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R&D Spillovers and Growth: Specialisation matters*

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RHH: R&D SPILLOVERS AND GROWTH

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Abstract

We explore the relationship between openness and growth by taking a closer look at trade-related knowledge spillovers at the industry level. First, we estimate the relation between sectoral R&D expenditures, trade-related spillovers and growth. Next, we incorporate these R&D linkages in a computable general equilibrium model for the world economy. We simulate trade liberalisation in the model with R&D spillovers and compare the effects on GDP in different regions with a non-R&D based model simulation. We find that the GDP effects of trade liberalisation are magnified considerably by R&D spillovers for some regions — notably Japan and South-East Asia. In other regions, such as China, the additional GDP effects are modest. These findings can be traced back to changing specialisation and import patterns.

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1. Introduction

Recent evidence suggests that international knowledge spillovers are important. The opening up of economies can have growth effects, via knowledge spillovers related to openness, that increase the productivity of research or production. The theoretical literature also suggests that openness might reduce duplication of research effort. Moreover, increased openness allows countries to benefit from specialisation (or scale) opportunities in research, or to benefit from an increase in the relevant market size.¹

This paper employs the empirical results on openness, R&D and growth, and integrates these in a dynamic Computable General Equilibrium (CGE) model. We examine the importance of R&D and R&D spillovers for trade liberalisation. This is done in two steps. First, we estimate the relation between total factor productivity (TFP) and R&D and R&D spillovers. Second, we use the results in WorldScan, a CGE model for the world economy with considerable sectoral detail. Within that framework we simulate the consequences of trade liberalisation.

Closely related to our study is the work by Coe and Helpman (1995, CH hereafter) and Bayoumi, Coe and Helpman (1999, BCH hereafter). CH directly

quantify the relation between technological change, openness and research expenditures within the OECD. They show that R&D is beneficial not only for the performing countries, but also for their trade partners. BCH use the estimated equation in the dynamic multi-country 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 by 2075.²

The analysis in this paper adds to BCH's paper in several respects. First, we distinguish different industries or sectors in the model, while MULTIMOD is a macro-econometric model. This distinction enables us to analyse specialisation patterns of R&D-intensive and R&D-extensive products. Second, given our sectoral model, we can distinguish between intra-regional spillovers and inter-regional spillovers. Third, we collect and incorporate R&D data for non-OECD regions, whereas BCH's assumptions imply that these regions perform no R&D until 2075. Fourth, to highlight the role of trade as a vehicle for R&D spillovers, we perform an exercise different from the one performed by BCH. We argue that reduction of existing trade barriers over time constitutes a relevant policy shock, whereas BCH increase imports and exports of manufactures by 5%-points exogenously. Our analysis provides the following insights.

First, we show that trade-related R&D spillovers do not *necessarily* magnify the effects of trade liberalisation. This is related to our trade-liberalisation experiment. We introduce trade liberalisation starting from the trade barriers in the data. By implication, the relative prices of the regional varieties are affected by trade liberalisation. Trade flows may be redirected, thus affecting the ‘imported’ knowledge flows. This results in very low benefits from international spillovers for those regions that import fewer knowledge-intensive products. The BCH experiment veiled this result by increasing the import intensity in a neutral way across countries (and by the absence of sectoral detail also across industries).

Second, trade liberalisation is particularly beneficial for regions that specialise in R&D-intensive goods. Particularly in these sectors, trade is stimulated by the elimination of relatively large sectoral trade distortions. Increased production stimulates R&D efforts and depresses producer prices. As a consequence, demand for these products rises further.

The third point made in this paper is that the distinction between intra-national spillovers and international spillovers is crucial, and involves certain trade-offs. This point is easily understood once it is recognised that goods imported are not produced domestically. So, increased ‘imported’ international

spillovers come at the cost of domestically generated knowledge (which might be important for intra-national spillovers).³ Trade liberalisation might cause regions to specialise in sectors that are not R&D intensive or that do not create sizeable spillovers to other sectors in the own economy. These factors may offer a potential explanation for the difficulty of finding a (positive) role for openness on growth in the data (Rodriguez and Rodrik (1998)).

2.The empirical strategy

2.1. Preliminary discussion

As stated in the introduction, our aim is to examine the relationship between technological change, knowledge spillovers, and trade (liberalisation). This section sets out first the recipe we follow in the paper and next discusses some of the ingredients in greater detail.

Before providing the procedure we follow, we discuss our aim more extensively. We attempt to answer the question: how do technological change and knowledge spillovers affect the results of a trade-liberalisation policy.

