Estimating International Technology Spillovers Using Technology Flow Matrices

By

Bart Verspagen

Contents: I. Introduction. – II. The Different Guises of R&D Spillovers. – III. Measurement Issues. – IV. The Empirical Approach and Construction of the Variables. – V. Estimation Results. – VI. Total Factor Productivity and the Domestic and Foreign Sources of its Growth. – VII. Conclusions and Summary.

I. Introduction

Knowledge spillovers are an important source of economic growth. Thus, they have attracted attention from policymakers (e.g., how to promote spillovers from the public to the private sector, or how to promote spillovers to small firms?), as well as researchers. Griliches (1992) and Nadiri (1993) provide surveys of studies showing the importance of knowledge spillovers. One of the channels through which such spillovers work are traded goods, which is especially stressed in the open economy endogenous growth models as pioneered by Grossman and Helpman (1991). Coe and Helpman (1995) have shown the empirical relevance of this idea. The idea of traded goods as carriers of spillovers was already prominent in the seminal exposition by Griliches (1979), although he introduced the issue in terms of traded intermediaries between firms rather than between nations. There are, however, as stressed by Griliches, many other mechanisms through which technology spillovers may take place. In the terminology of Griliches, spillovers transmitted through traded goods are so-called rent spillovers. Pure knowledge spillovers, on the other hand, are transmitted by channels such as conferences,

---

Remark: An earlier version of this paper was presented at the 24th General Conference of the International Association for Research in Income and Wealth, Lillehammer, Norway, August 18–24, 1996, Session 7 organized by Bart van Ark, under the title 'Technology Spillovers and Growth. A Reassessment of the Empirical Evidence'. The paper has benefitted greatly from my previous work on R&D spillovers with Bart Los, and from comments by participants at the above mentioned conference, and seminars at the University of Groningen and New York University. The usual disclaimer applies, however. My research has been made possible by a fellowship of the Royal Netherlands Academy of Arts and Sciences.

scientific literature, labour mobility (generally without 'transfer sums' paid by the employee's new firm), patent information, or pure imitation.

This opens up scope for applying different weighting schemes than just import weights to the issue of international spillovers, as was done by, for example, Park (1995), Lichtenberg and Van Pottelsberghe (1996), Nadiri and Kim (1996) (see also Mohnen 1995, for a survey). One possible way of doing so that has so far remained relatively unexplored, is the use of so-called technology flow matrices. The aim of this paper is to apply this method to the international case. Technology flow matrices, as developed e.g. by Scherer (1982) and Putnam and Evenson (1994), describe how technological knowledge developed in one sector of the economy spills over to other sectors. Extending this into an international context, the method used in this paper will attempt to measure how technology from one sector in a particular country spills over to other sectors in a set of countries, including the one in which the knowledge was originally developed. As was argued by Verspagen (1997) and Los and Verspagen (1996), different technology flow matrices may result, depending on which transmission mechanism for spillovers one takes as the main focus of analysis. Thus, one might argue that the matrices developed by Scherer (1982) and Putnam and Evenson (1994) are mainly aimed at tracking rent spillovers, while the matrices proposed by Verspagen (1997) are aimed at measuring pure knowledge spillovers.

From a practical point of view, R&D spillovers are crucially related to the issue of 'why growth rates differ' (e.g., Denison 1967; Fagerberg 1994). Technology being the main source of long-run economic growth, the economic performance of nations is related to the ability to generate new knowledge domestically and the ability to apply this knowledge, as well as knowledge generated abroad, in the economy. Technology policy, especially in the somewhat larger countries, as well as at the international level (e.g., the EU technology programmes) has traditionally focused on the domestic generation of knowledge, and the diffusion of knowledge from government research institutions to firms, in particular to small and medium-sized firms. The concept of spillovers puts this emphasis of knowledge generation and/or diffusion from the public to the private sector in a different perspective, because it suggests that an important part of the knowledge used domestically is generated abroad. This raises a practically-oriented research question: what is the importance of foreign vs domestic sources of knowledge?

The paper starts in Section II by discussing the conceptual framework on knowledge spillovers introduced by Griliches (1979), and how this is related to the more recent new growth theory and the debate on international trade and R&D spillovers. Section III discusses how these concepts can be applied in an empirical way, while Section IV explains the way in which the variables in this study were constructed. Section V presents empirical results on estimations of the elasticities of 'direct' and 'indirect' (both foreign and domestic) R&D. In Section VI, these results will be used in so-called 'growth accounting' exercises aimed at quantifying the importance of foreign and domestic R&D for the countries in the sample. Section VII summarizes the findings of this paper and discusses the implications for the debate on international knowledge spillovers.

II. The Different Guises of R&D Spillovers

One reason for the existence of R&D spillovers is the fact that technology has important public good aspects. Knowledge can be used by more than one firm at the same time, without the use by one firm prohibiting the use by other firms (non-rivalry), and other firms than the firm that developed the knowledge can often not be excluded from using the knowledge (non-excludability). As is now widely recognized, this establishes the need for intellectual property rights (for example, in the form of a patenting system) and, moreover, this may lead to 'underinvestment' (from an economy-wide perspective) in knowledge-creating activities such as R&D. Knowledge, in other words, has important externalities, or spillovers.

The exact mechanisms through which spillovers occur are manyfold, but still ill-understood. For example, knowledge may be 'embodied' in people, who, if they change jobs, carry the knowledge to their new employer, or it may be embodied in products like investment or intermediary goods. Knowledge may be exchanged at conferences and meetings, or through the (specialized) press. Other, more controversial processes through which spillovers may occur are reverse engineering and even industrial espionage. The sources of relevant technological knowledge are also manyfold. Knowledge may stem from universities, public research institutes, other firms or private inventors. Within the group of other firms, knowledge may either stem from direct competitors who are in the same line of business, or from firms producing completely different products, but with 'relevant' technologies underlying their production process.

