Openness, Growth and R&D Spillovers: Uncovering the Missing Link?*

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Short version, prepared for the third annual conference on Global Economic Analysis
Melbourne, Australia, June 27-30, 2000.

Abstract

Research and development (R&D) raises not only the own technology levels, but also that in other sectors and abroad. We examine the trade-related diffusion of R&D in three steps. First, using OECD and UNESCO data we provide an overview of global R&D expenditures. Second, we estimate the relation between sectoral R&D expenditures and growth. Finally, these R&D linkages are incorporated in WorldScan: a dynamic applied general equilibrium model for the world economy. We simulate trade liberalisation and analyse the effects on GDP in different regions. We find that the GDP effects of trade liberalisation are magnified considerably for some regions - - notably Japan and South-East Asia - - where for others - - for example China and Sub-Saharan Africa - - the GDP effects are not blown up at all. These findings can be traced back to changing specialization patterns and changing import patterns. A region either specialises in R&D-intensive sectors or imports R&D-intensive goods. Some regions import the knowledge-intensive goods from knowledge-poor regions. Such a 'double unfortunate' trade and production pattern explains the results for Sub-Saharan Africa and China.

Keywords: R&D, spillovers, trade liberalisation, AGE models

* Suggestions by Hans Timmer considerably improved the paper. The authors acknowledge Henri de Groot and Theo van de Klundert for stimulating discussions and comments on an earlier version. Nico van Leeuwen is acknowledged for research assistance.

1 Introduction

Are countries with lower barriers to trade experiencing more economic progress? Trade economists typically answer this question affirmative despite the fact that neo-classical trade theory predicts that lower barriers to trade will lead to higher levels of welfare only (as long as a country is small). The Solow growth theory predicts no link between trade barriers and growth whatsoever. Only in the transition phase openness might have an effect on growth. Models of endogenous growth provide the ‘missing link’ between openness and growth.[1] Openness has growth effects via knowledge spillovers related to openness that affect the productivity of research or production, or reduce duplicationary research effort. Openness can also allow to benefit from specialisation (or scale) opportunities in research or generate a market-size effect.[2]

Coe and Helpman (1995) have quantified directly the relation between technological change, openness and research expenditures within the OECD. They have shown that R&D is not only beneficial for the performing countries but also for their trade partners.[3]

This paper integrates the empirical results and the theory in an Applied General Equilibrium (further AGE) model. We examine the importance of R&D and R&D spillovers in quantifying the effects of trade liberalisation.[4] We do so in two steps. First, we estimate an equation related to Coe and Helpman (1995). The results are subsequently implemented in WorldScan, an AGE model for the world economy with considerable sectoral detail. Finally, the consequences of trade liberalisation are considered.

Closely related is the work by Bayoumi, Coe and Helpman (1999, further BCH) who implement the estimated equation of Coe and Helpman (1995) in the dynamic multicountry model of the IMF (MULTIMOD). They show that a trade expansion by developing countries of 5% of their GDP raises their output by 6.5%-points in 2075.[5]

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[1] That such a link exists is partly based on casual observations about the effect of an isolationalist policy on technological sophistication and partly on empirical work, by, for example, Sachs and Warner (1995). The empirical relation is, however, controversial. See Rodriguez and Rodrik (1999).

[2] Grossman and Helpman (1991) discuss the effects on research productivity and the reduction of duplicationary research. See Romer and Rivera-Batiz (1991) for the scale effect in research. The market-size effect is discussed in Acemoglu (1998).

[3] How important trade partners are is still open to debate. Lichtenberg and Pottelsberghe de la Potterie (1998) argue that FDI flows matter.

[4] Numerical estimates in AGE modelling have shown consistently low welfare increases by trade liberalisation in case the models where of the static CRS type.

[5] There exist, to our knowledge, few other studies that perform similar exercises. Exceptions are Van Meijl and Van Tongeren (1999), who propose an absorption-capacity based spillover measure and test the numerical consequences of that by bringing the spillover measure to the GTAP data and model. Rutherford and Tarr (1998) develop an R&D based CGE model for the small-open economy. Their model, however, remains highly stylized and is only simulated. We add to these contributions by estimating the relations present in the data and implementing them in a calibrated model that is able to generate transition dynamics.

The analysis in this paper adds to BCH's paper in several respects. First, given that we have sectoral detail in the model we can distinguish intra-regional spillovers alongside inter-regional spillovers. Second, we collect and incorporate R&D data for non-OECD regions whereas BCH's assumptions imply that these regions do not perform any R&D till 2075. Third, to highlight the role for trade as a vehicle for R&D spillovers we perform a different exercise as BCH. We argue that a relevant policy shock is to reduce existing trade barriers over time, whereas BCH increase imports and exports of manufactures by 5%-points. These differences in the approaches immediately allow us to pin down the points this paper makes.

First, we show that trade-related R&D spillovers not *necessarily* magnify the effects of trade liberalisation. This is related to our different perspective on the relevant trade-liberalisation experiment. We introduce trade liberalisation starting from the trade barriers in the data. This implies that the relative prices of the regional varieties are affected by trade liberalisation. This may redirect trade flows and thereby affect the 'imported' knowledge flows. This results (for some regions) in very low benefits from international spillovers as they import less knowledge-intensive products. The BCH experiment veiled this as they increased the import intensity in a neutral way.

