable and nationally costly policies. The long-run GDP increases slightly more in the export promotion case than in the R&D support case; see table 1. As before, the consumption increase is smoothed along the path, and the level of consumption is slightly higher than in the R&D support case along the whole transitional path.

We have also simulated a third policy alternative, a *general* export-promoting instrument that favours all goods, not only R&D-based goods. This

[25] Indications on their strengths could be obtained by performing the same shift analyses on alternatively specified and calibrated models, but their mutual interaction effects and their interactions with other remaining distortions would still be difficult to grasp quantitatively.

instrument stimulates absorption through exporting, but does not target the absorptive capacity of firms. Besides being subject to heavy international regulations and of small policy relevance, our exercise shows that general export promotion of all goods is neither recommendable from the national point of view. As shown in table 3, welfare drops by 0.1 per cent compared to the reference. Long-run GDP falls by 0.4 per cent. A reduction of R&D (amounting to 2.6 per cent in the long run) contributes to less accumulated R&D knowledge, lower absorptive capacity, and lower trade than in the reference. On average, absorbed productivity falls.

Table 3. General export promotion; percentage deviations from the reference in the long run

R&D	-2.6
Accumulated R&D knowledge/no. of patents	-3.4
Average absorbed productivity	-0.3
GDP	-0.4
Export	-0.5
Import	-0.1
Welfare*	-0.1

* percentage change in discounted value

These results show that the absorption argument alone is not strong enough empirically to defend export promotion. Only if the trade instrument is designed to fuel domestic R&D will efficiency and welfare improve. Similar results are found in previous studies of import liberalisation in endogenous growth models with absorption through import (Diao et al., 1999; Ghosh, 2007). Despite the fact that import liberalisation potentially also generates welfare improvements through better exploitation of comparative advantages, this has proved far less efficient than R&D stimulating measures such as those studied in our main policy alternatives. Furthermore, the scope for liberalisation is small, as the Norwegian level of protection is generally low. We conclude that economic, as well as legal, arguments weigh against pursuing general trade policy instruments any further.

3.4 Sensitivity analyses

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, tested the sensitivity of our policy results to different strengths of the absorption elasticity; see table 4.[26] In the

[26] We have previously tested the model performance for variations in other central parameters. Bye et al. (2009) report results for the spillover parameter, s_I, in the R&D production function in

regime labelled *none*, the parameters λ_1 and λ_2 in eq. (3) are set to zero. This fully removes absorption endogeneities both through trade and absorptive capacity effects of R&D, and makes the productivity growth through cross-border learning exogenous. The main regime is denoted *moderate* in table 4, while a *strong* absorption regime is constructed by increasing λ_1 and λ_2 by 33 per cent.[27]

Table 4: Relative performance of export promotion vs. R&D support under different absorption regimes (per cent)

Strength of absorption effects:	none	moderate (main)	Strong
The R&D industry			
No. of firms/patents/varieties	-7.4	-2.9	-1.6
Export of R&D-based capital	-0.9	4.7	6.7
Home deliveries per firm	3.4	0.7	0.4
Absorbed productivity level	0	0.4	0.6
The traditional manufacturing industry			
Export	0.2	-1.8	-1.2
Absorbed productivity level	0	-0.4	-0.2
Macroeconomic variables			
GDP growth*	-0.01	0.00	0.01
Average absorbed productivity level	0	-0.3	-0.2
Welfare**	0.1	0.2	0.2

* absolute deviation from the R&D support case in the transitional path
** percentage change in discounted value from the R&D support case

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 support to export promotion implies less accumulated R&D knowledge. In the regimes with moderate and strong absorption, we also obtain a slightly lower 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, once again, positive effects more than offset these losses. These include a diversion of

eq. (7) and the mark-up factor, m_{Ki}, in the markets for R&D-based capital varieties; see eq. (10). The conclusions are that increases and decreases of these parameters have symmetric effects and that the sensitivities appear fairly similar irrespective of policy scenarios. This implies that welfare rankings among policy alternatives tend to be robust in this model within the tested parameter ranges.

[27] 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.

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/or 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.[28] 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. Along with this effect comes a more pronounced superiority of export promotion in terms of welfare when absorption effects are allowed.