Within the various forms of spillovers, Griliches argued that spillovers embodied in products form a specific category. For example, one may imagine a firm using computers in its production process benefitting from technological developments in the computer industry. The extent to which, for example, improvements in the calculation speed of the new computer has an impact on the productivity of the computer-using firm may be assumed to be proportional to the investment in new computer equipment that the firm undertakes. The more old computers it replaces by new computers, the higher the productivity gains will be. However, there is one problem with this line of reasoning. Computers are traded goods, and one would expect that increased performance of computers would therefore be reflected in higher prices. If, for example, the computer industry would consist of only one firm, and demand would be perfectly inelastic, this monopolist would have the bargaining power to make the computer-using firms pay a price which reflects the increase in performance completely, i.e., the price-quality ratio would remain constant. In this case, there would be no spillovers at all, because the computer-using firm will not experience any increase in productivity (the 'physical' productivity gains, e.g. in terms of the number of calculations per unit of time, will be completely offset by increases in the price it has to pay for computers).[1]

The reason that one does not see such a situation in practice (in the above example, computer prices have been falling steadily over the last decades, while performance, at the same time, has been going up drastically) is that in reality markets are not completely concentrated, and demand is elastic to some extent. The more competitive an industry is, and the higher the price elasticity of demand, the lesser the extent to which price increases will be offsetting the quality increases. Thus, we would expect that these spillovers would not only be related to the magnitude of the trade flows, but also to the market structure in the supplying and using industries.

Griliches (1979) termed this form of spillovers 'rent spillovers', because they are crucially related to the rents of both the receiving and supplying firm. On a different, more semantic level, Griliches (1992) has argued that as long as goods are being traded between the supplying and receiving party, there are no 'real' externalities, in the strict

---

[1] Implicit in this discussion is the assumption that performance increases of the investment good result from technological change, i.e., they are not matched by proportionate increases of the production costs for the investment good-producing firm.

sense of the word, involved. Although one might therefore argue that the term 'spillover' is less appropriate in this case, there is no need to abandon the terminology as long as it is clear that rent spillovers involve a different process than the pure knowledge spillovers, the other form of R&D spillovers that Griliches noted.

Knowledge spillovers are true externalities: in principle, they do not involve any market transactions (although, obviously, knowledge spillovers may occur between parties who are involved in market transactions), so they are the real instance of the public goods aspects of technology that were discussed above. In summary, rent spillovers are mainly related to the market structure in the technology-producing industries, while pure knowledge spillovers stem from the nonrival and nonexcludable character of technology.

III. Measurement Issues

In the empirical literature, it has become standard practice to transform R&D expenditures into a stock measure (by summing over some period of time, and applying a depreciation rate, usually fixed), and to relate this stock to productivity performance of the firms, sector or nation. The stock idea captures the notion that knowledge is cumulative, i.e., that it is not only presently developed knowledge that matters. By assuming depreciation of the knowledge stock the notion that newly developed knowledge makes some of the older knowledge obsolete (e.g., digital technology rendered analog computers obsolete) is captured as well. By calculating two R&D stocks, one consisting of 'own' R&D efforts, and the other of R&D efforts by other firms (or sectors, or nations), one may estimate different elasticities (or rates of return) with regard to 'direct' and 'indirect' R&D, the latter of which is taken as R&D spillovers. This is also the approach that will be adopted in this paper.

An important consideration in this approach is which R&D expenditures to include in the indirect R&D stock. As was argued by Jaffe (1986) in the context of a firm study, and later on by Park (1995) in the context of international spillovers, R&D undertaken by one firm may be more relevant than R&D by another firm. This does not necessarily have to be related to 'technological similarity' (as Jaffe and Park argue) between firms, however. A firm undertaking research in computer technology, for example, may benefit more from R&D by firms in electronics than from R&D by other firms in computer technology. This 'intersectoral' nature of technology spillovers was the subject of studies like, e.g., Scherer (1982), Putnam and Evenson (1994) and Verspagen (1997). In these studies, so-called technology flow (or spillover) matrices were constructed which quantify the technology flows between sectors.

Scherer (1982) and Putnam and Evenson (1994) take the perspective of 'innovation-producing' sectors and 'innovation-using' sectors. For example, the development of a new type of plastics will be 'produced' in the chemicals industries, and 'used' in the plastics products industry. Such an 'input-output' line of reasoning, as argued by Verspagen (1997), is a natural extension of Griliches' (1979) concept of rent spillovers.

Pure technology spillovers, as argued above, are not directly related to such input-output relations. Verspagen (1997) proposed three different matrices to measure such spillovers from a more 'technology-oriented' perspective (see also Grupp 1996). It was argued that these methods are more in line with Griliches' concept of pure knowledge spillovers. The first two of the three methods use data from the European patent office, which assigns each patented invention to a single 'main technology class', and one or several 'supplementary technology classes'. A concordance scheme between the technological classes (so-called IPC) and industries (ISIC, rev. 2) assigns both the main technology class and the supplementary technology class to an industry. The main technology class is taken as an indication of the industry that generates the knowledge, and the supplementary technology class is taken as an indication of a spillover-receiving firm.

This paper will, in order to keep the number of regressions to be presented within reasonable limits, only use the first of the two matrices based on EPO data. A third spillover matrix in Verspagen (1997), which is constructed using data from the U.S. patent office on the basis of patent citation information, will also not be used.[2] The results for the first EPO matrix will be compared to those for the matrix constructed by Putnam and Evenson (1994). The latter is taken as aimed at measuring rent spillovers, the matrix from Verspagen (1997) as aimed at measuring pure knowledge spillovers. The matrix constructed by Putnam and Evenson is known as the 'Yale matrix', terminology that will be used to identify this approach below.

The present paper constructs indirect R & D stocks on the basis of these spillover matrices by summing over R & D performed by firms

---

[2] The interested reader is referred to Verspagen (1997) and Los and Verspagen (1996) for differences between estimations based on all three matrices.

in different sectors and different countries, and using the spillover matrices as well as trade flows as weights in the summation (formal definitions will be given below). The current approach thus extends on the approach by Coe and Helpman (1995) by using sectoral data and assuming a different a priori weighting scheme for sectoral technology linkages: in the current approach these are based on explicit measuring on the basis of patent statistics, while equal weights of one were (implicitly) assumed by Coe and Helpman.[3]

IV. The Empirical Approach and Construction of the Variables

This paper uses the approach that was pioneered by Griliches and Mairesse (1984) in the context of a micro-level study on the determinants of R&D on productivity. It starts from a simple Cobb-Douglas production function

$$Q_{ijt} = A_{ij}\, K^{\alpha}_{ijt}\, L^{\beta}_{ijt}\, RD^{\varrho}_{ijt}\, IRD^{\delta}_{ijt}\, IRF^{\phi}_{ijt}\,, \qquad (1)$$

where Q is production, A is a scale variable, K is the capital stock, L is labour input, RD is 'own' R&D, IRD is domestic 'indirect' R&D, and IRF is foreign 'indirect' R&D (all R&D variables are measured as stocks, see below). The subscripts i, j and t refer to a country, sector and period, respectively, while α, β, ϱ, δ and ϕ are elasticities that will be estimated. Expressing all variables except indirect R&D in labour-intensive form, taking logs and denoting $\lambda = \alpha + \beta + \varrho - 1$, this can be written as

$$q - l = a + \alpha(k - l) + \lambda\, l + \varrho\,(rd - l) + \delta\, ird + \phi\, irf\,. \qquad (2)$$

Smaller-case letters denote (natural) logs, subscripts are suppressed for simplification. Note that when $\lambda = 0$, the production structure is characterized by constant returns to scale with regard to the sector's 'own' inputs (including R&D). For estimation purposes, an error term is appended to this equation.