Hence we relate technological change and spillovers to trade. On the one hand this is not very far fetched, as the theory usually takes this as the relevant

relation and the empirical literature emphasising this relation is abundant. On the other hand, the empirical relation between trade and knowledge (spillovers) is by no means rock-solid. A consensus is emerging that spillovers exist; whether and how trade relations act as an international propagation mechanism is however disputed (we discuss this literature later in greater detail). Our contribution is to be seen against this background. We do not contribute to the debate on *how* international spillovers arise. We assess what implications knowledge (spillovers) have on trade liberalisation *if* these spillovers are related to trade and in particular imports; something we argue to be plausible (see section 2.3).

2.2. The strategy in 7 steps

The steps we use to assess the impact of trade liberalisation on growth in a multi-industry setting are as follows (in reverse order).

1. We simulate a trade liberalisation experiment if technology is (partly) driven by knowledge accumulation and spillovers.
2. We construct an analogous trade-liberalisation experiment if technology is unaffected by trade liberalisation and compare this to the ‘endogenous’ technology experiment.

3. Technology is endogenous in the sense that we use the following specification in the model. Production (Y) in industry i in country k at time t looks like:

$$Y_{ikt} = F_{ikt} f(K_{ikt}, L_{ikt}, I_{ikt}) \quad (1)$$

Where F is the Total Factor Productivity (TFP), f is the production function of capital (K), labour (L) and intermediate inputs (I). TFP is determined by the level of exogenous technological change (A) and by the endogenous technological change (B), $F_{ikt} = A_{ikt} \cdot B_{ikt}$. In the standard simulation -- referred to in step 2. -- with only exogenous technological change B is unity.⁴ We follow the logic of Grossman and Helpman (1991) that research productivity, and thus productivity growth, depends on the knowledge stock available for R&D.⁵ Thus, in the simulation with endogenous technological change:

$$B_{ikt} = \left(R_{ikt}^{DD} \right)^{\gamma_{ik}^{DD}}. \quad (2)$$

That implies that B is determined by the level of accumulated knowledge.

More precisely R^{DD} represents the knowledge stock build-up by own

R&D (the superscript should be read as Direct Domestic). γ is the sector-

and country-specific knowledge-productivity elasticity. It is constant over time.

4. R^{DD} is a simple stock of accumulated R&D expenditures:

$R_{ikt}^{DD} = (1 - \delta)R_{ikt-1}^{DD} + rd_{ik}Y_{ikt}$ where δ is the depreciation rate of knowledge and rd is the R&D intensity. We simplify by assuming that the R&D intensity (rd) in each industry remains constant at the level of the final year for which we have observations.⁶ R&D spending is covered by excess profits, related to mark-up pricing.

5. We introduce knowledge spillovers from other industries in the same region and spillovers from other regions as follows:

$$F_{ikt} = A_{ikt} \left(R_{ikt}^{DD} \right)^{\gamma_{ik}^{DD}} \left(R_{ikt}^{ID} \right)^{\gamma_{ik}^{ID}} \left(R_{ikt}^F \right)^{\gamma_{ik}^F}. \quad (3)$$

R^{ID} represents the R&D spillovers from other sectors in the own region (Indirect Domestic). This stock is an input-output weighted summation of the own-R&D stocks of the delivering industries (R^{DD}). R^F represents the R&D spillovers from abroad (Foreign). R^F is a summation of other regions' industries' R^{DD} stocks, weighted with import relations (the appendix provides the exact formulation). Since we aim to examine a trade liberalisation experiment we allow the import weights to change over time

in simulations. The IO coefficients in the R^{ID} weighting construct are kept at their base-line levels in the simulations.

6. To obtain parameters for the equation governing TFP development we estimate the following TFP-growth equation:

$$\hat{F}_{ikt} = c + \beta^{DD} rd_{ikt} + \beta^{ID} \sum_{j \neq i}^I \omega_{jikt} rd_{jkt} + \beta^F \sum_{l \neq k}^K \sum_j^I n_{jilkt} rd_{jlt} + v_{ikt} . \quad (4)$$

ω and n denote the input-output weights from sector j to sector i in country k , and the import weights from sector j in country l to sector i in country k respectively. In contrast to the simulation (that has a forward looking character) we exploit in the estimation both the cross-section and the time variation in rd .

7. From the estimated equation we derive the coefficients we use in the model, equation (3). The details of the required integration of the equation (4) to derive equation (3) are relegated to the appendix.

2.3. Elaboration on some steps

R&D-intensities and estimation

In step 6 we estimate an R&D-spillover equation explaining TFP-growth by R&D and R&D spillovers. This paper is not the first attempt to measure

national and international spillovers. CH (1995), Keller (2002a), Park (1995) and Branstetter (2001), among others, have done so before.⁷ This paper exploits their ideas and implements them in a CGE model.

Estimating equation (4) instead of using an equation estimated by others is necessary as we translate the estimated equation into the equation we use in the CGE model. For consistency the estimated equation should be based on the same industry and region division as employed in the model. We estimate such an equation ourselves because appropriate estimates are not available.