The second point this paper makes is that it is crucial to distinguish intra-national spillovers alongside international spillovers as it brings to the fore the trade-off between the two. This point is easily understood once the trivial observation, that goods that are imported are not produced domestically, is recognized. Note that a large market induces more R&D. Hence, increased 'imported' international spillovers come at a cost of domestically generated knowledge (which might be important for intra-national spillovers).[6] Hence, trade liberalisation might cause regions to specialize in sectors that have low growth potential.

The rest of this paper is organized as follows. In Section 2 we discuss our empirical model. The estimation results for this model are presented in Section 3. This section also contains a discussion of the data. Section 4 presents WorldScan, the AGE model. Section 5 presents our main results. Section 6 concludes.

2 The empirical model

There is a substantial literature, both theoretical and empirical, that relates R&D expenditures to productivity growth. The view that technological progress benefits not only from R&D performed within the sector but also from R&D performed 'elsewhere' is also well established (see Nadiri, 1993, for an overview of the literature). More recently, inspired by endogenous growth theory, the link between

[6] For this point it is crucial that knowledge spillovers are tied to imports. As such, nothing precludes spillovers related to exports (learning by competition on the international market); here we choose, however, to follow the lines set out in the theory and empirical work discussed above.

productivity and R&D performed in other countries has been emphasised in empirical work.[7] This section sets out a model to re-examine these intra- and international spillovers.

We start with the following reduced form equation between total factor productivity (denoted as F) and R&D (industries are denoted by i ($i \in \{1,...I\}$) and regions by k ($k \in \{1,...K\}$))

$$\hat{F}_{ikt} = c + \gamma^{DD} \hat{R}^{D}_{ikt} \tag{1}$$

where a constant c captures the unexplained exogenous growth trend. An error term is added. The Rs denote weighted knowledge stocks (that are a function of R&D expenditures). The superscripts to the Rs have the following meaning: DD is Direct (same sector) Domestic and ID Indirect (other sectors) Domestic. The superscript F should be read as Foreign. A hat over a variable denotes a growth rate. Note that we assume competitive markets and a production technologies with constant returns to scale in labour and capital[8].

The construction of our knowledge stocks, R^{DD}, R^{ID}, R^{F}, requires some discussion. We need to distinguish statistical aggregation from economic integration; the former is a statistical fallacy whereas the latter is the real phenomenon we are interested in. We follow Grossman and Helpman (1991) in the logic that research productivity and thus productivity growth depends on the knowledge stock available for R&D.[9] Therefore, knowledge stocks are weighted *sums* of other sectors' and countries' R&D-capital stocks.

$$R^{ID}_{ik} = \sum_{j \neq i}^{I} \omega_{jik} R_{j} \tag{2}$$

where ω and n denote the IO-coefficient and the sectoral bilateral trade flow. Thus both changes in the weights and changes in the different R&D-capital stocks affect the knowledge-stock construct. This preferred theoretical specification suffers from two problems when used in applied work. First, it suffers from an aggregation bias. That is, this construct is very sensitive to statistical aggregation of countries (see Lichtenberg and Pottelsberghe de la Potterie, 1998, and Jacobs *et al.*, 1999).[10] We solve this problem

[7] See Grossman and Helpman (1991) for a thorough theoretical analysis of these issues.

[8] Note, for later reference, that the assumption of a production function that is homogeneous of degree one implies that TFP is homogenous of degree zero, hence independent of the scale of the economy.

[9] The assumption is that importing from a knowledge-rich country positively affects the knowledge stock for R&D.

[10] Assume a world with three countries, white domestic R&D capital stocks (R) for countries 2 and 3: $R_2 = 10$, $R_3 = 20$. Then, if country 1 imports 10 from country 2 and 10 from country 3, its foreign R&D capital stock (R^F) should be calculated as follows, assume the weights sum to unity: $R^F = \frac{10}{20} 10 + \frac{10}{20} 20 = 15$. If we assume that countries 2 and 3 merge into one single country, the foreign R&D

by allowing the spillover coefficients to differ for different spillover sources. The limitations of the data do, however, not allow to estimate the numerous different parameters. We use, as an identifying assumption, that spillovers are related to the size of the country. Hence, though we use the theory in the AGE model, we estimate equation (3) as follows:

$$\hat{R}_{ik}^{DD} = \hat{R}_{ik} \quad 1 \tag{3}$$

which is an approach that is largely insensitive to aggregation as it avoids weighting the growth rates of large countries or large delivering sectors heavily.[11] The adjustment of the weights can thus be interpreted as that we allow the γ_s to be specific for every sector and region.[12] The second problem is that we use a subset of countries to obtain data for our regions containing more countries. Therefore, we choose to approximate our R&D stocks by R&D intensities. R&D intensities are defined as the R&D expenditures divided by value added.

$$\hat{R}_{ik}^{DD} = \frac{Y_{ik}}{R_{ik}} \frac{RD_{ik}}{Y_{ik}} \tag{4}$$

We write our estimating equation (equation (1)) as:

$$\hat{F}_{ikt} = c + \beta^{DD} \frac{RL}{Y_i} \tag{5}$$

The results we report on in the next section are based on this expression.

Three integration or scale effects can be distinguished. First, a change in the knowledge stocks over time, now approximated by the R&D intensities that vary over time. This effect we capture in (5).

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capital stock of country 1 becomes (with the same trade flows as before): $R^{F} = \frac{20}{20} 30 = 30$ which is twice as large as the foreign R&D capital stock estimated from two distinct countries. That is, the foreign capital stock suffers from an aggregation bias. This example is taken directly from Lichtenberg and Pottelsberghe de la Potterie (1996).