---

[3] Coe and Helpman (1995: 863), commenting on the type of spillover matrices used in this paper, state that "in microeconomic studies of technological spillovers it is common to seek a metric, such as 'technological closeness', in order to gauge the intensity of spillovers ... In our case it is most natural to use import shares as measures of intensity. This is the more so whenever productivity gains are related to imports of intermediate inputs as exemplified by the theoretical model". From the point of view adopted here, this remark is besides the point, because the two weighting schemes are applied for different purposes: the matrices capture intersectoral spillovers, while import shares capture the international distribution of spillovers. Only a combination of the two can provide a full picture.

All data used to construct the variables are taken from the OECD STAN, ANBERD and BITRA databases (with two exceptions noted below). Output is measured as value added in constant prices (directly taken from STAN, which applies sectoral producer price indices) and PPP to the US dollar, labour as the number of persons employed (data on hours worked were unavailable). The capital stock is constructed by applying a perpetual inventory method to the time series for investment (converted into constant prices, in investment PPP to the US dollar, the latter taken from the Penn World Tables), according to

$$K_t = (1 - \psi)\, K_{t-1} + I_t, \tag{3}$$

where ψ is the exogenous deprecation rate (assumed to be 0.15), and I is investment. The initial capital stock (at time t) is calculated as I_{t+1} times 5, consistent with an initial growth rate of the stock of 5 per cent. A similar approach (also using a value of 0.15 for the depreciation rate and an assumed initial growth rate of 5 per cent) is used to construct the knowledge stocks at the sectoral level, using R&D expenditures instead of investment in fixed capital. In this case, a specific deflator is not available, and the PPP for GDP (again from the Penn World Tables) is used to convert to a common currency. In the estimations, the two first observations for the knowledge and capital stocks were omitted, in order to avoid problems related to the initialization of these stocks.

The indirect knowledge stocks are calculated using the intersectoral and international weights. For the domestic indirect knowledge stock, *IRD*, this is done as follows:

$$IRD_{ik} = \sum_j \omega_{jk}\, RD_{ij}(1 - m_{ij}), \tag{4}$$

where m denotes the share of imports on the domestic market, ω_{jk} is the share of inventions made in sector j spilling over to sector k, as measured by either the 'Yale' matrix, or the pure knowledge spillover matrix, and i denotes the country. For the indirect international knowledge stocks, the definition is:

$$IRF_{ik} = \sum_h \sum_j \omega_{jk}\, RD_{hj}\, s_{ihj}\, m_{ij}, \tag{5}$$

where s_{ihj} is the share of country h in imports of goods j into country i. The import-weighting of the indirect R&D variables has a straightforward interpretation in the case of the Yale (rent spillovers) technology flow matrix: it forms only a natural extension of the embodiment idea that underlies the technology flow matrix in this case. In the case of pure knowledge spillovers (EPO matrix), the interpretation is perhaps less straightforward, because this matrix does not rely on assumptions regarding embodiment. However, in this case import-weighting is taken as an indicator of the degree of interaction between the countries involved, which is likely to have an impact in terms of to what extent spillovers flow between the countries. In addition to these theoretical reasons for import-weighting, there is also a very practical reason for applying these weights: because the technology flow matrices are assumed to be identical for all countries, the import-weighting introduces variation in the data for international indirect R&D variables (see also Mohnen 1995).

Finally, note that this paper follows earlier papers such as Verspagen (1997) and Van Meijl (1995) in setting the diagonal of the spillover matrix to zero ($\omega_{jj}=0$) when calculating domestic spillovers. The reason for doing so is that if the diagonals are relatively important, 'own' (direct) R&D and (domestic) spillovers will be correlated due to double counting, leading to multicollinearity. Setting $\omega_{jj}=0$, and noting that all estimations are performed for sectors, avoids double counting and internalizes intra-sectoral spillovers into the elasticity of 'direct' R&D. For foreign spillovers, there is no double counting, so there is no direct danger for multicollinearity (nor is it possible to 'internalize' spillovers similarly to the domestic case). Thus, the diagonal is not set to zero for foreign R&D spillovers.

V. Estimation Results

The available dataset is a panel of 22 sectors, 14 countries and, in principle, 19 years (1974–1992).[4] However, data for some of the years are missing, while in some cases, complete time series are missing. Thus, the panel is 'unbalanced'. Following Griliches and Mairesse (1984), two different estimation forms will be used. The first explores

---

[4] Countries: Australia, Canada, Denmark, (West) Germany, Finland, France, United Kingdom, Italy, Japan, Netherlands, Norway, Spain, Sweden, United States. Sectors (ISIC rev. 2 codes): food, beverages, tobacco (31), textiles, leather, footwear (32), wood and wooden products (33), printing and publishing (34), chemicals, excl. pharmaceuticals (351 + 352 – 3522), refined oil and related products (353 + 354), rubber and plastic products (355 + 356), glass, stone clay (36), ferrous basic metals (371), non-ferrous basic metals (372), simple metal products (381), machinery (382 – 3825), computers and office machines (3825), electrical goods (383 – 3832), radio, TV, telecommunication equipment and electronic components (3832), ships and boats (3841), automobiles (3843), aerospace (3845), other transport equipment (384 – 3841 – 3843 – 3845), instruments (385), other manufacturing (39).

the cross-section dimension of the data, and consists of doing an ordinary least squares estimate on the mean values over time for each country/sector combination. This is the so-called BETWEEN estimate. The second, so-called WITHIN estimate, consists of an ordinary least squares estimation on data from which the country/sector mean (over time) has been subtracted. This is equivalent to using the pooled data and including a dummy-intercept for each country/sector combination, and thus takes into account so-called fixed effects for each individual country/sector. This estimation form thus focuses on the time-series dimension of the data. (A possible third estimation, the TOTAL, which is an OLS on the full panel, is not documented in order to save space.)