Equation (4) is formulated in terms of R&D intensities, instead of R&D stocks as in CH (1995). We explain TFP growth by R&D-intensities and spillovers thereof (see equation (4)). A specification in R&D-intensities and spillovers has a long tradition in the literature, see for an example Griliches and Lichtenberg (1984). The CH approach is criticised conceptually⁸ as well as econometrically. Edmond (2001), for example, shows that the international spillover parameter is unstable, using a more appropriate specification, and employing a cointegration test different from CH.⁹

The weighting schemes

We use input-output weights and import-related weights to construct the R^{ID} and

R^F variables. The rationale for using input-output weights is thoroughly explained and discussed by Griliches and Lichtenberg (1984). The relevant transmission mechanism of *international* spillovers is uncertain and hotly debated.¹⁰ We do not pretend to solve this issue. The lack of consensus about the diffusion mechanism of international spillover makes us present our work as a *what-if* exercise. We argue, however that our *if* – international spillovers relate to industry-specific imports – is plausible. In a recent survey Keller (2001) argues that the: "evidence...underlines the importance of international technology diffusion" (p.43) and that "R&D spillover regressions..now point to a robust link between import and technology diffusion" (p.44).¹¹ And, finally, he discusses literature on industry heterogeneity and concludes that the "results are consistent with international technology spillovers varying greatly in strength across different sets of goods." (p.34). Though the existing evidence is supportive of the hypothesis we employ, we acknowledge the uncertainty about international spillovers explicitly by presenting and discussing results when international spillovers are absent.

2.4 Data

The ANBERD database of the OECD (1999a) provides the R&D expenditures

for business enterprises of 15 OECD countries. The data cover the period from 1973 to 1997 at a sectoral level, according to the ISIC2 classification. They are highly disaggregated for the manufacturing sectors, but not for services.¹²

We combine 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. Table 2.1 reports the R&D intensities for the four OECD regions in the model.¹³

(Insert table 2.1)

Overall, the R&D intensities in the Services and Agriculture sectors are lower than in Manufacturing. The variation within the manufacturing sectors 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 sector consists of sub-sectors like Wood, Food and Tobacco, Textiles and Paper, which are R&D-extensive sectors. The Energy-intensive Goods sector is R&D intensive because it includes Chemicals, Rubbers and Plastics as sub-sector. The R&D intensity of other sub-sectors, like Stone and Clay and Basic Metals, is lower. The Capital Goods sector consists only of Fabricated Metal products, which is very R&D intensive.

From the last column in Table 2.1, we see that the United States and Japan

carry out most of the R&D, while Pacific OECD is lagging behind. The US conducts a relatively large amount of R&D in Capital Goods, Consumer Goods and Services, whereas Japan is active in Energy-intensive Goods and Raw Materials. Western Europe carries out much R&D in Agriculture.

The expenditures on R&D for the developing countries are derived from UNESCO. Table 2.2 presents the results for the regions in our model. R&D is the highest in the most developed region, South-East Asia.¹⁴

(Insert table 2.2)

2.5 Estimation

The estimation results presented in this section are used in the simulations in the next section. The dependent variable, TFP, is based on ISDB data (OECD, 1999b). The independent variables were discussed in the previous section.

(Insert table 2.3)

Table 2.3 presents the regression results for equation (4) based on three estimation methods. The first two columns are for reference only. Column (III) provides the input for the modelling exercise in the next section. Additional results, referred to in this section, are available from the authors.

Despite the fact that we use R&D intensities rather than R&D stocks the time series properties urge us to estimate our model by dynamic OLS (see Funk,

2001, and Kao, Chiang and Chen, 1999). We report the results in column (III) without the included differenced leads and lags. The own within-sector R&D and the indirect domestic R&D coefficient are significant. This supports the hypothesis that within-region R&D spillovers exist. The estimated coefficient for the indirect effect might seem relatively high compared to the direct effect. However, the use of a weighting matrix of which the columns do not add up to unity hampers a direct comparison. The foreign R&D coefficient is not significant. Leaving the latter variable out does not substantially affect the parameter estimates.

The size of our estimated coefficients is in line with findings in the existing literature. The coefficient on own R&D (β^{DD}) has a direct interpretation as it measures the rate of return. A rate of return of 19% is not far off the average of the reported numbers in Nadiri's (1993) overview. To compare the other coefficients with the literature we translate them in R&D-stock elasticities. Nadiri provides a range of estimates from 0.18 to 0.26 for the indirect domestic R&D stocks. Mohnen (1996) provides in his overview estimates up to 0.24. Our estimates for the indirect domestic R&D stock range from 0.1 to 0.4 for the capital goods sectors in the different regions (and are somewhat lower for other sectors). The elasticity for own R&D is higher than for intra-industry spillover

in OECD regions and the other way around in non-OECD regions.