[11] The theoretically correct approximation of the domestic and foreign spillover stock looks like:

$$\hat{R}_{ik}^{ID} = \sum_{j \neq i}^{I} \frac{\omega_{jik} R_{jk}}{\sum_{h \neq i}^{I} \omega_{hik} R_{hk}} \hat{R}_{jk} \qquad \hat{R}_{ik}^{F} = \sum_{l \neq k}^{K} \sum_{j}^{I} \frac{n_{jilk} R_{jk}}{\sum_{m \neq k}^{K} \sum_{h}^{I} n_{himk} R_{hm}} \hat{R}_{jk}$$

Here one clearly sees the weights that cause the aggregation bias.

[12] This is exactly how we implement the estimated equation in the model.

Second, a change in the weight matrix affects the spillover construct. Now this is only the case if R&D investments are positive whereas in a specification with R&D stocks, integration-induced changes in the weights would affect the R&D construct directly.[13] Related is that by using R&D intensities (equation (5)) instead of an equation based on properly weighted levels integrating a country with an average R&D intensity in the global economy has no effect on the R&D construct. Third, we introduce another effect of global integration that is easily clarified by discussing the weighting coefficients, ω and *n*. We use the following definitions:

$$\omega_{ijkt} = \frac{U^{D}_{ijkt}}{Y^{G}_{ikt}} \qquad n_{ij} \tag{6}$$

where *U* indicates intermediate-input use (superscripts *D* and *M* stand for domestic and imported) and Y^G denotes gross production. Hence, integrating a formerly isolated country, with an average R&D intensity, in the global economy will affect the knowledge spillover *if* the import quote, approximated by the imported use over gross production, goes up. This interpretation closely follows a returns to variety production function (see De Groot and Nahuis, 1998). Hence, if the intermediate inputs of an economy are useful, spillovers increase.

To summarise, the measure proposed here is largely insensitive to statistical integration of two countries but allows economic integration to affect the growth potential in several important ways.[14]

3 Data and estimation

In this section we present the data that are used in the estimation procedure and the model. First, we have constructed the dependent variable, TFP. It is based on OECD data. Lejour and Nahuis (2000) discuss the details. In this section, we describe R&D intensities for OECD and non-OECD regions and we present estimation results for the specification discussed above.

R&D intensities

The size and importance of R&D spillovers between countries and industries depends to a large extent on the knowledge stocks in the different sectors and countries. First, this section describes the observed R&D intensities. Second, we discuss the construction of the sectoral and regional business-enterprise R&D intensities in WorldScan.

The ANBERD data base of the OECD (1999a) provides the value of R&D expenditures for

[13] In the estimations we do not have time-series variation in the weights.

[14] The insensitivity to statistical integration is important as the division of countries over the regions in our AGE model is not motivated by considerations of knowledge spillovers.

business enterprises of 15 OECD countries from 1973 to 1997 at a sectoral level according to the ISIC2 classification. The data are highly disaggregated for the manufacturing sectors but not at all for services. Moreover, for most countries no data for Agriculture and Mining (Raw Materials) are included. The ANBERD data base contains a risidual (total, minus R&D in manufacturing and services) which has to be split up between Agriculture and Mining.[15]

We combined the ANBERD data with the ISDB data (OECD, 1999b) to derive R&D intensities per sector for the various countries. The latter database provides value added data at a sectoral level. This enables us to derive R&D intensities per sector and country. Table 3.1 reports these for the four OECD regions in WorldScan. In order to derive the sectoral business enterprise R&D intensities for the OECD regions in WorldScan, we simply aggregate the country data to WorldScan sectors and regions. We assume that the underlying country data (see Lejour and Nahuis (2000) Table A.2) are representative for the relevant WorldScan regions.[16]

Table 3.1 Sectoral R&D intensities in WorldScan for the OECD as ratio of sectoral value added (1990)

sectoral R&D intensities	Agriculture	Raw Materials	Consumer Goods	Energy -int. Goods	Capital Goods	Services	average
Western Europe	0.62	0.96	0.59	4.49	9.39	0.23	1.81
United States	0.53	0.53	1.11	5.23	15.22	0.53	2.21
Japan	0.10	2.65	1.16	8.10	10.64	0.12	-2.25
Pacific OECD	0.18	0.46	0.61	2.42	7.07	0.41	1.00
Average OECD	0.45	0.68	0.92	5.34	11.84	0.36	2.05

Source: OECD (1999a, 1999b) and own calculations.

In general, the R&D intensities in the sectors Raw Materials and Agriculture are higher than in Services, but lower than in Manufacturing. The variation within Manufacturing is interesting. The R&D intensities in Energy-intensive Goods and Capital Goods are very high, while they are relatively low in Consumer Goods. The latter consists of sub sectors like Wood, Food and Tobacco, Textiles and Paper which are R&D extensive sectors. The sector Energy-intensive Goods is R&D intensive because of the sub sector Chemicals, Rubbers and Plastics is included. The R&D intensity of other sub sectors like Stone and Clay and Basic Metals is lower. The sector Capital Goods consists only of Fabricated Metal products, which is very R&D intensive.

If we compare the regions, we see that the United States and Japan carry out most of the R&D

[15] For the US, Agriculture and Mining is included in Services. We assume that the R&D intensity is equal in these three sectors in the US. More details are provided in Appendix A.