The way in which the R&D stocks are constructed assumes that R&D becomes effective immediately, which is an odd assumption to make, given that one would expect that the effects of research only penetrate the production process after a certain lag. In order to avoid this problem, all R&D variables were lagged one year.[5]

Tables 1 and 2 document the BETWEEN and WITHIN estimations for various samples. For the complete sample, there are significant differences between the BETWEEN and WITHIN estimates in terms of the significance of the spillover variables. Domestic spillovers are significant and positive in both estimations (although for knowledge spillovers using BETWEEN only at the 7 per cent level with a t-value of 1.81), but are highest for the WITHIN estimates. Foreign spillovers are not significant, although positive, in the BETWEEN model. In the WITHIN model, the estimated elasticities for foreign spillovers are higher and significant. For knowledge spillovers, the elasticity for foreign spillovers is higher than for domestic spillovers, but for rent spillovers, the two are about equal.

Direct R&D and the capital-labour ratio are both significant and positive, and have plausible values in both the BETWEEN and

---

[5] In the case of direct R&D, this means that the right-hand side variable is the lagged R&D stock minus the current labour input (both taken in logs). Indirect R&D is not expressed in labour-intensive form. Estimations with different lag lengths (zero to four years) were performed. The general picture that emerged from this is that especially the parameter estimates for indirect R&D are sensitive to lagging. The other parameters, including the one for direct R&D do not change very much for different lags. For indirect R&D, the parameter values do not change very much between the estimations with positive lags, the major dividing line is between not lagging at all and lagging one year. Therefore, it was decided to run all subsequent regressions in this paper with all R&D values lagged one year. The results for other lag lengths are not presented here in order to save space, but are available from the author on request.

Table 1 – *BETWEEN-Estimations of the Basic Equation*

	α	ϱ	δ	ϕ	λ	a	adj. R^2
			Total sample				
Knowledge	0.426	0.068	0.029	0.012	−0.003	4.570	0.56
	12.88	3.73	1.81	0.74	−0.12	8.06	
Rent	0.427	0.052	0.056	0.025	−0.025	4.174	0.56
	13.65	2.74	2.59	1.66	−1.01	7.95	
			High-tech sample				
Knowledge	0.427	0.045	0.166	−0.033	−0.211	5.497	0.67
	4.20	0.65	2.52	−0.71	−2.33	3.01	
Rent	0.480	0.025	0.229	0.047	−0.233	2.580	0.68
	5.05	0.37	3.25	0.77	−3.01	1.19	
			Medium-tech sample				
Knowledge	0.322	0.104	0.008	0.025	0.043	5.012	0.47
	4.93	4.24	0.35	0.88	1.40	4.22	
Rent	0.322	0.084	0.043	0.030	0.010	4.797	0.47
	5.11	3.02	1.25	1.20	0.27	4.37	
			Low-tech sample				
Knowledge	0.331	0.018	0.020	0.051	0.039	4.789	0.35
	6.10	0.73	1.00	2.17	1.37	6.45	
Rent	0.311	0.035	0.016	0.036	0.034	5.301	0.34
	5.83	1.46	0.58	1.77	1.09	7.92	

Note: First line gives parameter estimate, second line corresponding t-value.

WITHIN estimations. The WITHIN estimates yield strongly negative values for the coefficient on labour, which points to strong decreasing returns to scale with respect to capital, labour and direct ('own') R & D. This seems to be an unrealistic result, but it is one that has been found by other studies on R & D and productivity (e.g., Griliches and Mairesse 1984). It might be the result of misspecification (see, e.g., Mairesse and Sassenou 1991, for a discussion). In order to test for the impact this has on the other elasticities, regressions were estimated in which labour was excluded as a separate factor, i.e., in which constant returns to scale were imposed. These showed no marked differences with respect to the results reported here. These regressions are available from the author on request.

Given the different production structure and differences in technological opportunities between sectors, one might indeed argue that the estimated elasticities vary between sectors. In Verspagen (1995), a

Table 2 – *WITHIN-Estimation of the Basic Equation*

	α	ϱ	δ	ϕ	λ	adj. R^2
Total sample						
Knowledge	0.302	0.077	0.095	0.133	−0.250	0.92
	18.00	7.85	8.56	13.71	−14.09	
Rent	0.298	0.054	0.138	0.130	−0.256	0.92
	17.75	5.31	11.31	13.47	−14.23	
High-tech sample						
Knowledge	0.157	0.111	0.115	0.101	−0.483	0.95
	4.00	4.14	5.23	4.44	−8.94	
Rent	0.169	0.009	0.282	0.080	−0.523	0.96
	4.55	0.32	9.68	3.42	−10.12	
Medium-tech sample						
Knowledge	0.421	0.130	0.081	0.079	−0.044	0.84
	13.45	5.01	2.86	4.20	−1.53	
Rent	0.435	0.143	0.058	0.062	−0.016	0.84
	14.12	5.77	2.72	3.57	−0.65	
Low-tech sample						
Knowledge	0.200	0.032	0.084	0.141	−0.433	0.88
	8.22	2.61	6.20	10.95	−15.83	
Rent	0.179	0.012	0.132	0.152	−0.440	0.88
	7.22	0.93	7.45	11.02	−16.11	

Note: First line gives parameter estimate, second line corresponding t-value.

distinction between high-, medium- and low-tech sectors proved fruitful for estimating the relationship between R&D and productivity. Tables 1 and 2 therefore document separate regressions for high-, medium- and low-tech sectors. The assignment of individual sectors into these broad categories is admittedly arbitrary, although it is based on mean R&D-output ratios. High-tech industries (ISIC, rev. 2 codes between brackets) include pharmaceuticals (3522); computers and office machines (3825); electronics (3832); aerospace (3845) and instruments (385). Medium-tech industries include chemicals (351 + 352 – 3522); machinery (382 – 3825); electricals (383 – 3832); automobiles (3843) and other transport (384 – 3841 – 3843 – 3845, includes among other things high-speed trains). All other sectors are classified as low-tech.