4 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 of 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. In particular, we introduce a role for the export channel, which is novel when compared to earlier macroeconomic studies. The disaggregate approach also allows us to study industrial differences and variations with respect to trade, innovation, and growth prospects. 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.

We combine the modelling of innovation processes with the modelling of absorption within an empirical setting, where existing policies also affect the outcome. We particularly focus on the interplay between domestic innovation, spillovers of productivity growth from abroad, and public efforts to stimulate trade and innovation. The policy shifts performed in the analysis are chosen for their *á priori* ability to increase growth and welfare at realistic budgetary levels. Our study finds that promotion of R&D-based technology export performs

[28] Bye et al. (2009) is a comparable policy study within a setting without endogenous absorption effects.

slightly better than R&D support in terms of economic efficiency. R&D support is better fit for meeting the externalities related to domestic innovations and absorption. However, promoting R&D-based export yields more favourable interactions with existing inefficiencies. A general export promotion of *all* goods is found to deteriorate growth and welfare. It illustrates that it is not sufficient to target trade alone, without stimulating factors behind absorptive capacity and domestic innovation.

How the different policy alternatives qualitatively influence economic activities, growth, and welfare are of generic relevance irrespective of the scaling of the policy measures, the particularities of countries, and the quantitative outcome of this specific modelling exercise. While a first-best response to inefficiencies caused by initial policy interventions would be to remove the distortions, this is seldom feasible. One example is the widespread inclination of governments to preserve traditional industrial patterns at the expense of economic efficiency in both developed and developing economies. Advantages that have already been won are politically hard to withdraw. Our study indicates that a second-best option can be to support R&D-based industries that have larger efficiency potentials. However, even for innovative industries, it proves challenging to introduce export-promoting instruments within the limits of international competition rules. Our results suggest that direct R&D support is a good substitute in terms of its effects on economic efficiency and growth. Which scheme is the preferable is, of course, an empirical, country-specific question. In the case of Norway, the welfare superiority of export promotion over R&D support also holds when absorption effects are excluded, but becomes more pronounced when absorption effects are strong.

There are several other features that may be added to the model that are empirically significant and relevant from a growth- and welfare-enhancing policy perspective. In economies with significant price wedges in the labour/leisure choice, as in the Norwegian economy, labour supply responses to policies may have important welfare impacts that are left out of our model. It is also reasonable to expect different responses in wages and labour supplies among segments of labour, a feature that would be captured by combining endogenous labour supply with skill-specific labour groups. Skilled labour can be an important growth engine and is found to be a factor that is crucial for the economy's capacity to absorb knowledge from abroad; e.g., Griffith et al. (2004) and Aw et al. (2007) in the case of absorption through imports and exports, respectively. Accumulation of human capital and education policies will interact with innovation policies in ways that are crucial to understand to choose optimal growth promoting policies. Governmental R&D and its interlinkages with private R&D is another public policy field relevant for productivity growth and welfare that is left for future research.

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
Overseas Transport and Services to Oil and Gas Exploration
Crude Oil
Natural Gas
Pipeline Transport of Oil and Gas
Production of Electricity
Wholesale and Retail Trade
Public Sector

Appendix B 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 are 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 2, we disregard inputs of intermediate goods. In consumption i denotes good i and j denotes CES composite j. We include policy variables representing the studied growth policies in this presentation, but for simplicity, other policy variables in the CGE model 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) $$P^W=\frac{c}{\left(1+\alpha_2\right)s}\left(X^W\right)^{\frac{1-s}{s}}$$

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

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

(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.16) $$J^{KM}=\dot{K}^M+\mu^{KM}K^M$$

(B.17) $$P^{KM}=(r+\mu^{KM})P^{JM}-\dot{P}^{JM}$$

(B.18) $$J^{KV_i}=\dot{K}_i^V+\mu^{KV}K_i^V$$

(B.19) $$P^{KV_i} = (r + \mu^{KV})P^H_{K_i} - \dot{P}^H_{K_i}$$

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.20) $$R = R_{-1} + X_R$$

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

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

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

(B.1'') $$PV_{i0} = \int_0^\infty e^{-rt}\left(\pi_{it} - P^K_t K_{it}\right)dt - P_{R0} + P^J_0 K_{i0}$$