[16] With respect to the sectoral aggregation we assume that the sectors Services and Trade and Transport have the same R&D intensity which is approximated by the R&D intensity of services in the OECD data. For the manufacturing sectors we aggregate the sectors S3100, S3200, S3300 and S3900 to the sector Consumer Goods. The sector Capital Goods is simply S3800, while the sector Energy-intensive Goods consists of the other desaggregated manufacturing sectors, S3400 to S3700 and S3900.

while Pacific OECD is lagging behind. The United States carries out relatively much R&D in Capital Goods, Consumer Goods and Services, while Japan is active in Energy-intensive Goods and Raw Materials. Western Europe carries out a lot of R&D in Agriculture.

UNESCO (1999) provides, for about 100 countries, the expenditures on R&D as ratio of Gross National Product for several years in the 80s and 90s. For the industrial countries these have sometimes a time-series dimension; for most other countries data are limited to a few years. The coverage, however is wide. The R&D intensities vary widely among the countries. In general these intensities are much lower for developing countries than for the industrial countries. Table 3.2 presents the results for the non-OECD WorldScan regions. R&D in the most developed region, South-East Asia, is the highest.[17]

Table 3.2 R&D intensities for the non-OECD regions in 1995

R&D intensity	total R&D[2]	share BE[1]	BE R&D[2]
Eastern Europe	0.90	47.1	0.42
Former Soviet Union	0.73	67.1	0.49
Latin America	0.55	29.5	0.16
Middle East	0.76	41.6	0.32
Sub-Saharan Africa	0.61	52.7	0.32
China	0.61	31.9	0.19
South-East Asia	1.33	70.0	0.93
South Asia & Rest	0.69	26.5	0.18

Source: UNESCO (1998, 1999).

[1]BE = business-enterprise R&D (as a share of total R&D)

[2] as ratio of GNP

For some regions the coverage is limited to a few countries, such as Sub-Saharan Africa (only South Africa) and Middle East (only Turkey and Israel). The coverage for Former Soviet Union and Eastern Europe, China, South Asia & Rest and South-East Asia is fairly good. The business-enterprise R&D intensities vary more widely than those of total R&D. The numbers on the share of business-enterprise R&D reinforce the differences; see for example the effects on China and South-East Asia.

Empirical findings

This section presents the main empirical findings. The model in equation (5) is estimated for all sectors WorldScan distinguishes. Lejour and Nahuis (2000) present robustness analysis and results for the manufacturing sectors only. The results presented in this section will be made operational in the AGE

[17] For our purposes we face two problems. First, the data include all expenditures on R&D, not only business enterprise. Second, the data do not include a sectoral division. The first problem is solved by using Table 5.6 from UNESCO (1998). This statistical yearbook provides information on the R&D expenditures by sector of performance. We interpret the productive sector in this table as business enterprises. The second problem is solved by using the average OECD relative R&D intensities also for the non-OECD regions. These relative intensities are multiplied by the business enterprise R&D ratio in Table 3.2.

model in the next section.

One remark should be made beforehand. Our regression analysis has only two aims. First, we want to establish that the relations, found in the literature,[18] can also be traced at the aggregation level of WorldScan. Second, the estimates should provide parameters for the AGE model we employ in the next section.

Table 3.3 OLS estimation results for equation (7). Dependent variable is ($T\hat{F}P$).†

Variable	*(I) Direct effect*	*(II) Direct + indirect effect*	*(III) Domestic and Total*
DD	.216***	.205***	.167**
	[.069]	[.069]	[.074]
ID		2.112**	2.636**
		[.966]	[1.041]
TF			0.618
			[.457]
R^2 (adjusted)	0.02	0.03	0.03
N	432	432	432

† Sample period is 1973-1991, 6 sectors and 4 regions. All regressions include a constant. The explanatory variables are lagged by one year. Standard errors are given in parentheses under the estimates. *, **, and *** denote statistical significance at the 10% level, the 5% level, and the 1% level, respectively.

Table 3.3 presents the regression results based on equation (5). First, we include the own R&D stocks. We find a significant rate of return for the own within-sector R&D stock. Inclusion of the indirect domestic R&D stock in column (II) supports the hypotheses that within-region R&D spillovers exist. The estimated coefficient for the indirect effect is relatively high, because we use weighting matrices of which the columns do not add up to unity. Inclusion of the foreign spillover variable in column (III) yields an estimate for our foreign R&D construct of 0.6. The estimate is not very precise, however. The inclusion does not substantially affect the coefficients for the domestic variables. This regression is our major input for the modelling exercise in the next section.

4 WorldScan and R&D

WorldScan has been developed to construct scenarios. WorldScan relies on the neoclassical *theories of growth and international trade*.[19] The standard neoclassical *theory of growth* distinguishes three factors to explain changes in production: physical capital, labour, and technology. WorldScan augments the

[18] For that aim it is problematic that we reduce the variation in the data considerably by aggregation of the data to our desired sectoral and regional level. The relations we establish are confirmed by work of Coe and Helpman (1995), Park (1995), Keller (1997) and Verspagen (1997b).

[19] An Armington trade specification amends the neo-classical trade theory. This is to explain two-way trade and to allow for market power to determine trade patterns in the medium run, while allowing for Heckscher-Ohlin mechanisms in the long run

simple growth model in three ways. First, WorldScan allows overall technology to differ across countries. Second, the model distinguishes two types of labour: high-skilled and low-skilled labour. Sectors differ according to the intensity with which they use high-skilled and low-skilled labour. Countries can raise per capita growth by schooling and training the labour force. Third, in developing countries part of the labour force works in a low-productivity, informal sector. In this sector workers do not have access to capital and technology. Reallocation of labour from the low-productivity sector to the high-productivity sectors enables countries to raise per capita growth as well.