The results seem to indicate that there are indeed important differences between sectors with regard to all of the elasticities. The less significant results for spillover variables using the BETWEEN model remain: only domestic spillovers in high-tech and foreign spillovers in low-tech are significant for subsample BETWEEN estimates. For the WITHIN model, all spillover variables are significant. The elasticity of direct R&D, surprisingly, is highest in the medium-tech sectors. It is not significant in the high-tech or low-tech sectors for BETWEEN, and for WITHIN, significant estimates are only obtained in the knowledge spillovers variants of the equations.

In summary, it is clear that the impact of all three R&D variables that are considered in this paper differs between sectors. With regard to direct R&D, the picture is clear: the impact is highest in medium-tech industries, and lowest in low-tech industries. A more complicated situation emerges for indirect R&D. In medium-tech industries, the elasticities on domestic and foreign spillovers are about equal, in both variants of the spillover variables. This also holds for high-tech using knowledge spillovers, and low-tech using rent spillovers. Domestic rent spillovers in high-tech are much more effective than foreign (possibly indicating the importance of local user-supplier interfaces), whereas foreign knowledge spillovers are more effective than domestic in low-tech.

Comparing the estimated elasticities for equations with rent spillovers and knowledge spillovers shows differences indeed, although these are not always straightforward to interpret. There is no fixed pattern in which one type of spillovers generally yields higher elasticities than the other type. This makes it difficult to give an economic interpretation of the numeric differences, but the results do show that the results one gets depend on which of the two spillover concepts is used. Unfortunately, estimating an equation with both types of spillovers present proved to be uninformative due to multicollinearity problems.[6]

The comparison of the BETWEEN and WITHIN results provide an interesting perspective on the results of Coe and Helpman (1995). As Mohnen (1995) concludes, Coe and Helpman find relatively strong effects of international R&D spillovers when compared to other studies investigating this effect (such as Gittleman and Wolff 1995, and Verspagen 1994). The main methodological difference between those

---

[6] Estimating such an equation is possible, of course, but the individual parameter estimates on the two types of spillovers would be difficult to interpret due to the collinearity between the variables. For pure prediction purposes, however, this would not be a problem, but if one is interested, as is the case here, in the individual parameters, such an approach is not very useful.

papers and the Coe and Helpman study is that the latter use a WITHIN methodology, while the others used a setting that can be characterized as BETWEEN (a cross-country sample of means over time). The results here indicate that BETWEEN and WITHIN estimates may differ widely. It has to be noted, however, that the model here is different from that by Coe and Helpman. Not only did they use country-level data for a wider set of countries, not applying any other weighting than by imports, they also used TFP as a dependent variable, which, in effect, means they did not estimate α, but inferred it from the data in combination with the constant returns to scale (with regard to capital and labour) and perfect competition assumptions. Although one may conjecture that especially the latter makes a large difference with the results found here (because of the implausible value for λ found in the WITHIN estimates), the results also indicate that the various R & D elasticities are not very sensitive for including l.

It thus seems as if at least part of the strong evidence in favour of the importance of foreign knowledge spillovers found by Coe and Helpman (1995) results from their specific time-series focus, a point already suggested by Mohnen (1995). Adopting a cross-country/sector focus, at least in the results here, makes a world of difference, leading to a much smaller impact of (international) spillovers.

The results presented in this paper do not have much to say about the reasons underlying the differences between the time-series and cross-section perspectives. One interpretation is that part of it might be related to differences in the ability of individual countries to assimilate (foreign) R&D spillovers. In a time-series perspective like the WITHIN model, such differences are likely to be picked up in the (implicit) time series-specific dummy variables, which is impossible in a cross-section (BETWEEN) framework. Thus, leaving differences in capability to assimilate spillovers out of the analysis may distort BETWEEN estimates (due to misspecification), while leaving WITHIN estimates relatively unaffected. This is not to say that the WITHIN estimates are not valid. They do, however, seem to leave out a significant part of the story on spillovers, namely that spillovers are not 'automatic' but depend on the receivers' capability to assimilate spillovers.

One might even speculate further, and argue that such differences with regard to the capability to assimilate spillovers would be less prominent in the case of rent spillovers than the case of pure knowledge spillovers. The reason for this would be that in the case of pure rent spillovers, less 'originality' or 'creativity' is required to incorporate these spillovers in a firm's own production process. Using a piece of machinery, even if it is innovative and new, is 'easier' than implementing and using the results of another firm's R&D in one's own innovation process. Thus, it could be expected that the differences between the WITHIN and BETWEEN estimates would be larger in the case of pure knowledge spillovers than in the case of rent spillovers. This is indeed the case: for rent spillovers, the BETWEEN estimates still yield 'somewhat significant' results, while for pure knowledge spillovers, *t*-values drop below any acceptable levels.

The time-series perspective of the WITHIN estimations introduces another danger into the analysis, related to the possibility of spurious correlation due to non-stationarity of the main variables in the analysis. If the variables in the analysis are indeed non-stationary, the results of estimates using levels as in Table 2 are only useful in case they can be regarded as co-integration relationships. (The BETWEEN estimates lack a time dimension, so they do not suffer from this problem.) The analysis here does not explicitly test for non-stationarity of the variables, nor for co-integration of the estimated equations in Table 2. The reason for this is that the time series are relatively short (about 20 years at most), and that techniques for testing for non-stationarity using the panel dimensions of the data are relatively undeveloped yet (see Los and Verspagen 1996, for an application and discussion of R&D variables at the firm level).

Instead, the issue is tackled by estimating an error correction model (ECM) variant of the Cobb-Douglas equation applied so far, using the Engle-Granger 2-step procedure (see e.g., Banerjee et al. 1993). This procedure, similar to Coe and Helpman (1995), amounts to estimating the WITHIN model in levels as in Table 2, calculate the residuals from this regression, and include them (lagged one period) in a first difference version of the original model. If the estimated relationship is a co-integrating one, the lagged residual will turn up negatively, indicating the variables move towards their long-run equilibrium (as indicated by the parameter estimates of the model, the so-called co-integration vector). The (first-step) estimated elasticities from such a model can thus be interpreted as true long-run relationships between the variables involved.