(B.3'') $$\left[\left(X^H_{Ki}\right)^\rho + \left(X^W_{Ki}\right)^\rho\right]^{1/\rho} = \left[f\left(L_i\tau, K^M_i\tau\right)\right]^s$$

(B.8'') $$C_i = c\left[\left(X^W_{Ki}\right)^{1/s} + \left(X^H_{Ki}\right)^{1/s}\right]$$

(B.9'') $$\bar{\pi}_i = P^H_{Ki}\left(X^H_{Ki}\right)X^H_{Ki} - c\cdot\left(X^H_{Ki}\right)^{1/s} + P^W_K(1+\alpha_3)X^W_{Ki} - c\cdot\left(X^W_{Ki}\right)^{1/s}$$

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

(B.21) $$\varepsilon_{Ki} = -\frac{\partial X^H_{Ki}}{\partial P^H_{Ki}}\frac{P^H_{Ki}}{X^H_{Ki}}$$

(B.22) $$m_{Ki} = \frac{\varepsilon_{Ki}}{\varepsilon_{Ki} - 1} = \frac{\sigma_{KV}}{\sigma_{KV} - 1}$$

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

(B.23) $$(1+\beta)P_{R0} = \int_0^\infty e^{-rt}(\overline{\pi}_t)dt$$

B.3 Consumer behaviour

(B.24) $$U_0 = \int_0^\infty u(d_t)e^{-\theta t}dt$$

(B.25) $$u(d_t) = \frac{\sigma_d}{\sigma_d - 1} d^{\left(\frac{\sigma_d - 1}{\sigma_d}\right)}$$

(B.26) $$W_0 = \int_0^\infty P_t^D d_t e^{-rt} dt$$

(B.27) $$d_t = \left[\mu \cdot P_t^D\right]^{-\sigma_d}$$

(B.28) $$D_t = d_t(1+n)^t$$

(B.29) $$D_{it} = \omega_{i.0}\left(\frac{P_{jt}^D}{P_{it}^D}\right)^{\sigma_j} \frac{VD_{jt}}{P_{jt}^D}$$

(B.30) $$P_i^D = \left((1-\upsilon_i)(P_i^H)^{(1-\sigma_{HI})} + \upsilon_i(P_i^I)^{(1-\sigma_{HI})}\right)^{\frac{1}{1-\sigma_{HI}}}$$

(B.31) $$\frac{D_{t+1}}{D_t} = (1+n)(1+g)$$

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 output of the final good firm
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	Composite of R&D-based capital
K^M	Other ordinary capital
J^{KM}	Gross investment, other ordinary capital
P^{JM}	Price of investment good, other ordinary capital
P^{KM}	User cost of capital, 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
P_R	Shadow price of patents
K_i^V	R&D-based capital variety *i*
P_i^{KV}	User cost of R&D-based capital variety *i*
J^{KV_i}	Gross investment, R&D-based capital variety *i*
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_i^D	Price of 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
VF	Composite of variable input factors

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
β	R&D subsidy	scenario-specific
α_2	General subsidy to final goods export deliveries	scenario-specific
α	Subsidy to export deliveries of R&D-based capital	scenario-specific
μ^{KV}	Depreciation rate, R&D-based capital	good and user-specific
μ^{KM}	Depreciation rate, other ordinary capital	good and user-specific

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 figure B.1 in appendix B, 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 in the domestic price of R&D-based capital varieties.[29]

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 to avoid unrealistic industrial specialisation patterns.[30] 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 to be equal to 4. The elasticity of scale related to previous knowledge is equal to 0.5 to ensure decreasing spillover effects of the knowledge base, supported by both theoretical and empirical findings (see Jones, 1995; 1999; Leahy and Neary, 1999).

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[29] 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 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.

[30] 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.