The simulations in Section 5 are variations on the so-called Globalisation scenario.[20] The idea behind the scenario is that when developing countries grow fast or start to grow rapidly, the linkages between the OECD and the non-OECD countries intensify. Fast development outside the OECD area and liberalisation of capital, goods and service markets produce closer economic integration of rich and poor countries. More generally, the scenario extrapolates and probably exaggerates the current globalisation tendencies. We take it as point of departure because it stresses that linkages between developed and developing regions can become stronger and spillovers between these regions can become larger.

The Globalisation scenario is optimistic about future economic progress in both developed and developing regions. In this scenario many poor countries catch up, though not completely, with rich countries. Non-OECD countries grow at a per-capita rate of about 4%. Only few countries have been able to maintain such a growth rate for two decades or more. In the scenario, trade liberalisation is not confined to trade blocs, but applies globally. The OECD countries open up their markets further. Whereas barriers to trade in manufacturing goods are already low, agriculture is still heavily protected in the globalisation scenario.

modelling R&D

WorldScan has been calibrated on the GTAP data base, Version 4 (McDougall *et al.*, 1998). From this data set we not only derive the demand, production and trade patterns, but also the labour and capital intensity of the different sectors. The incorporation of R&D affects the model and the data. To start with the latter, our base-year data derived from the GTAP database do not include expenditures on R&D. We assume that these are implicitly incorporated in the intermediate deliveries on services. Therefore, we subtract the expenditures on R&D from the GTAP data on intermediate deliveries on services. As described before the R&D data are derived from the OECD (1999) and UNESCO (1998) data for the base year 1995. We also subtract R&D expenditures from the value of production. Based on the modified GTAP data we calibrate the production function. Then we construct a new producer price as the unit cost price plus a mark up which covers the R&D expenditures. As a result, the volume of production times the new producer price is equal to the production value in the original GTAP data. Total demand for services now consists of intermediate demand, investment demand, final consumption demand and R&D

[20] CPB (1999) provides more details of the Globalisation scenario. This scenario is akin to the High Growth scenario which CPB and OECD have constructed for their collaborative study on globalisation and the consequences for the OECD countries (OECD, 1997).

demand. The total value of the demand for services is still the same as in GTAP.

TFP is a function of R&D stocks and the R&D-spillover stocks. Denote *F* as TFP then

$$F_{ikt} = A_{ikt}\left(R_{ikt}^{DD}\right)^{\gamma^{L}} \tag{7}$$

A represents the exogenous TFP level. γ's are the adjusted sector and country coefficients estimated in Section 3. This adjustment is necessary to translate the estimated equation in the equation above. Details are provided in Appendix D. The constructs for the own R&D stock, the indirect and foreign R&D stock were already defined in equation (2).

The sectoral R&D stocks in period *t* equal those in period *t-1* --corrected for deprecation -- plus the R&D expenditures. The deprecation rate, δ, is set at 5% for the R&D stock in all sectors and regions.[21] The R&D expenditures are by assumption a constant fraction, $\overline{RI}$, of sectoral value added in period *t-1*, thus

$$R_t = \overline{RI}\,Y_{t-1} + (1-\delta)R_{t-1}\ . \tag{8}$$

We also use this equation to construct the R&D stock for the base year assuming that the ratio of the R&D stock to value added is constant.

In the scenario period TFP grows due to an exogenous increase in *A* and an endogenous increase in the R&D stocks. In the baseline without R&D we have imposed an exogenous increase in sectoral and regional TFP in the model such that the model produces the characteristics of the Globalisation scenario. In the baseline simulations including R&D we have assumed that the total increase in TFP was similar as in the baseline without R&D. As a result the exogenous increase in *A* is much lower in the simulations with R&D than without R&D. We follow this method to make the baselines comparable to each other. The effects of trade liberalisation are then also comparable.[22]

5. Simulation results

This section presents the effects of trade liberalisation in case R&D is introduced in WorldScan. We distinguish the effects of trade liberalisation in the presence of own R&D efforts, of sectoral spillovers and of international R&D spillovers. These effects are measured by comparing the results for two simulations: a baseline simulation without trade policy and a policy variant consisting of trade

[21] In the estimations, we assumed that R&D stocks did not depreciate. Some sensitivity analysis of our simulations with respect to the assumed depreciation rate is presented in Appendix D. There we set δ equal to zero. The qualitative results are not altered.

[22] In the policy simulations we use the calculated increases in *A* as exogenous.

liberalisation. First, we present the results of introducing R&D on GDP growth for the various regions in the baseline simulation. Second, we turn to the macroeconomic effects of trade liberalisation and the role of R&D (spillovers). Third, we discuss the sectoral effects for some regions.

The incorporation of R&D and spillovers in our baseline simulation has a significant effect on GDP growth in the model. While thus far a substantial part of GDP growth was explained by TFP growth (CPB, 1999), the contribution of exogenous TFP growth is declined in favour of growth in R&D and R&D spillovers. Table 5.1 shows the factors that contribute to GDP growth in the various regions.

CPB (1999) explains that a substantial part of GDP growth in the non-OECD regions can be attributed to the growth in employment. This is caused by population growth, schooling and labour reallocation from the low-productivity sectors to the high-productivity sectors. On average capital accumulation contributes for about 40% to GDP growth. The rest can be attributed to R&D and TFP. This is our main interest here.