Table 3 documents the results from this procedure. Note that WITHIN estimates were used in the (first step) level estimations (an alternative would have been to use TOTAL estimations here). This means that although no dummy variables were included in the second step (estimation on first differences), the results do account for fixed

Table 3 – *Error Correction Model Estimates (Based on WITHIN-Level Estimates)*

	α	ϱ	δ	ϕ	λ	res (−1)	adj. R^2
			Total sample				
Knowledge	0.203	0.102	0.034	0.049	−0.232	−0.252	0.19
	8.40	7.36	3.88	4.99	−7.77	−23.50	
Rent	0.187	0.090	0.064	0.075	−0.236	−0.257	0.19
	7.61	6.37	4.80	5.76	−7.87	−23.70	
			High-tech sample				
Knowledge	0.159	0.177	0.025	0.061	−0.282	−0.253	0.16
	2.85	4.83	1.15	2.80	−3.75	−10.91	
Rent	0.143	0.137	0.083	0.074	−0.273	−0.287	0.19
	2.58	3.60	2.95	2.54	−3.67	−11.83	
			Medium-tech sample				
Knowledge	0.348	0.078	0.022	0.032	−0.104	−0.266	0.18
	8.35	2.44	1.01	1.42	−1.97	−11.84	
Rent	0.339	0.074	0.065	0.036	−0.119	−0.272	0.18
	7.96	2.33	1.86	1.57	−2.21	−11.89	
			Low-tech sample				
Knowledge	0.087	0.084	0.040	0.045	−0.342	−0.257	0.21
	2.38	5.15	3.99	3.76	−7.93	−17.35	
Rent	0.061	0.071	0.061	0.105	−0.339	−0.251	0.21
	1.62	4.27	3.84	5.32	−7.81	−17.01	

Note: First line gives parameter estimate, second line corresponding t-value.

effects, and should properly be compared to the static estimations in Table 2.

The ECM estimates generally yield higher elasticities for direct R&D and lower elasticities for R&D spillovers. The medium-tech sample is an exception to this, where direct R&D has lower elasticities. For the sample as a whole, the significant and positive impact of R&D spillovers remains present. In medium-tech, however, the significant impact of spillovers largely vanishes in Table 3, only domestic rent spillovers are significant (although at the 6 per cent level, with a t-value of 1.86). Otherwise, only domestic knowledge spillovers in high-tech are insignificant, whereas spillovers in low-tech sectors remain positive and significant throughout.

Overall, the results in this section suggest that R&D spillovers, either in the form of pure knowledge spillovers or in the form of rent spillovers, are indeed an important factor in explaining international differences in productivity (growth). There is some, although indirect, evidence, however, that the receiving country's capability to assimilate such spillovers does matter.

VI. Total Factor Productivity and the Domestic and Foreign Sources of Its Growth

The analysis now turns to the underlying question in the paper: what are the sources of national TFP growth? In order to provide some insights into the implications of the estimation results with regard to this question, simulations were carried out in which the growth rate of TFP as predicted by the estimated ECM's for high-, medium- and low-tech in Table 3 were used. In order to do this, the predicted growth rate of TFP was first calculated at the level of the 22 sectors in each country, using the functional form (2) in combination with the parameter estimates in Table 3 and the underlying data on R&D stocks and import shares. Note that this assumes that R&D is the only source of TFP growth, or, in other words, TFP is not calculated as a residual, but rather as the summed effect of all three R&D variables. This implies that the TFP growth rates given here do not correspond with TFP growth rates that would result from the actual data, when calculated using the familiar residual formula.

The calculations were done for the growth rate of TFP and the R&D stocks over the 1980–1988 period. These results were weighted by 1980 sectoral shares in production to obtain a manufacturing-wide result. The effects related to direct R&D and domestic indirect R&D were aggregated into the domestic component of TFP growth, the effects related to the foreign indirect R&D variable were assigned to each of the 13 other countries. For three countries in the sample (Canada, Denmark, Spain), complete sectoral production data were not available, which is why they are excluded in the columns of Table 4.[7] This table gives the results of the calculations in terms of the

---

[7] In order to avoid problems with the availability of some of the underlying data on import shares and import propensities, the contributions of foreign countries to domestic TFP was calculated on the basis of the partial derivatives of the total foreign knowledge stock with respect to the knowledge stocks of the foreign countries, or in other words, import shares and import propensities were assumed to remain constant (1980 values of these variables were used). Thus, the equation for the contribution country *k* to country *i*'s TFP growth rate in sector *j* is calculated as $\left(\sum_{l} \omega_{lj}\, R\dot{D}_{kl}\, s_{ikl}\, m_{il}\right) / IRF_{ij}$. The dot indicates the change from 1980 to 1988 of the R&D stock variable.

Table 4 – *The Simulated Impact of (Foreign) R&D on TFP Growth, in per cent of Total TFP Growth over 1980–1988*

	AUS	DEU	FIN	FRA	GBR	ITA	JPN	NLD	NOR	SWE	USA
					Knowledge spillovers						
AUS	36	0	0	0	1	0	0	1	1	0	1
DEU	7	47	8	9	10	7	2	11	9	8	15
FIN	0	0	32	0	1	0	0	1	0	0	1
FRA	3	3	3	31	4	3	2	3	3	3	6
GBR	2	1	2	1	12	1	0	2	2	1	3
ITA	2	2	2	2	2	45	1	3	2	2	3
JPN	17	14	17	21	26	16	71	29	22	20	32
NLD	1	0	0	1	1	1	0	21	1	1	1
NOR	0	0	0	0	0	0	0	0	16	0	0
SWE	1	1	1	1	2	1	0	2	2	32	2
USA	29	30	34	31	41	25	23	25	41	30	33
CAN	1	1	1	1	2	1	1	1	1	1	2
DNK	0	0	0	0	0	0	0	0	0	0	0
ESP	0	0	0	1	1	0	0	1	1	0	1
					Rent spillovers						
AUS	22	1	0	1	1	0	0	1	1	1	1
DEU	11	33	9	11	10	8	5	13	9	10	15
FIN	1	1	20	1	1	1	0	1	1	1	1
FRA	4	3	3	19	4	3	2	4	3	3	5
GBR	2	1	2	1	9	1	1	2	2	1	2
ITA	2	2	2	2	2	34	1	3	2	2	4
JPN	23	25	23	28	29	22	69	35	26	26	39
NLD	1	1	1	1	1	1	0	9	1	1	1
NOR	0	0	0	0	1	0	0	1	8	0	1
SWE	2	1	1	1	2	1	1	2	1	19	2
USA	30	31	36	32	38	26	19	28	43	34	25
CAN	2	2	1	1	2	1	1	2	1	1	3
DNK	0	0	0	0	1	0	0	1	1	0	1
ESP	1	1	1	1	1	1	0	1	1	1	1