When calculating the foreign-spillover elasticity in an analogous way, we find coefficients for OECD regions that are at the lower end of the elasticities reported by Mohnen (1996).¹⁵ That the coefficient is insignificant is not without precedence. Keller (2002a) shows that the importance of foreign spillovers decays with distance. It is possible that aggregating our data to the simulation model aggregation level, limited the cross-section variation and the degrees of freedom too substantially. We deal with this uncertainty by sensitivity simulations.

3. The CGE model and R&D

The CGE model we use is an applied dynamic general equilibrium model for the world economy. The model relies on the neoclassical theories of growth and international trade. We augment the growth model by incorporating the relation between TFP and R&D stocks and R&D-spillover stocks as specified in equation (3). In the base year we calibrate the variable A_{ik} by inverting equation (3), in which we substitute the values of the R&D stocks. The value of TFP (F_{ik}) follows from calibrating the production function.¹⁶

TFP grows in the scenario period, due to an exogenous increase in A and an endogenous increase in the R&D stocks. In the baseline without R&D, an exogenous increase in sectoral and regional TFP has been imposed in the model. We assume, in the baseline simulations including R&D, that the total increase in TFP is equal to that in the baseline without R&D. As a result, the exogenous increase in A_{ik} is lower in the simulations with R&D than in those without R&D. We follow this method to ensure that the baselines are identical.¹⁷

With respect to trade, we adopt an Armington specification, explaining two-way trade between regions and allowing for market power of each region. In the long run, trade patterns are determined by Heckscher-Ohlin mechanisms, i.e. based on factor endowments. Trade liberalisation by abolishing formal trade barriers has two effects. First, it affects relative prices of intermediate inputs and final goods. This changes the demand for different goods from different origins, leading to trade creation. The second implication of abolishing formal trade barriers is that it affects the terms of trade, i.e. the price of exports relative to the price of imports.

Imports tariffs in manufacturing products and agriculture are relatively high, in particular in the non-OECD regions. If these tariffs are eliminated (our

trade-liberalisation exercise), prices of these products will fall, and intermediate and final demand is stimulated. Production of the stimulated sectors increases and if these sectors are R&D intensive, like the Capital and Energy-intensive sectors, the R&D stocks of these sectors also increases. This raises TFP in these industries. As these goods are also intensively used as intermediate inputs in the production of other goods, users substitute towards using more of these inputs. The competitive position of the inputs users also improves. In turn, the demand for these goods increases, raising their own R&D stock, and so on. The substitution toward cheaper internationally trade inputs (and final goods) increases the relevant foreign R&D stock. All these three factors raise TFP growth and boost economic growth.

4. Simulation results

This section presents the effects of trade liberalisation when R&D is introduced in the CGE model. We distinguish the effects of trade liberalisation in the presence of own-R&D efforts, sectoral spillovers, and international R&D spillovers. We measure these effects by comparing the results for two simulations: a baseline simulation without trade policy and a policy variant

consisting of trade liberalisation. First, we show how the introduction of R&D affects 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 and its spillovers. Finally, we discuss the sectoral effects for some regions.

As has already become clear in the previous sections, R&D and R&D spillovers affects GDP growth in the model. To get some idea of the importance of these factors in GDP growth in our simulations, Table 4.1 shows the factors that contribute to GDP growth in various regions.

(Insert table 4.1)

According to Table 4.1, own R&D is only relevant in the OECD and South-East Asia, the regions that perform nearly all of the R&D in the world. The relevance of the sectoral and international spillovers varies per region. We discuss this issue at greater length below. For all regions in Table 4.1 sectoral spillovers contribute more to GDP growth than do own-R&D efforts. This is hardly surprising. The sectoral spillovers are mainly driven by those goods that are relatively important as intermediate goods, such as Capital Goods and Energy-intensive Goods. These sectors are also relatively R&D intensive. Thus, as far as GDP growth is concerned, the indirect contribution via sectoral spillovers

seems to be larger than the direct contribution of own R&D.

We analyse the effects of R&D spillovers in trade by carrying out a trade-liberalisation exercise with four different cases. In the first case, TFP is not affected by R&D. In the second, TFP is only affected by own-R&D expenditures. The third case shows how TFP is affected by own-R&D and sectoral spillovers, and the fourth case adds international spillovers to the above.

The first simulation assumes no relationship between R&D and TFP. All regions agree to abolish their sectoral tariffs and export subsidies between 2000 and 2020. In the Agriculture and Raw Materials sectors, the import tariffs and export subsidies are reduced by only 50% (because of the high initial rates of tariff protection). The effects on GDP in the OECD are modest, but the Asian regions gain substantially in 2020, the end of the simulation period. The GDP gains in Latin America are also high. The first column in Table 4.2 presents these results.