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

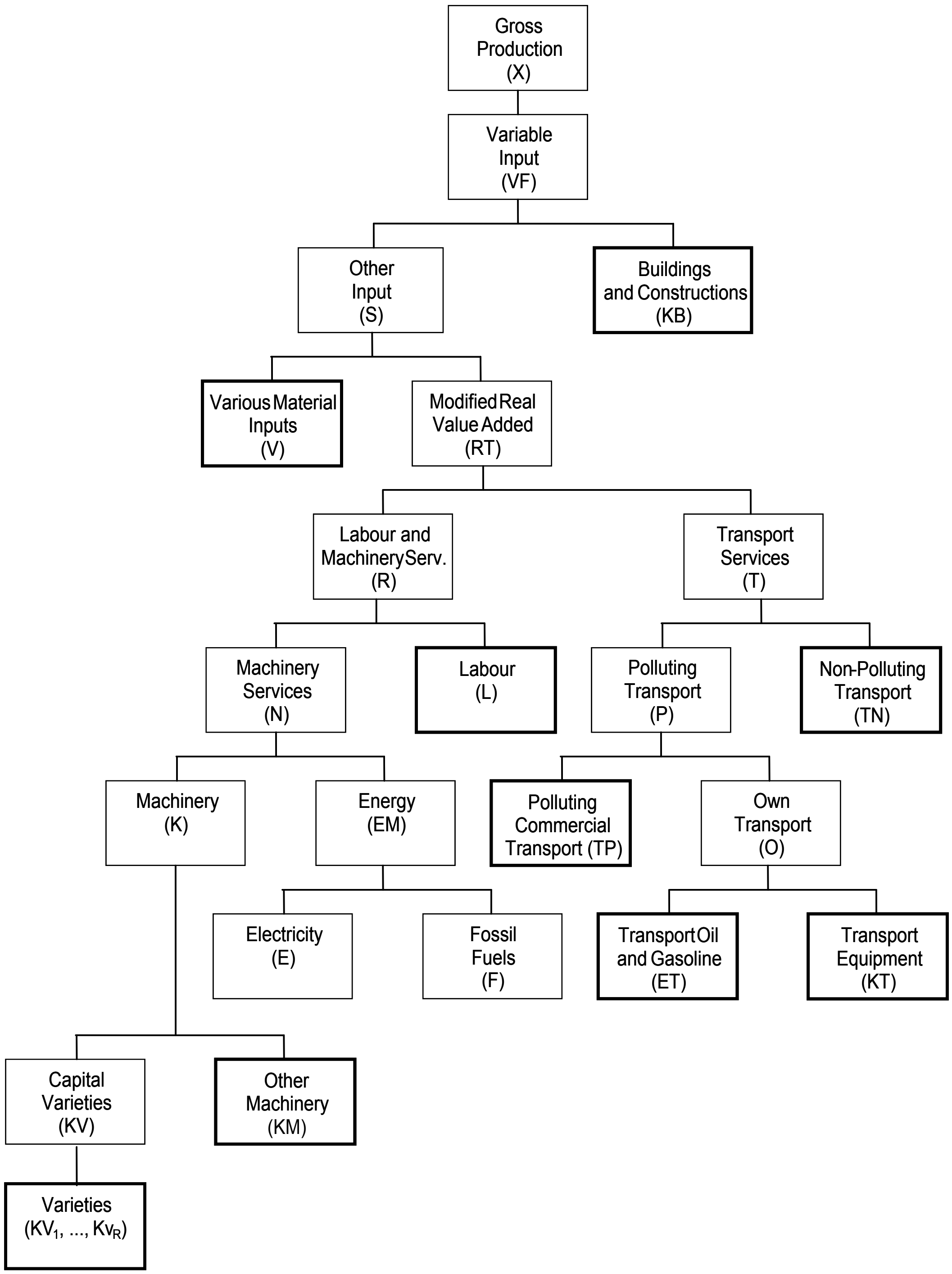
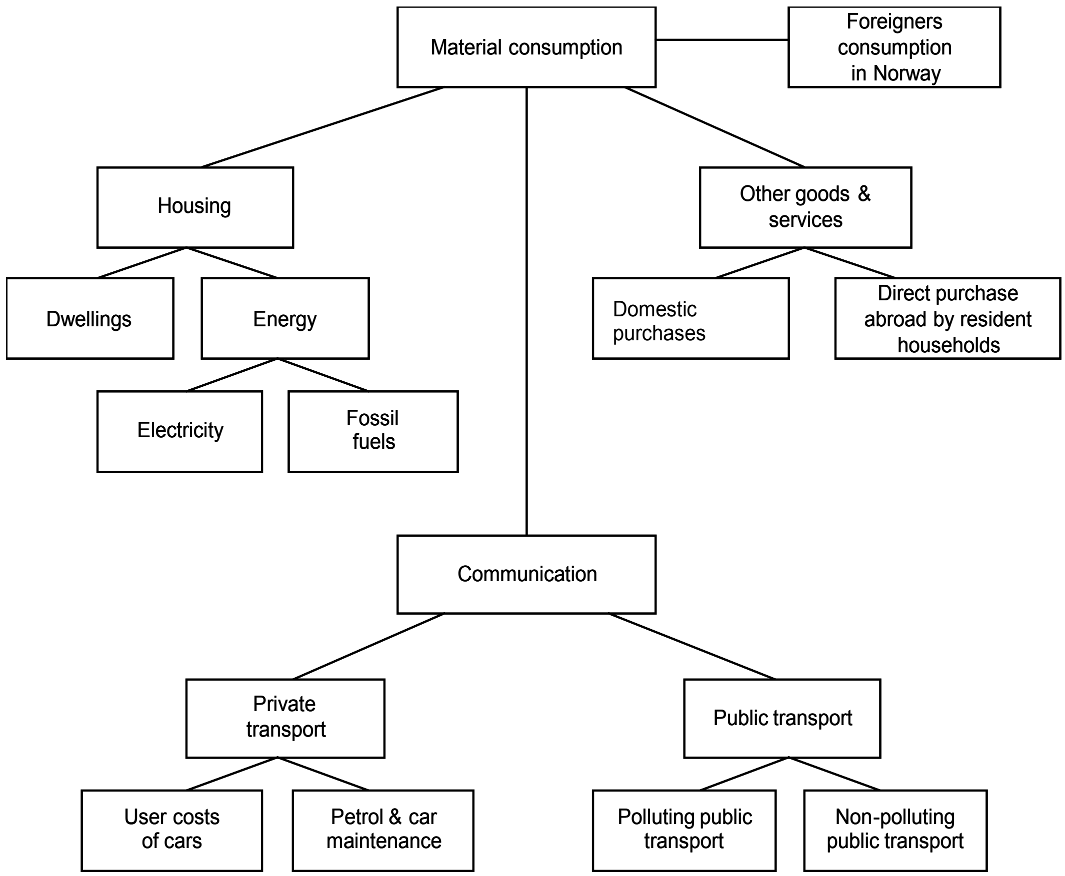