Table 5.1 Growth accounting
annual contributions of the productive factors

country	Western Europe	United States	Japan	Pacific OECD	Eastern Europe	Former Soviet Union
employment	-0.1	0.4	-0.2	0.4	0.0	0.2
capital accumulation	0.8	1.0	1.1	1.0	1.3	2.1
own R&D	0.1	0.2	0.1	0.1	0.0	0.0
sectoral R&D spillovers	0.1	0.2	0.1	-0.1	0.1	0.1
international R&D spillovers	0.1	0.1	0.0	0.2	0.2	0.1
total factor productivity	1.4	0.8	1.2	0.6	2.9	2.9
gross domestic product	2.4	2.7	2.4	2.1	4.5	5.5
country	**Middle East & N. Africa**	**Sub-Saharan Africa**	**Latin America**	**China**	**South-East Asia**	**South Asia & Rest**
employment	1.6	2.7	1.3	0.7	1.4	1.8
capital accumulation	3.1	2.0	2.5	4.2	3.1	2.6
own R&D	0.0	0.0	0.0	0.0	0.1	0.0
sectoral R&D spillovers	0.1	0.1	0.1	0.2	0.5	0.1
international R&D spillovers	0.1	0.1	0.1	0.2	0.2	0.1
total factor productivity	0.8	0.2	1.0	1.9	1.2	1.3
gross domestic product	5.7	5.1	4.9	7.2	6.4	5.9

Source: WorldScan simulations.

According to Table 5.1, R&D explains a part of GDP growth which was attributed to TFP before. Own R&D is only relevant in the OECD and South-East Asia, the regions which perform nearly all R&D in the world. The relevance of the sectoral and international spillovers varies per region. Below we will discuss this issue at greater length. Table 5.1 shows that for most regions the spillovers contribute more to GDP growth than own sectoral R&D efforts. This is not surprising. In particular, the sectoral spillovers are mainly driven by those goods which are relatively important as intermediate goods such as Capital Goods and Energy-intensive Goods. These sectors are also relatively R&D intensive.

This implies that the contribution of sectoral spillovers to GDP growth is larger than the contribution of own R&D. The growth-accounting analysis learns that a part of TFP growth can be explained by R&D. R&D growth thus raises GDP growth. This result is also confirmed in our analysis of trade liberalisation. Without R&D in the model, the effects of trade liberalisation on GDP are in general modest. We want to examine whether this is also the case if R&D is included in WorldScan. We carry out a trade-liberalisation exercise in four different cases. These cases are discriminated by the fact that TFP is not affected by R&D, TFP is only affected by own R&D expenditures, TFP is affected by own R&D and sectoral spillovers, and TFP is affected by own R&D and sectoral and international spillovers.

The first simulation assumes no link between R&D and TFP. We assume that all regions agree to abolish all their tariffs and export subsidies between 2000 and 2020. In the sectors Agriculture and Raw Materials the import tariffs and export subsidies are reduced by only 50%, because of the initial high rates of tariff protection. The results are similar to those in Lejour and Tang (2000). The effects on GDP in the OECD are modest, but the Asian regions gain substantially in 2020, the end of the simulation period. Also the GDP gains in Latin America are large.[23] The first column in Table 5.2 presents these results.

The second simulation assumes that increases in the sectoral R&D stock raise the TFP level in that sector. This simulation does not take account of sectoral and international spillovers on TFP. Column (2) shows the extra GDP effects of trade liberalisation on GDP due to own R&D expenditures. These extra effects are modest, except for Western Europe, Japan and South-East Asia. These regions specialise in Capital Goods and Energy-intensive Goods. Trade liberalisation stimulates growth in these sectors and thereby the R&D efforts.

[23] The substantial GDP effects can partly be explained by our assumption that consumer preferences for a certain variety (in the Armington demand functions) depend positively on the share in global production of the region in which the variety is produced.

Table 5.2 Cumulative GDP effects of trade liberalisation in 2020

region	no R&D (1)	own R&D (2)	sectoral R&D spillovers (3)	international R&D spillovers (4)	relative GDP increase due to R&D (5)
United States	1.5	0.0	0.3	0.4	53.2
Western Europe	1.7	0.5	2.3	0.1	169.3
Japan	2.3	1.0	7.4	0.2	372.1
Pacific OECD	3.8	0.2	0.5	0.2	24.1
Eastern Europe	5.0	0.2	1.0	0.8	40.2
Former Soviet Union	1.6	0.1	0.2	0.2	36.2
Latin America	9.5	0.3	0.7	0.4	14.6
Middle East & N. Africa	4.8	0.3	0.4	2.1	58.8
Sub-Saharan Africa	5.0	0.1	-0.3	0.7	10.2
China	15.0	0.1	-0.5	0.9	3.4
South-East Asia	14.9	1.4	6.0	1.5	59.6
South Asia & Rest	15.9	0.2	0.4	0.6	7.0

Source: WorldScan simulations.

Column (3) shows the extra GDP effects of trade liberalisation due to the sectoral spillovers. These effects vary widely. In South-East Asia the sectoral R&D spillovers increase the GDP effects of trade liberalisation with 6% points. In Sub-Saharan Africa and China however, the sectoral spillovers have a small negative effect on GDP. The results vary by region because of the regional differences in the development of the R&D-intensive sectors. From Table 3.1 we know that the sectors Capital Goods and Energy-intensive Goods are R&D intensive. In regions which do not specialize in these sectors, the R&D-intensive sectors become relatively less important during the process of trade liberalisation. Then, the average R&D content of the intermediate goods produced in the own region decreases. Examples are Sub-Saharan Africa and China. In other regions the R&D-intensive sectors expand relatively quickly. As a consequence, the average R&D content of the intermediate goods increases. This explains the sectoral spillovers in Western Europe Japan, and South-East Asia. Thus, the importance of sectoral spillovers depends on the specialisation pattern. Regions can specialise in R&D-intensive or R&D-extensive sectors. We will discuss this issue in greater detail below.