(Insert table 4.2)

The second simulation allows for increases in the sectoral R&D stock that raise the TFP level in that sector. This simulation does not take account of sectoral

and international spillovers on TFP. Column (2) shows the additional GDP effects of trade liberalisation on GDP due to own-R&D expenditures. These extra effects are modest, with the exceptions of Western Europe, Japan and South-East Asia. These regions specialise in Capital Goods and Energy-intensive Goods. Trade in these sectors, and in Consumer Goods, is stimulated. The reason is that these sectors still have tariffs — contrary to the services sectors in the base year. So, trade liberalisation stimulates growth in R&D-intensive sectors. As a result, R&D efforts in these sectors increase due to the constant R&D intensity. As a consequence, producer prices will be lower than would be the case without R&D. The GDP effects of trade liberalisation are therefore larger than the results in column (1).

Column (3) shows the additional GDP effects of trade liberalisation due to sectoral spillovers. These effects vary widely. In South-East Asia, sectoral R&D spillovers increase the GDP effects of trade liberalisation by 8.5%-points. In China, however, the sectoral spillovers exert 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 2.1 we know that the Capital Goods and Energy-intensive Goods sectors are R&D intensive. In regions that do not specialise in these sectors, the R&D-intensive sectors

become relatively less important during the process of trade liberalisation. The average R&D content of the intermediate goods produced in the own region thus decreases. An example here is China. In other regions, the R&D-intensive sectors expand relatively quickly. As a consequence, the average R&D content of intermediate goods increases. This explains the sectoral spillovers in Western Europe, Japan, and South-East Asia, see also Table 4.3. The effects of sectoral spillovers thus depend on the specialisation pattern. Regions can specialise in R&D-intensive or R&D-extensive sectors.

(Insert table 4.3)

An increasing share of R&D-intensive sectors in value added enhances the growth of the R&D stocks in these sectors, and affects regional R&D stocks similarly. The last two columns in Table 4.3 show a high positive correlation between the changes in the R&D stocks of the R&D-intensive sectors and the regional R&D stock. If we compare column (3) in Table 4.2 with column (1) in Table 4.3, we see that the sectoral spillovers are very high in regions that specialise in the production of R&D-intensive goods.¹⁸

The negative sectoral spillovers in China and the US, (see Table 4.2), can be explained in a similar way. China specialises in Consumer Goods and the US in Agriculture and Services, at the expense of R&D-intensive goods. It follows,

therefore, that their regional R&D stocks decrease when trade liberalisation takes place.¹⁹

International R&D spillovers

So far we have analysed the relation between own R&D and productivity and between domestic R&D spillovers and productivity; the two relations that turned up significantly in our estimation. The remainder of this subsection introduces international R&D spillovers; a relation that is far less solidly established in empirical work (and in our estimations). An exception is Schiff, Wang and Olarreaga (2003), who show that the coefficient for the foreign spillovers is significant for developing countries. The remaining results of this subsection should therefore be interpreted with more caution, or even as a sensitivity analysis. We apply the estimation results for the OECD also for the Non-OECD, but for the latter countries the international spillovers are probably more important than the domestic ones.

International R&D spillovers further enhance the GDP effects of trade liberalisation, as can be seen in column (4) of Table 4.2. Although the importance of these spillovers differs per region, international R&D spillovers are overall more important for the non-OECD regions than for the OECD

regions. Relatively speaking, non-OECD regions import a great deal from the OECD, whose products are relatively R&D intensive, as can also be seen in Tables 2.1 and 2.2.

The size of the international spillovers can analogously be explained by the R&D content of the imports. The origin of imports is important here, and also the sectoral composition. Column (2) in Table 4.4 shows the relative increase in the R&D content of the imports. All regions import relatively more R&D because they import relatively more R&D-intensive goods. Column (1) presents an indicator for these changes. The US, in particular, imports more of these goods, which leads to a considerable rise in the R&D content of imports. The large increases in the R&D content of the imports have various effects on TFP growth as is depicted in column (4). The various elasticities of the foreign R&D stock to TFP explains this variation. Table 4.4 shows these elasticities for the Capital Goods sector. This is a very illustrative sector, because the foreign capital stock is most important in this sector. The elasticities are lower for the OECD than for the non-OECD.²⁰ Therefore the large increase in the R&D content of imports in the US has less effect on TFP growth than the smaller increase in R&D content related imports in the non-OECD.

Note that there is no one-to-one relation between the increase in TFP and

GDP, because there are also GDP spillovers between regions through trade. The increase in GDP for Latin America for example is relatively high, compared to the change in TFP. The reason is that other regions, such as the United States, demand more products from Latin America.

(Insert table 4.4)

The discussion above analyses the contribution of R&D and R&D spillovers to the effects of trade liberalisation. 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. First, regions may carry out many R&D activities themselves.

Alternatively, regions may, relatively speaking, import many R&D-intensive goods. The analysis shows a trade-off between specialising in R&D-intensive goods and importing these goods. Compared to other regions, Western Europe, Japan, and South-East Asia shift towards producing more R&D-intensive goods. On the other hand, their R&D-import content lowers. These regions thus have high sectoral spillovers compared with the international R&D spillovers (see Table 4.2).

