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ACCESS TO EXTERNAL KNOWLEDGE: AN EMPIRICAL ANALYSIS OF ALLIANCES AS SPILLOVER CHANNEL

by

R. VEUGELERS
K. DE BACKER

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Access to external knowledge: an empirical analysis of alliances as spillover channel

Reinhilde Veugelers **and** ***Koen De Backer***

KULeuven & CEPR Fellow *KULeuven*

Department of Applied Economics
Naamsestraat 69
3000 Leuven
Belgium

Abstract:

The theoretical IO literature has modeled the relationship between spillovers and cooperative (R&D)-agreements extensively; suggesting that spillovers induce cooperation as a means to internalize these involuntary effects, while cooperation simultaneously enhances voluntary spillovers through information sharing. The empirical literature on this topic however is scarce. This paper empirically assesses the interactions between alliances and transfers of knowledge. A first finding is that, consistent with the theoretical literature, the occurrence of alliances is correlated with traditional measures of (involuntary) spillovers, based on input-output relations and technology proximity. But not only R&D-cooperation corresponds to (the lack of) appropriability; the evidence shows that also non-R&D alliances are associated with transfers of knowledge. In a second part the impact of external know-how on the performance of industries in OECD-countries is analyzed. Following the association of alliances with spillovers, the impact of external know-how is weighted by the occurrence of alliances with the external source, based in the same industry or in other industries. Using information about 588 inter- and intra-industry R&D and non-R&D alliances formed in the period '86-'96, we find that industry R&D levels accessed through intra-industry R&D alliances have a negative impact on (the growth of) own productivity, while this effect is positive for industries with intra-industry non-R&D alliances. Know-how from other sectors has no significant impact on productivity, unless for those sectors with which R&D alliances are prevailing that extend beyond R&D to include production and/or distribution. In contrast to the findings in other studies, this effect of inter-industry spillovers is found to be negative.

Key words: spillovers, alliances, absorptive capacity
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Email: Reinhilde.Veugelers@econ.kuleuven.ac.be
Tel: 32 16 32 69 06
Fax: 32 16 32 67 32

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1. Introduction

The pervasiveness of networking has become a significant feature in current innovation practices. In view of the increasing complexity and multidisciplinary character of research, even the largest and most self-contained of organizations requires information from beyond its boundaries. Innovation increasingly derives from a network of companies interacting in a variety of ways, ranging from formal structures such as R&D consortia, joint ventures, to informal, implicit coordination, mutual exchange, "informal" know-how trading (von Hippel (1987). But companies can use also freely available information or involuntary spillovers from innovators in their innovation process.

In their strive for access to external know-how, the exploitation of complementarities between partners and sharing of risks and costs, firms increasingly revert to cooperative modes. The phenomenon of R&D cooperation has received considerable attention in the theoretical literature. Many I.O. models stress as important feature in cooperation, the utilization and protection of know-how. Cooperation is seen as a means to internalize involuntary spillovers. At the same time, cooperation allows firms to voluntarily optimize know-how transfers by sharing information. Alliances are therefore not only important to promote the creation of know-how, but at the same time can be an effective instrument in the diffusion of know-how. From an innovation policy point of view, the impact of R&D cooperation on the innovative capacity of a nation, should be assessed not only through its effect on increasing the stock of know-how, but also on its diffusion potential.

Despite the importance of alliances and diffusion, little empirical evidence exists, linking the two phenomenon, and its implications on firm, sector or country performance. So far, the empirical literature has focused on trying to measure spillovers and assessing their impact on innovative and growth performance. Typically information from input-output tables or patent information on technology users and suppliers is used to identify which agents generate spillovers and who receives spillovers. The conclusion of these studies (for an overview, see e.g. Geroski (1996), Griliches (1992)) seems to be that spillovers are important and have a substantial impact on productivity growth.