Note: Countries in rows are 'TFP-generating countries', countries in columns 'TFP-receiving countries', i.e., cell with row USA and column NLD means TFP growth in the Netherlands generated by R&D stocks in the United States. Bottom row of each sub-block (without country label) indicates TFP growth (per cent) over 1980–1988 due to R&D. Calculations on the basis of regression results in Table 4 and the underlying data in those regressions.

percentage share that each country contributes to the TFP growth of the other countries. The rows give R&D/TFP-generating countries, the columns R&D/TFP-receiving countries. For example, the line for the United States in the upper block of the table shows that the United States contributes 23 per cent of the total TFP growth in Japan (the lowest value), and 41 per cent of TFP growth in the United Kingdom and Norway (the highest values).

It has to be kept in mind that these results are based on WITHIN estimations, which, compared to TOTAL or BETWEEN estimations, yield relatively high elasticities for foreign indirect R&D. Similar calculations carried out for TOTAL estimations show markedly higher contributions of domestic R&D (these are available on request from the author). Given this framework, it turns out that the domestic contributions to TFP growth are larger when using pure knowledge spillovers instead of rent spillovers. Pure knowledge spillovers thus appear to be more 'local' than rent spillovers. Overall, the domestic contributions to TFP growth are small, typically less than one third of total TFP growth. Japan stands out as having a high value for the domestic contribution of R&D.

The United Kingdom, Norway and the Netherlands stand out with low values of domestic TFP growth. There are three countries which have a relatively large impact on other countries' TFP growth: Germany, Japan and the United States (in increasing order of importance).

VII. Conclusions and Summary

This paper adds to the recent literature on international R&D spillovers. Starting from a discussion of the different types of spillovers and the channels through which they occur, the paper proposes to use so-called technology flow matrices to quantify international spillovers at a sectoral level. Two such matrices were used. One of these, developed by Putnam and Evenson (1994), was argued to be capturing so-called rent spillovers, which result from the trade of improved products. The other one, developed by Verspagen (1997), aims at measuring so-called pure knowledge spillovers, which are related to the non-complete appropriability of technology developed by firms. (See Griliches 1979, for more details about the distinction between rent spillovers and pure knowledge spillovers.)

The technology flow matrices measure the proportion of technology efforts in each sector that spills over to each other sector. By applying these proportions as weights together with import-share weights, the stocks of so-called 'indirect' R&D (one stock for R&D from domestic sources, and one for foreign sources) were calculated for a panel of 22 sectors, 14 countries and 19 years. A production function was estimated in which the stocks of indirect R&D were included alongside with direct (i.e., within-sector) R&D, the capital-labour ratio, and labour input.

The results of this exercise point out that the strongest effects (in terms of the estimated size of the elasticities) are obtained when applying a pure time-series perspective, i.e., when estimating a fixed effects (WITHIN) model. The results are weaker when estimating in the cross-section dimension. In the latter case, the estimated elasticities for rent spillovers drop to a 10 per cent significance level or lower, whereas the pure knowledge spillovers drop below the 10 per cent significance level altogether.

This result is consistent with the literature on international technology spillovers that does not apply technology flow matrices (but instead estimates on country-aggregated data). In this literature, the analysis by Coe and Helpman (1995) stands out for its strongly significant results. The present results suggest that at least part of this strong correlation is due to the time-series perspective. Other papers on the subject, such as Gittleman and Wolff (1995) applied a cross-section perspective, and found non-significant results on international R&D spillovers.

It was argued that this result might be due to the fact that foreign R&D is more effective in some countries than in others, or, in other words, that a country's capacity to assimilate foreign knowledge spillovers (in any form) matters. This would be consistent with finding more significant and higher parameters for foreign R&D in a time-series context as compared to the cross-country/sector domain. It also seems plausible that this holds to a larger extent for pure knowledge spillovers than for rent spillovers. Future research on models like the one by Coe and Helpman or the present one may yield additional conclusions on this matter.

The WITHIN model was also estimated as an error correction model, using the Engle-Granger 2-step procedure, in which the significant negative coefficient on the lagged residuals from level estimations pointed to co-integration. The general significance of the proposed R&D variables was confirmed by this procedure, although the values of the parameter estimations in the ECM turned up somewhat different from the level estimations (as expected).

With regard to the distinction between rent spillovers and pure knowledge spillovers, the results indicate that this distinction is relevant to the debate on international R&D spillovers and their relation through trade. The estimation results show that the distinction between the two technology flow matrices does have an impact on the estimated elasticities of foreign and domestic indirect R&D.

Finally, some simulations were undertaken with regard to the contribution of foreign R&D to R&D-related TFP growth on the basis of the estimation results. This analysis is aimed at providing insight into the answer to the practical question as to what is the 'foreign' contribution to domestic productivity growth. The estimated contributions of foreign R&D sources to domestic TFP growth, estimated using the 'optimistic' WITHIN-ECM coefficients, turned out to be substantial: on average, around two thirds of total TFP growth for the case of pure knowledge spillovers, and somewhat higher for rent spillovers. Thus, pure knowledge spillovers turn out to be more local than rent spillovers. On the TFP-generating side, the United States, Japan and Germany stood out as the main countries having an impact on other countries' TFP growth.

Overall, these results underline the importance of international and domestic R&D spillovers for productivity growth in the major OECD countries. The different ways in which this impact is being estimated, seems to suggest that there are indeed many ways in which these spillovers work. A simple interpretation, either in the form of R&D spillovers embodied in purchased inputs, or in the form of knowledge freely floating across international borders is not favoured, rather the evidence points to a mix of these different ways being at work simultanously. Econometric exercises like the present can underline the importance of R&D and its spillovers for growth, but the usefulness in quantifying the mechanisms through which these effects occur remains, until now, limited, due to problems with multicollinearity and the relatively rough nature of the available indicators.

References

Abramovitz, M. (1979). Rapid Growth Potential and Its Realization: The Experience of the Capitalist Economies in the Postwar Period. In E. Malinvaud (ed.), *Economic Growth and Resources, Vol. I.* London: Macmillan.