Figure B.2. The nested structure of consumption activities



Appendix C The reference path: calibration and growth dynamics

The model is calibrated to the 2002 Norwegian National Accounts. In the transition path, 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 reference 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. Exogenous activities, such as public consumption and output, mostly follow Norwegian Ministry of Finance (2004). The exogenous levels of offshore investments and oil and gas export result from a smoothing of their expected present values in Norwegian Ministry of Finance (2004). 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 by 1.4 per cent annually. This is in the lower range of exogenous price growth estimates in Norwegian Ministry of Finance (2004) 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.

In Norwegian Ministry of Finance (2004), total factor productivity (TFP) growth rates are entirely exogenous and valued at, on average, 1 per cent annually. Our model distinguishes between exogenous and endogenous components. In line with empirical findings, e.g., Coe and Helpman (1995) and Keller (2004), we calibrate 5 per cent of the domestic growth to stem from domestic innovation in the part of the transitional reference path where a stable growth period is obtained, i.e., 60–80 years from now. [31] The assumed 5 per cent growth resulting from domestic innovation 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 eq. (3). As the econometric material is still relatively

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

scarce, the parameterisation is tested by sensitivity analyses. Based on estimations for Norwegian industries, we set the parameter determining the absorption through the import channel, λ_2, to 0.075 (Grünfeld, 2002). This is also fairly in line with Griffith et al. (2004). The historical import channel impact in Coe and Helpman (1995) is also in the range of our estimate for λ_2, when we take into account that they have not specified the influence of absorptive capacity. We do not represent the relative gap from the international technology frontier explicitly as in Griffith et al. (2004), but as in Grünfeld (2002) we assume a decreasing effect of domestic absorptive capacity to account for effects of approaching the frontier. We ensure this by specifying the Ω-functions in eq. (6).