By using patent information or input-output tables, the existing empirical studies have only considered the impact of involuntarily flows of knowledge on performance. However there remains a large not yet analyzed area of voluntary spillovers, present in several forms of cooperation and joint ventures. Geroski (1996) concludes that:

> *"The rich information flows which connect innovation producers and users seems to me to be much more important than other involuntary flows between more widely dispersed agents. Whether upstream/downstream flows are truly spillovers is not clear, but there is a lot of evidence to suggest that many firms try to nurture them.*

Case studies often suggest that cooperative relations between innovation users and producers are a prime determinant of the success of innovative activities".

Also Griliches (1998) points to the importance of interaction between producers and users of knowledge instead of the rather freewheeling involuntary character of :spillovers:

> *"Knowledge is not like a stock of ore, sitting there waiting to be mined. It is an extremely heterogeneous assortment of information in continuous flux. Only a small part of it is of any use to someone at a particular point of time and it takes effort and resources to access, retrieve and adapt it to one's own use. Thus models of externalities must perforce be models of interaction between different actors in the economy."*

With cooperation a vehicle for voluntary know-how transfers and an instrument to respond to involuntary spillovers, alliances can be considered as a spillover channel to access externally available know-how, as alternative to the traditional spillover measures. This study provides an empirical analysis using alliances to assess the impact of external know-how on industry growth performance. After a review of the theoretical and empirical literature on R&D cooperation and alliances, section 4 presents a measure of inter and intra-industry spillovers, on the basis of the pattern of intra- and inter-industry alliances. Also included is a correlation analysis between the alliance matrix and the more traditional spillover-matrices and the results on productivity growth. The alliance data allow to explicitly take on board any difference between intra-industry and inter-industry cooperation, R&D and non-R&D alliances and the national versus international dimension.

2. *Theoretical perspectives on spillovers and R&D-cooperation*

A central element in theoretical IO models on horizontal R&D co-operation is how firms can utilize and protect their intellectual property. Voluntary or involuntary transfers of knowledge among firms generate important spillovers. The presence of such spillovers implies that a distinction must be made between a firm's innovative effort and its effective knowledge base, representing the total amount of knowledge available to the firm. This knowledge base results from its own R&D as well as from the R&D from other firms, to the extent that this R&D has spilt over. When anticipated by market participants such spillovers tend to complicate R&D cooperation strategies in a non-trivial way.

The Industrial Organization literature has modeled spillovers and R&D-cooperation extensively (e.g. Katz (1986), d'Aspremont and Jacquemin (1988), for an overview see De Bondt (1991)). The setting consists typically of competitors in the output market who have the choice between independent R&D and coordinating their R&D-investments[1]. The results suggest that R&D co-operation is most beneficial for technological progress when technology is difficult to keep proprietary. Indeed, although spillovers will increase the stock of effective knowledge and hence have a market expansion or cost reduction effect, large spillovers typically have a disincentive effect on the firm's levels of non-co-operative R&D. This disincentive effect has its full impact in a strategic two-stage model, where firms take into account that whenever knowledge leaks out to competing firms, this will have a negative impact on their own profitability, thus reducing the attractiveness of investing in R&D. Through co-operation in R&D, focusing on mutual interests, this externality problem can be overcome. In an industry-wide research joint venture, firms will internalize these spillovers, which will have a positive effect on R&D levels when leakage is high.

Not only will cooperating firms have a higher incentive to invest in R&D when spillovers are large, also the profits from cooperation increase with spillovers. The higher involuntary spillovers are, the more attractive and profitable R&D-cooperation is for firms in an industry.

The disincentive effect from spillovers is shaped by the product market competition. Firms producing differentiated products face a smaller competitive effect; which will lead to a lower critical spillover level, and a larger incentive to cooperate (De Bondt and Veugelers (1991)). Similarly, the negative impact of inter-industry spillovers on independent R&D-investments is smaller than the impact of intra-industry spillovers (Steurs, (1995)). Firms in one industry benefit from R&D of firms in another industry without suffering from the positive spillover externality on these firms (in case of independent industries). The internalization of the spillover-externality by inter-industry cooperation leads to higher R&D investments (relative to intra-industry cooperation) and higher profits.