The United States and China shift toward importing more R&D-intensive goods. The contribution of R&D to the GDP effects of trade liberalisation in these regions takes place mainly through international spillovers, whereas they

experience small or even negative effects related to the sectoral spillovers. For China this even implies that the GDP effects of trade liberalisation are even lower if we take account of R&D spillovers. For most of the regions the GDP effects rise significantly (due to R&D-based technology), as is shown in Column (5) in table 4.2.

Sensitivity analysis

It is often claimed that the OECD countries carry out nearly all the R&D in the world economy. Tables 2.1 and 2.2 support this view, with the exception of South-East Asia. We carry out a sensitivity analysis concerning trade liberalisation by assuming that non-OECD regions perform no R&D at all.²¹ BCH (1999) present a similar simulation. The analysis clearly shows the importance of international R&D spillovers for developing economies. Table 4.5 shows the results in deviation from Table 4.2 (the case in which the non-OECD countries carry out R&D). Column (1) shows the GDP effects if own-R&D outlays raise TFP. Not surprisingly, the effects for the OECD regions are only slightly affected. The effect is negative due to less positive demand linkages from the non-OECD regions. For South-East Asia there is a negative effect on GDP. This is due to the lack of own-R&D efforts.

The more striking results are presented in columns (2) and (3). First, consider the sectoral R&D spillovers. The negative numbers for the OECD regions show that the GDP effects of sectoral spillovers become smaller if developing economies do no R&D activities at all. This is due to the lower GDP gains from trade liberalisation for the non-OECD regions. This depresses GDP gains for the OECD. GDP gains in one region spill over to other regions through trade and capital flows.

(Insert table 4.5)

The GDP gains in the non-OECD regions are smaller when they don't perform own R&D. They miss the domestic sectoral spillovers (as they perform no R&D). Compared with the results in Table 4.2, GDP increases in column (2) are negative in non-OECD regions. Only non-OECD regions that specialise in R&D-extensive goods, in the previous simulations, have modest GDP gains now (for example, China).

Also the international R&D spillovers are smaller if the non-OECD regions perform no R&D. Trade liberalisation leads to increased trade between the OECD and the non-OECD. Here, most regions import a larger share of their products from the non OECD. These imports do not embody R&D now. This reduces the GDP effects of international R&D spillovers. The international

R&D spillovers for Latin America even become negative (combine Table 4.5 and 4.2).

Column (4) presents the total effects of trade liberalisation relative to the previous simulations. The international spillovers for all regions are lower. This does not apply, however, to the sectoral spillovers for regions that specialise in R&D-extensive products. The gains from trade liberalisation are thus lower for most regions. An exception is China. If China would rely exclusively on international R&D spillovers, its gains from trade liberalisation would be higher, as shown by the positive numbers in column (4) in Table 4.5.

5. Conclusions

Do R&D and R&D spillovers increase the effects of trade liberalisation? While supporting this hypothesis, our analysis also indicates that the magnitude of the changes/gains is conditional on the specialisation pattern. A more intense trade relation with one sector or region is often correlated with a less intense relation with other sectors or regions. So, spillovers might increase *or* decrease. A change in the input of an intermediate good or trade pattern thus raises productivity only if it is a change towards R&D-intensive sectors or regions.

This is the main conclusion of the paper. This conclusion stands whether international spillovers are important or not. The same holds for our qualitative results. In a quantitative sense international spillovers are outweighed by within-region sectoral spillovers and international spillovers do not substantially alter the general picture.

Although R&D enlarges the benefits from trade liberalisation, the effects are specific to each region and sector. Here, we can see clearly the value added of the CGE model which allows for regional and sectoral detail. We have thus been able to explore inter- and intra-regional spillovers of R&D. Sectors and regions seem to 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 that already have a comparative advantage in R&D-intensive sectors rely on this mechanism. As production of R&D-intensive goods is skill- and capital intensive, intra-regional spillovers are vital for Western Europe and Japan. Other regions specialise in Agriculture, or are not rich in skills or capital. They obtain the R&D spillovers through international linkages. For some regions, the gains from trade liberalisation are

even reduced through negative sectoral spillovers. Trade liberalisation stimulates these regions to specialise in R&D-extensive products. As a consequence, the R&D-intensive sectors shift to other regions.

These drawbacks should not lead policymakers to restrict trade, as trade liberalisation still pays off. One policy option is to stimulate R&D. Our analysis indicates that if regions increase their R&D expenditures, the negative spillovers of trade liberalisation will decrease or even disappear — causing sectoral spillovers to become even more important. A policy that stimulates R&D does not necessarily have to be directed toward R&D-intensive sectors. It makes sense to stimulate sectors that produce goods that are often used as intermediate goods. As those goods are often imported, it might be more effective for policymakers to aim their R&D-stimulating policy at those sectors most often used to produce intermediate goods domestically, such as services.