— (1994). The Origins of the Postwar Catch-Up and Convergence Boom. In J. Fagerberg, B. Verspagen, and N. von Tunzelmann (eds.), *The Dynamics of Technology, Trade and Growth.* Aldershot: Edward Elgar.

Banerjee, A., J. Dolado, J. W. Galbraith, and D. F. Hendry (1993). *Co-Integration, Error-Correction, and the Econometric Analysis of Non-Stationary Data.* Oxford: Oxford University Press.

Coe, D. T., and E. Helpman (1995). International R&D Spillovers. *European Economic Review* 39 (5): 859–887.

Cohen, W. M., and D. A. Levinthal (1989). Innovation and Learning: The Two Faces of R&D. *Economic Journal* 99 (September): 569–596.

Denison, E. F. (1967). *Why Growth Rates Differ: Postwar Experience in Nine Western Countries.* Washington, D. C.: The Brookings Institution.

Fagerberg, J. (1994). Technology and International Differences in Growth Rates. *Journal of Economic Literature* 32 (3): 1147–1175.

Gittleman, M., and E. N. Wolff (1995). R&D Activity and Cross-Country Growth Comparisons. *Cambridge Journal of Economics* 19 (1): 189–207.

Griliches, Z. (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. *Bell Journal of Economics* 10 (1): 92–116.

— (1992). The Search for R&D Spillovers. *Scandinavian Journal of Economics* 94 (Suppl.): S29–S47.

Griliches, Z., and J. Mairesse (1984). Productivity and R&D at the Firm Level. In Z. Griliches (ed.), *R&D, Patents and Productivity.* Chicago: University of Chicago Press.

Grossman, G. M., and E. Helpman (1991). *Innovation and Growth in the Global Economy.* Cambridge, Mass: MIT Press.

Grupp, H. (1996). Spillover Effects and the Science Base of Innovations Reconsidered: An Empirical Approach. *Journal of Evolutionary Economics* 6 (2): 175–197.

Jaffe, A. B. (1986). Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value. *American Economic Review* 76 (5): 984–1001.

Lichtenberg, F., and B. van Pottelsberghe de la Potterie (1996). International R&D Spillovers: A Re-Examination. NBER Working Paper 5668. Cambridge, Mass.

Los, B., and B. Verspagen (1996). R&D Spillovers and Productivity: Evidence from U.S. Manufacturing Microdata. MERIT Research Memorandum 96-007. University of Limburg. Maastricht.

Lundvall, B.-A. (ed.) (1992). *National Systems of Innovation: An Analytical Framework.* London: Pinter.

Mairesse, J., and M. Sassenou (1991). R&D and Productivity: A Survey of Econometric Studies at the Firm Level. *STI Review* 8: 9–43.

Mohnen, P. (1995). Some Estimates of International R&D Spillovers. Paper presented at the Tip Conference "The Emerging Knowledge-based Society", September 21–22, Vienna.

Nadiri, M. I. (1993). Innovations and Technological Spillovers. NBER Working Paper 4423. Cambridge, Mass.

Nadiri, M. I., and S. Kim (1996). International R&D Spillovers, Trade and Productivity in Major OECD Countries. Economic Research Reports 96-35. C. V. Starr Center for Applied Economics, New York.

Park, W. G. (1995). International R&D Spillovers and OECD Economic Growth. *Economic Inquiry* 33 (October): 571–591.

Putnam, J., and R. E. Evenson (1994). Inter-Sectoral Technology Flows: Estimates from a Patent Concordance with an Application to Italy. Yale University, mimeo.

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy* 98 (5, part 2): S 71 – S 102.

Scherer, F. M. (1982). Inter-Industry Technology Flows and Productivity Measurement. *Review of Economics and Statistics* 64 (4): 627–634.

Terleckyj, N. E. (1974). Effects of R & D on the Productivity Growth of Industries: An Exploratory Study. Report 140. National Planning Association, Washington, D.C.

Van Meijl, H. (1995). Endogenous Technological Change: The Case of Information Technology. PhD. Thesis. University of Limburg, Maastricht.

Verspagen, B. (1994). Technology and Growth: The Complex Dynamics of Convergence and Divergence. In G. Silverberg and L. Soete (eds.), *The Economics of Growth and Technical Change*. Aldershot: Edward Elgar.

— (1995). R & D and Productivity: A Broad Cross-Section Cross-Country Look. *Journal of Productivity Analysis* 6 (2): 117–135.

— (1997). Measuring Inter-Sectoral Technology Spillovers: Estimates from the European and US Patent Office Databases. *Economic Systems Research* 9 (1): 49–67.

* * *

Abstract: Estimating International Technology Spillovers Using Technology Flow Matrices. – This paper investigates the impact of international R & D spillovers on sectoral growth patterns in OECD countries. It applies panel regression techniques to a time-series cross-section panel. It arrives at the conclusion that knowledge spillovers are an important contributor to economic growth. The estimation results are applied in the form of a 'simulation' of TFP growth per country, splitting (R & D-related) TFP into a component due to domestic R & D and one due to foreign R & D. The results also show that the United States and Germany are the most influential countries in terms of contributions to other countries' TFP growth. JEL no. O30, O47

*

Zusammenfassung: Die Schätzung internationaler Technologie-Spillover mit Hilfe von Technologiefluß-Matrizen. – Der Verfasser untersucht die Auswirkung internationaler Spillover von Forschung und Entwicklung (R & D) auf die sektoralen Wachstumsmuster in OECD-Ländern. Er wendet Panel-Regressionstechniken auf ein Zeitreihen-Querschnitts-Panel an. Dabei kommt er zu dem Schluß, daß die Spillover von Kenntnissen wesentlich zum wirtschaftlichen Wachstum beitragen. Die Schätzergebnisse werden in Form einer „Simulation" des Wachstums der totalen Faktorproduktivität (TFP) pro Land angewandt, wobei die (R & D-relevante) TFP aufgespalten wird in eine Komponente, die durch heimische Forschung und Entwicklung (R & D) verursacht worden ist, und eine, die auf ausländischer R & D basiert. Die Ergebnisse zeigen, daß die Vereinigten Staaten und Deutschland die einflußreichsten Länder sind im Hinblick auf den Beitrag zum Wachstum der TFP anderer Länder.