The international R&D spillovers further raise the GDP effects of trade liberalisation, as can be seen in column (4) of Table 5.2. Its importance differs per region. In general, international R&D spillovers are more important for the non-OECD regions than for the OECD regions. Non-OECD regions import relatively much from the OECD, whose products are relatively R&D intensive, see also Tables 3.1 (and 3.2). An extreme example is the Middle East. This region imports much more Capital Goods and Energy-intensive Goods from the OECD due to trade liberalisation. As a result the international spillovers are high.

Column (5) shows the increase in the GDP effects of trade liberalisation with R&D relative to the GDP effects of trade liberalisation without R&D. On average the GDP effects are raised significantly (due to R&D-based technology). China, Sub-Saharan Africa, and South Asia and Rest are exceptions, however.[24]

Above we have seen that the large variety in GDP effects of trade liberalisation due to sectoral spillovers depends on the development of the R&D-intensive sectors. The sectors Energy-intensive Goods and Capital Goods are very important in this respect for two reasons. First, these sectors are very R&D intensive. Second, these goods are intensively used as intermediate goods.

Western Europe, Japan, Eastern Europe and South-East Asia specialise in R&D-intensive sectors. These sectors are also high-skilled labour intensive, which largely explains specialisation in these sectors by the former three regions (which are high-skilled abundant). In these regions the share of R&D-intensive sectors in value added rises. This enhances the growth of the R&D stocks in these sectors and has the same effect on regional R&D stocks. Lejour and Nahuis (2000) show that changes in the R&D stocks of the R&D-intensive sectors and the regional R&D stock are highly correlated. So, the sectoral spillovers are very high in regions which tend to specialise in the production of R&D-intensive goods. The United States and Pacific OECD specialise in Agriculture which is R&D extensive. As a consequence, their sectoral spillovers are very modest.

The negative sectoral spillovers in China and Sub-Saharan Africa in Table 5.2 can be explained in a similar way. These regions specialise in Consumer Goods and Agriculture, respectively, at the expense of R&D-intensive goods. So their regional R&D stocks decrease if trade liberalisation takes place. The sectoral spillovers for trade liberalisation are thus negative for these regions.

The size of the international spillovers can analogously be explained by the R&D content of the imports. These spillovers depend on the structure of the imports. It is very large for the Middle East, which explains the large international spillovers on GDP, see Table 5.2. The large increases in the R&D content of the imports in the United states and South Asia and Rest leads also to relatively high international R&D spillovers.

The changes in the R&D content of the imports are affected by the changes in the regional and sectoral structure of the imports. Regions tend to import less from the OECD, which have the highest R&D stocks. The reason is that trade liberalisation affects the relative consumer prices. Relative prices of products from non-OECD regions tend to become lower on average due to the elimination of import tariffs. Only Japan, Middle East and South-East Asia import relatively more from the OECD after trade liberalisation. This has a positive effect on the R&D content of the imports for these regions.

[24] Table 5.2 presents the GDP effects of trade liberalisation. These effects also include terms-of-trade effects. Alternatively, we could present the effects on the volume of consumption. The effects in the initial policy simulation without R&D in the model are different. The consumption gains for the Asian regions are substantially lower than the percentage gains in GDP in Table 5.2. The effects of introducing R&D in these simulations is the same as above, however. The same regions have relatively large sectoral or international spillovers. All conclusions thus hold whether the analysis is based on GDP effects or consumption effects.

The changes in sectoral structure of these imports are very important. All regions import relatively more R&D because they import relative more R&D-intensive goods, except for China (see Lejour and Nahuis (2000)). Trade liberalisation stimulates in particular trade in manufacturing products. The reason is that the fall in trade barriers in these sectors is larger than in Services and Raw Materials. In particular the United States and the Middle East import more of these goods, which leads to a considerable rise in the R&D content of the imports. So, although the sectoral spillovers in the United States are low, because it specialises in Agriculture, the international spillovers are high due to the increased imports of Energy-intensive and Capital Goods.

R&D magnifies the positive effects on GDP if the R&D content of the intermediate goods is high. This can be achieved in two ways. The first is that regions carry out a lot of R&D themselves. The second is that they import relatively much R&D-intensive goods. The analysis shows a trade off between specialising in R&D-intensive goods and importing these goods. Western Europe, Japan, Eastern Europe, Latin America and South-East Asia produce relatively much R&D-intensive goods. On the other hand, their R&D import content is low. These regions have thus high sectoral spillovers compared to the international R&D spillovers, see Table 5.2.

The United States, Middle East, Sub-Saharan Africa, China and South Asia & Rest import relatively much R&D-intensive goods. The contribution of R&D to the GDP effects of trade liberalisation are mainly through international spillovers in these regions whereas they experience low or even negative effects related to the sectoral spillovers.

We examine how sensitive the results are for the assumption that the R&D intensities in the non OECD remain as low as they currently are. We do so by implementing a relation between the R&D intensity and GDP per capita. So far we have assumed that the ratio of sectoral R&D expenditures to value added is constant in the simulation period. This seems to be reasonable for the developed regions in which R&D expenditures do not vary substantially over time, but not for the developing regions. The analysis of the R&D data of the UNESCO (1998) shows that R&D intensities increase as countries become more wealthy, see Figure 1. It shows the correlation between the R&D expenditures /GDP ratio and log GNP per capita (Worldbank, 1997) for about 85 countries in 1995.