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Appendix: Calibration

This appendix explains how the estimated equation is translated to the necessary model input. Helpful for this appendix is to recall that we estimated an equation in growth rates and implement an equation in levels in the CGE model and that the estimates are for an equation with R&D intensities whereas R&D stocks are introduced in the CGE model.

If we differentiate the equation in levels (see equation (3)) with respect to time we get

$$\hat{F}_{ik} = \hat{A}_{ik} + \gamma_{ik}^{DD} \hat{R}_{ik}^{DD} + \gamma_{ik}^{ID} \hat{R}_{ik}^{ID} + \gamma_{ik}^F \hat{R}_{ik}^F . \quad (\text{A.1})$$

As in the base-line simulation all variables – except of course the γ parameters – are time varying we drop time indices where it leads to no confusion.* A hat denotes a growth rate. The variables in equation (A.1) are defined as follows:

$$R_{ik}^{ID} = \sum_{j \neq i}^I \omega_{jik} R_{jk} , \quad (\text{A.2})$$

*As motivated in the main text, we keep the IO-coefficients at the base-line level in the policy simulations, so we do not take account of the changes in relative prices due to trade liberalisation on the inputs in production. We do so for simplicity and the costs are low. The main effect of changing relative prices is on the demand for home products and imports. We take account of this effect by the endogenous change in weighting coefficient for the imports.

and

$$R_{ik}^F = \sum_{l \neq k}^K \sum_j^I n_{jilk} R_{jl} . \quad (A.3)$$

where ω denotes the IO-coefficient from sector j to i , and n the sectoral bilateral trade coefficient from country l to k . Knowledge stocks are weighted sums of other sectors' and countries' R&D stocks. Differentiation of equation (A.2) with respect to time leads to (one can follow an analogous procedure for the own R&D stock and the foreign R&D stock):

$$\hat{R}_{ik}^{ID} = \sum_{j \neq i}^I \frac{\omega_{jik} \Delta R_{jk}}{R_{ik}^{ID}} . \quad (A.4)$$

The coefficient γ , times the growth rate of the R&D stock of indirect spillovers (see equation (A.1)) has to be equal to the one in the estimated equation (equation (4) in the main text). So,

$$\gamma_{ik}^{ID} \hat{R}_{ik}^{ID} = \beta^{ID} \sum_{j \neq i}^I \omega_{jikt} rd_{jkt} , \quad \forall i, k . \quad (A.5)$$

Use that:**

**We assume in equation (A.6) that R&D stocks do not depreciate. Here we follow the Terleckyj approach (1974). Simulations with a depreciation rate of 5% gave the same qualitative results and simialr quantitative results as in the paper.

$$\frac{\Delta R_{ik}}{R_{ik}} \equiv \frac{RD_{ik}}{R_{ik}} \equiv \frac{rd_{ik} Y_{ik}}{R_{ik}}, \quad (\text{A.6})$$

and (A.4) to write equation (A.5) as:

$$\gamma_{ik}^{ID} \sum_{j \neq i}^I \frac{\omega_{jik} \Delta R_{jk}}{R_{ik}^{ID}} = \beta^{ID} \sum_{j \neq i}^I \frac{\omega_{jik} \Delta R_{jk}}{Y_{jk}} \quad \forall i, k. \quad (\text{A.7})$$

Integrate both sides of equation (A.7) to get:

$$\gamma_{ik}^{ID} \sum_{j \neq i}^I \frac{\omega_{jik} R_{jk}}{R_{ik}^{ID}} = \beta^{ID} \sum_{j \neq i}^I \frac{\omega_{jik} R_{jk}}{Y_{jk}} \quad \forall i, k. \quad (\text{A.8})$$

Use the definition of R_{ik}^{ID} (equation (A.2)) to see that the left-hand side of (A.8)

is equal to γ_{ik}^{ID} . Thus the parameters of interest are the sector-country-specific

corrected estimates:

$$\gamma_{ik}^{ID} = \beta^{ID} \sum_{j \neq i}^I \frac{\omega_{jik} R_{jk}}{Y_{jk}} \quad \forall i, k. \quad (\text{A.9})$$

An analogous procedure is to be followed to obtain the other coefficients for

equation (A.1).

Notes

1. Keller (2002a) is a recent empirical contribution emphasising the importance of spillovers. Grossman and Helpman (1991) discuss the effects of knowledge spillovers on research productivity and the reduction of duplicated research. See Rivera-Batiz and Romer (1991) for the scale effect in research. The market-size effect is discussed in Acemoglu (1998).