Despite the ex ante profitability of collaboration, the stability of R&D agreements is often threatened by incentives for firms to cheat on their partners (e.g. Baumol (1993), Shapiro & Willig (1990)). What is learned from the expertise of the loyal partner can be used in own R&D projects. This matters especially when the partner is a (potential) competitor; given the importance of R&D in gaining a (long-term) competitive advantage. Hence, designing co-operative agreements should consider not only when they are profitable, but also stable, in the sense that no cheating would occur. Spillovers will not only affect the profits from collaboration, but also the incentives to cheat. Despite the supra noted conventional wisdom that spillovers increase co-operative profits, stable co-operation is easier to sustain when spillovers are low and this because of the lower incentives to cheat, at least when spillovers are exogenous and not influenced by the partners (see Kesteloot & Veugelers (1994)).

[1] Coordination of R&D-decisions does not allow joint R&D; synergies are not realized because of asset complementarity, a motive for R&D-cooperation often tackled in the empirical (management)

When spillovers are considered to be at least partly voluntary, firms that are partners in R&D co-operation can improve on the knowledge transfer among themselves, e.g. Kamien et al's Research Joint Venture typology where spillovers are perfect. [2] Larger incoming spillovers for partners through managing and sharing information; make R&D cooperation even more profitable. Hence, firms will typically have an incentive to maximally share information among partners. At the same time, information sharing stifles the incentives to cheat and hence makes cooperation more stable (Kesteloot and Veugelers (1994), Eaton & Eswaran (1997)). Apart from selectively sharing information between partners, the profitability and stability of R&D-cooperation is further enhanced by protecting information (i.e. limiting outgoing spillovers) against free riding of non-partners.

In the mainstream I.O. models firms are perfectly symmetric, they receive as much spillovers as they generate themselves. Hence a joint occurrence of positive and negative effects from spillovers results. When allowing firms to manage technology flows, spillovers will typically be no longer symmetric. With endogenous spillovers, settings will arise where partners will receive more than they generate or vice versa, leading to asymmetries in benefits and losses from cooperation. The aim of managing intellectual property is to minimize the creation of spillovers, excluding others from sharing. At the same time firms want to maximize incoming spillovers. As already indicated, they can do so by cooperating with other firms in information sharing cartels. Alternatively or at the same time, they can try to increase incoming spillovers by investing in "absorptive capacity", an idea pioneered by Cohen & Levintahl (1989) and recently integrated in the I.O. models on R&D cooperation by Kamien & Zang (1998).

Asymmetries in terms of technological capabilities to generate and absorb know-how may seriously influence firm's benefits and costs from cooperation. Such asymmetries are but one example of differences among partners in collaboration and consequent costs and benefits to cooperation. More recent models take into account that asymmetries typically exist between firms; in terms of size or R&D efficiency, asymmetries that will influence the size of (incoming) spillovers and their impact on the incentives to cooperate. A particularly interesting scenario to examine is the group of alliances between leaders and followers. Arguments can be put forward why leaders may learn more from followers, an effect that is reminiscent of Cohen & Levintahl 's (1989) work on absorptive capacity. Leaders may be more able to effectively learn from others, to the extent that they have built up a larger know-how base, which serves to efficiently absorb. But there are also arguments to suggest that followers may learn more from leaders. The leader has a larger know-how base that can be tapped by the followers, who may still be far from diminishing returns to knowledge creation.

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literature.

[2] Endogenous spillover model are increasingly being used, see a.o. Bhattacharya, Glaser & Sappington (1987).

Sinha and Cusumano (1991) demonstrate that big firms have a larger incentive to cooperate since they are better positioned to capture the benefits of cooperation. Veugelers and Kesteloot (1995) find that R&D-cooperation is typically beneficial for the advantaged firm (in terms of productive efficiency, R&D efficiency and/or absorptive capacity), but such firms will only have an incentive to collaborate if they receive a larger share in the benefits of the alliance. The latter effect arises because the larger firm also has a larger incentive to cheat. Cooperation is only attractive for the disadvantaged firm if the asymmetries are not too large. Similarly, Röller et al (1997) find that while the high cost firm always has an incentive to participate in R&D co-operation, the low cost firm does not have an incentive to join whenever products are highly substitutable and the asymmetry is large.