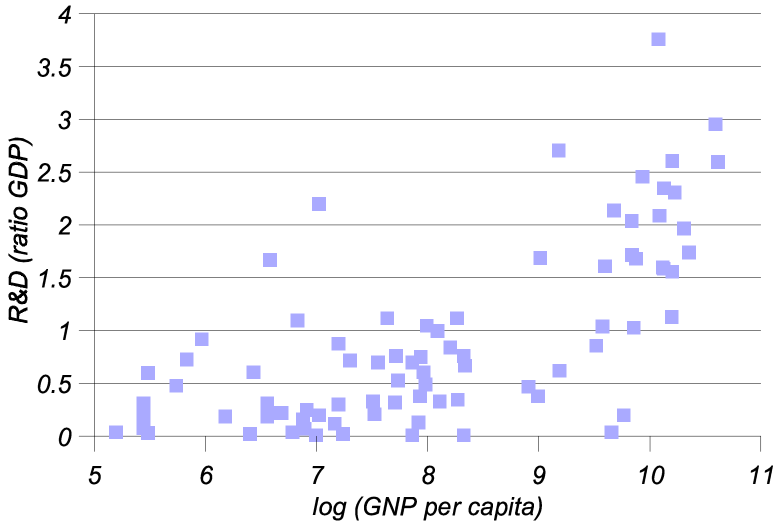

Figure 1. R&D intensity and income per capita

From this figure we see a positive relationship between economic development (measured by GNP per capita) and expenditures on R&D. A simple OLS regression shows clearly that if GNP per capita doubles, the R&D-GDP ratios increases absolutely by 0.38%. So, if low-income countries develop, their R&D-GDP ratio will increase substantially.

We analyse the GDP effects of the spillovers once we introduce this relation in our simulations. In the benchmark simulations presented above some spillovers were negative because the R&D content of the intermediate inputs decreased in the presence of trade liberalisation. At the moment that the R&D intensities in the non-OECD regions increase, the R&D content of intermediate goods will raise. Table 5.3 shows the results in deviation from those in Table 5.2.

Column (4) shows that only the non-OECD regions are seriously affected compared to the case of constant R&D intensities in the non OECD. The effects on the OECD regions are negligible. In the non-OECD regions the sectoral spillovers are much larger. The sectoral spillovers are positive for all regions. For all regions, except China, the total sectoral effect -- the sum of the columns(2) in Table 5.2 and 5.3 -- is positive. And for China this negative effect is much smaller now. The effects of the international spillovers are ambiguous. However the changes are fairly small.

Table 5.3 Deviations in the cumulative GDP effects of trade liberalisation due to increasing R&D intensities in the non OECD

region	own R&D (1)	sectoral R&D (2)	international R&D (3)	total (4)
United States	0.0	0.0	0.0	0.0
Western Europe	-0.1	0.0	0.0	0.0
Japan	0.0	0.1	0.0	0.0
Pacific OECD	-0.1	0.0	0.2	0.1
Eastern Europe	0.0	0.3	0.1	0.3
Former Soviet Union	0.0	0.1	0.0	0.1
Latin America	0.0	0.5	0.2	0.7
Middle East & N. Africa	0.0	0.4	-0.2	0.2
Sub-Saharan Africa	0.0	0.4	0.2	0.6
China	0.3	0.5	0.2	0.9
South-East Asia	0.0	1.2	-0.1	1.1
South Asia & Rest	0.5	0.6	0.1	1.2

Source: WorldScan simulations. All results are presented in deviation from Table 5.2

6. Conclusions

Do R&D and R&D spillovers provide a link between openness and growth? The answer to that question is affirmative according to our analysis. The introduction of R&D in our AGE model always increases the effect of trade liberalisation. The size of the effect depends heavily on specialisation patterns and changes of that pattern due to trade liberalisation. A more intense relation with one sector or regions often implies a less intense relation with other sectors or regions. A change in the input of intermediate goods or trade pattern only raises productivity if it is a change towards R&D-intensive sectors or regions.

This is one of the main conclusions of this paper. Although R&D enlarges the benefits from trade liberalisation, the effects are region- and sector specific. Here the value added of our AGE model WorldScan comes in. It allows for regional and sectoral detail. Therefore, we can model inter- and intra-regional spillovers of R&D. Sectors and regions face a trade-off with respect to these spillovers. R&D spillovers can be obtained by producing R&D-intensive and spillover-intensive goods domestically or by importing them. In the former case the intra-regional (sectoral) spillovers are important. Regions which already have a comparative advantage in R&D-intensive sectors rely on this mechanism. As producing R&D-intensive goods turns out skill- and capital-intensive, the intra-regional spillovers are important for Western Europe, Eastern Europe and Japan. Other regions which specialize in Agriculture or that are not skill- and capital-rich obtain the R&D spillovers by the international linkages. For some regions the gains from trade liberalisation are even reduced by negative sectoral spillovers. In the process of trade liberalisation, these regions specialise in R&D-extensive products. As a consequence the R&D-intensive sectors move away to other regions.

This is no reason to hamper trade. The gains of trade liberalisation are still positive. A policy option is stimulating R&D. If regions increase R&D expenditures the negative spillovers of trade liberalisation reduce or even disappear. Our analyses showed that the sectoral spillovers then become more important. A policy which stimulates R&D not necessarily has to be directed to the R&D-intensive sectors. It makes sense to stimulate those sectors which are often used as intermediate goods. However, as those goods are often imported, it could make more sense to target R&D-stimulating policy those sectors which are also often used domestically as intermediate goods such as services.

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