2. To the best of our knowledge, only a few other studies exist that perform similar exercises. Exceptions are van Meijl and van Tongeren (1999), who introduce an absorption-capacity-based spillover measure. They test its numerical consequences by applying the spillover measure to the GTAP data and model (Hertel, 1997). Rutherford and Tarr (2002) develop a highly-stylized R&D-based CGE model for the small-open economy. We add to these contributions the estimation of the relations present in the data and the implementation of them in a calibrated industry-level model with transition dynamics.

3. For this point it is crucial that knowledge spillovers are tied to imports. Nothing, however, precludes spillovers related to exports (learning by competing on the international market); here we choose, however, to follow the

lines set out in the theoretical and empirical work discussed above.

4. In the calibration for the simulations in step 1 and 2 we adjust A to have identical baseline TFP growth in both simulations.

5. See Keller (2002b) for a derivation of an equation analogous to equation (2) from an endogenous growth model. For simplicity we ignore the R&D spillovers from other sectors and countries for the moment.

6. We could relax this assumption without affecting the main results in the simulations. If we would increase the R&D intensities by some percentage the qualitative results would not change: the relative R&D intensities matter.

7. Park (1995) examines country-level data. Labour-productivity growth is explained by domestic R&D and foreign R&D weighted by technological distance. The elasticity of weighted foreign R&D is 17-18% compared to 11% for domestic R&D. Branstetter (2001) analyses spillovers between Japan and the United States. Domestic and foreign R&D stocks are a weighted sum of R&D expenditures of other firms, where the weights have been constructed on the basis of a technological distance matrix. The main finding is that national spillovers overwhelm international spillovers.

8. Lichtenberg and Pottelsberghe de la Potterie (1998) argue that CH's R&D spillover construct is sensitive to statistical aggregation of countries.

9. Kao, Chiang and Chen (1999) and Funk (2001) show that the foreign spillover

variable turns insignificant once the appropriate dynamic OLS estimator is used.

Coe, Helpman and Hoffmaister (1997) find a similar result in the analysis of R&D spillover among a wider set of countries. Import weighted R&D turns up insignificant unless it is interacted with an openness indicator (the import share of GDP).

10. Keller (1998) argues that the trade-weights are uninformative as random weights perform equally well. Coe and Hoffmaister (1999) counter Keller by arguing that Keller's weights have overly small variances.

11. Keller refers with "now" to the refinements of the CH specification. He moreover adds that "the available evidence does not point to strong learning-through-exporting effects" (p.27) and that the results on FDI are mixed.

Lichtenberg and Pottelsberghe de la Potterie (1998) argued that FDI flows matter most.

12. For most countries, no data for Agriculture and Mining (Raw Materials) are reported. The ANBERD database contains a residual (total minus R&D in manufacturing and services) that has to be split up between Agriculture and Mining. 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.

13. With respect to the sectoral aggregation, we assume that the Services and

Trade and Transport sectors have the same R&D intensity— which is approximated by the R&D intensity of services in the OECD data. For manufacturing, we aggregate the sectors S3100, S3200, S3300 and S3900 to the Consumer Goods sector. The Capital Goods sector is S3800, whereas the Energy-intensive Goods sector consists of sectors S3400 to S3700. The Pacific OECD consists of Canada, Australia and New Zealand.

¹⁴.According to the UNESCO data the business enterprise R&D expenditures related to GDP are about 0.3% lower in the OECD than in Table 2.1. Moreover the data do not include a sectoral division. This is solved by using the average values of the relative sectoral R&D intensities in the OECD also for non-OECD regions. As a sensitivity analysis we simulate the case in which the Non-OECD performs no R&D.

¹⁵.We report these for one sector in Table 4.4.

¹⁶.The model is calibrated on the GTAP database; see McDougall, Elbehri, and Truong (1998). The R&D stock for the base year is calibrated by assuming that the ratio of the R&D stock to value added is equal in the base year and previous year.

¹⁷.In the policy simulations, we treat the calculated increases in A_{ik} as exogenous.

¹⁸.The numbers in Table 4.3 are summary statistics. The first two columns in

Table 4.3 give an indication of the magnitudes in the third column. The latter presents the change in the R&D stock, which also indicates a change in the sectoral spillovers. However, there is no one-to-one relation with column (3) in Table 4.2 (as is obvious for the US). The increase in GDP effects can be explained by the additional demand for goods from the US by Western Europe, Japan and South-East Asia.

¹⁹. This should not be interpreted as that US industries are no longer R&D intensive: it is that due to trade liberalisation the composition of the US economy changes toward less R&D intensive sectors.

²⁰. The intuition is that the non-OECD regions import relatively more R&D intensive goods from R&D intensive countries than OECD regions do. This implies that the ‘imported’ R&D intensities are higher for the non OECD.

Equation (A9) in the appendix shows that the elasticity of the foreign R&D stocks is thus higher.

²¹. The results are of course related to the size of the estimated coefficient, though not in a highly sensitive manner. The qualitative results are insensitive to the coefficients. Sensitivity analysis with respect to the estimated coefficients can be obtained from the authors.