Summarizing the insights from the mainstream theoretical literature, R&D collaboration seems to be positively associated with transfers of know-how, involuntary through the internalization incentive and voluntary through the incentives for information sharing in collaborative agreements. More recent extensions of the literature dealing with cheating incentives, endogenous spillovers and asymmetries in absorption and R&D efficiency among partners have indicated that the gains from cooperation from the know-how transfers associated with alliances are not unanimously positive and symmetric. Some firms may win more than others, some may loose; some cooperative agreements are more likely to be beneficial, others detrimental.

3. *The empirical literature on spillovers and R&D-cooperation*

In contrast to the theoretical literature that analyzed the central role of spillovers in the analysis of R&D investments and the comparison between non-co-operative and co-operative R&D behavior extensively, the empirical literature studied the linkage between spillovers and R&D investment and performance only recently (see Geroski (1996) for a review)).

To start with, spillovers are difficult to characterize empirically. The channels through which spillovers occur are manifold and determine the extent of spillovers. Levin et al (1987), find that based on survey data typical spillover channels are the movement of personnel, informal communication networks, meetings, input suppliers and customers, patent applications and reverse engineering (see also Mansfield (1985)). These studies also suggest that independent R&D is a very efficient channel for absorbing external knowledge. Also Harabi (1995) finds that independent R&D is the most effective channel of intra-industry spillovers for Swiss companies. These results seem to agree with the model of Cohen & Levintahl (1989), where firms need to conduct R&D to be able to assimilate spillovers.

Survey results for Flanders from Eurostat/CIS confirm that the most effective mechanisms to tap external sources are (in order of importance) purchase of equipment/reverse engineering, movement of personnel, communication with other companies, licenses and R&D outsourcing. For firms co-operating in R&D the same ranking prevails, but all of the modes are used more often than non-cooperating firms, (see Veugelers (1998), supporting a positive correlation between cooperation in R&D and involuntary spillovers. When the firms were asked to evaluate different mechanisms to protect the gains from innovation, legal instruments (patents and registration) are rated less important than firm strategies to protect the benefits from innovation (secrecy, complexity and lead time). Again companies active in R&D co-operation consider all of the various mechanisms to keep technological developments proprietary more crucial as compared to non co-operating firms.

A crude analysis linking spillovers with R&D cooperation is provided in Veugelers & De Bondt (1992), who use the results from Bernstein (1989), Levin & Reiss (1988) and Bernstein & Nadiri (1989) to classify the industries according to the importance of spillovers [3] and test whether R&D co-operation occurs more in high spillover industries. They find evidence for a significantly higher number of joint ventures occurring in high and medium spillover industries. Also the frequency of more informal co-operative agreements is higher in these industries. All this strongly suggest that for firms both the creation and absorption of knowledge transfers are important for firms cooperating in R&D.

Having empirically identified the importance of spillovers, assessing the impact of spillovers on R&D and performance is the next step.

Empirical research specifically focusing on the relation between spillovers and R&D-cooperation is rather limited. Brandstetter and Sakakibara (1998) as well as Henderson and Cockburn (1996) find some evidence that R&D-cooperation has a positive impact on research productivity, which they attribute to increased spillovers. In a paper by Cassiman and Veugelers (1998) the relationship between spillovers and R&D-cooperation is analyzed explicitly; firms which rate incoming spillovers as more important and which are able to limit outgoing spillovers are more likely to cooperate. At the same time cooperating firms have higher incoming spillovers and higher protection of know how; an indication that R&D-cooperation is used by firms to manage information flows.

Most of the empirical literature on spillovers analyzes the impact of external knowledge via spillovers on the performance of agents (firms, industries and countries...).[4] The framework typically used in these studies is:

Performance = f(own R&D, external R&D)

[3] High spillover industries are (tele)communcations, semi-conductors, instruments, chemicals and electronics. Medium spillovers industries are mainly the transport equipment industries . Low spillover industries include food & drink.