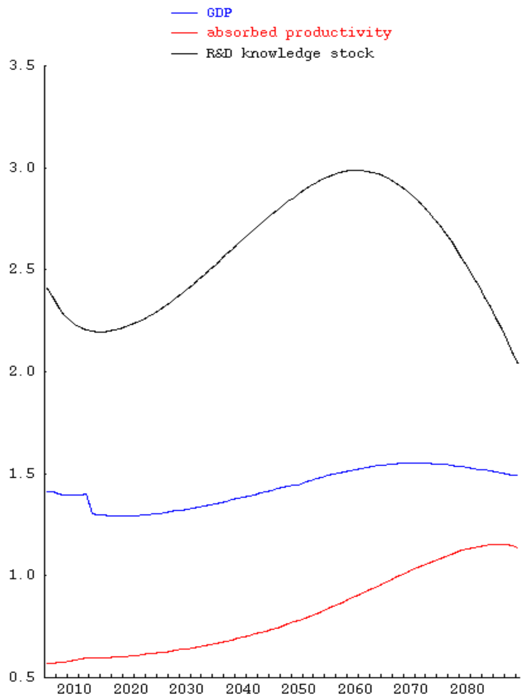
Our main sources with respect to export effects are Alvarez and Lopez (2006), Delgado et al. (2002), and Baldwin and Gu (2003). Based on these, we assume export as a more effective channel for spillovers than import.[32] We include absorptive capacity effects in the export term, too, and use a λ_1- parameter of 0.15, which is a doubling compared to the parameter for the import channel.

In addition to effects from import and export, the absorbed productivity equation, eq. (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), as 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 TFP growth arrives at levels comparable with the projections in Norwegian Ministry of Finance (2004). In the last part of the transition path, i.e., 60–80 years from now, the stable GDP growth rate of the reference amounts to 1.6 per cent annually. For technical reasons we have set all exogenous and endogenous growth drivers to zero in the far future (after about 100 years) to ensure that a balanced growth path is reached within a limited number of periods. Sensitivity tests show that the relative effects of the different policy analyses appear independent of this timing, as do the growth rates within the stable part of the transition period. Only the durability of the stable period is affected.

The growth rate of GDP is fairly stable between 1.3 and 1.6 per cent in the transition period, before it descends to zero in the long run. Figure C.1 shows the GDP growth in the transitional part of the reference path and the two fundamental growth drivers: growth in accumulated R&D knowledge and growth in the average absorbed productivity level across borders.

[32] There also exist empirical findings of the opposite relationship, as in Falvey et al. (2004).

Figure C.1. GDP growth and growth drivers in the transitional part of the reference scenario (per cent)



In the first part of the transition period, the growth in the R&D knowledge stock descends slightly because the standing on shoulders effect from a relatively modest R&D knowledge stock is weak, and R&D activity, therefore, increases slowly. As the knowledge stock is enlarged, its growth rate starts increasing until the diminishing returns dominate and pull the growth rate downwards. In the long run, it will reach zero.

The increasing growth rate of the average absorbed productivity level is a result of rising absorptive capacity brought along by increased *effective* input of R&D-based capital. Diminishing absorptive capacity effects ($\Omega''<0$ in eq. (6)) counteract this effect, but not sufficiently during the transition period to cause decreasing absorption growth on average. Only in the very long run will absorption growth decline and eventually reach zero because of both convergence and stabilised R&D activity. The growth in the average absorbed productivity level hides large differences among industries. A substantial part of the economy has little trade and/or uses little R&D-based capital, and its TFP growth is predominantly exogenous and constant. The average absorption dynamics shown in Figure C.1 is driven by a few exposed and R&D-intensive manufacturing industries, especially traditional manufacturing.

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