[4] This literature benefits from the new growth theory, which focus on knowledge and its externalities (e.g. spillovers) as source of sustained growth.

Because knowledge transfers are not perfect, a measure of distance is used in order to identify the agents from whom most knowledge spills over. The 'closer' generator and receiver are, the higher the level of spillovers is. Several weighting schemes for composing the external knowledge of the receiving agent are used, based on economic, technological or trade relations.

A first methodology assumes that spillovers follow the pattern of economic transactions (i.e. supplier –customer relations): customers receive spillovers because suppliers cannot perfectly discriminate between customers. This approach based on *input-output tables* (Terleckyj (1974), Sveikauskas (1981)), measures merely the so-called rent-spillovers and not necessarily knowledge spillovers[5] (Griliches (1979)).

A second methodology is targeted to measure the pure knowledge spillovers and is principally based on *patent information*, although a few papers use innovations as information source (Sterlachini (1989), Acs, Audretsch & Feldman (1992)). Patent information is used to identify producers and users of knowledge (Scherer (1982)); The so-called Yale studies use information on producing sectors and principal uses, information which is directly available in some patent administrations (e.g. Canada). Another approach developed by Verspagen (1994) uses the distinction between main versus supplementary sectors available in the EPO-office, in order to identify users and producers of knowledge. Patent-citations are another source of information to trace spillovers, used e.g. by Jaffe, Henderson & Traijtenberg (1993) to look for geographical clusters. A somewhat different approach is used by Jaffe (1986), who constructs a technological distance between agents on the basis of the technological overlap between patents of different firms.

In order to account for international spillovers, Coe and Helpman (1995) use *trade relations* between countries in computing stocks of external knowledge. Foreign direct investment is another channel for transferring international spillovers (Lichtenberg and van Pottelsberghe de la Potterie (1996)).

A last approach is developed by Bernstein & Nadiri (1988), who instead of measuring spillovers, directly estimate spillover effects based on an adjustment-cost model of investment and factor demand. However the long time series of data needed often make this approach difficult to apply.

All these studies show that spillovers do exist and are likely to be substantial (Griliches (1992)). Spillovers appear to be present at all levels of aggregation, be it that the social rate of return differs between levels of aggregation; Griliches (1994) attributes this to the differing depreciation rates. On average the social rate of return on R&D (i.e. private return plus all the

[5] Rent spillovers arise because prices of intermediate inputs are not fully adjusted for quality improvements resulting from R&D-investments in upstream industries. Knowledge spillovers arise when the knowledge embodied in an industry's innovation contributes to innovations in another industry.

indirect effects) exceeds the private rate of return by 50% to 100% (for an overview see Mohnen (1996), Nadiri (1995)). A first glance at the results of different studies seems to suggest that rent spillovers contribute more to output or productivity growth than knowledge spillovers. However, such a comparison across studies is misleading given the different methodologies and assumptions regarding depreciation, lagged effects...). Furthermore only a few studies confront the different approaches in the same setting; these studies suggest the opposite, namely that the knowledge spillovers yield a higher return than rent spillovers. Verspagen (1997) for instance, finds that knowledge spillovers constructed via technology proximity matrices contributes more to the growth in TFP (total factor productivity) than rent spillovers on the basis of input-output matrices. A similar result is obtained by van Pottelsberghe de la Potterie (1997): knowledge 'technology flow' spillovers yield the highest return, followed by knowledge 'technology proximity' spillovers and input related spillovers.

Although the evidence points to the importance of spillovers in explaining the performance of agents, it is difficult to disentangle spillovers from other factors such as increasing returns or rent spillovers due to measurement error (Geroski (1996)). Furthermore typically in studies at the industry-level only inter-industry spillovers are taken into account; abstraction is made of intra-industry flows of knowledge. In line with the theoretical literature which identifies positive as well as negative effects, the empirical literature is unable to yield stylized results especially for intra-industry spillovers. Bernstein & Nadiri (1989) for instance, find intra-industry spillovers to lower unit costs, but simultaneously diminish the stock of own R&D, indicating the importance of the disincentive effect of spillovers. But other studies suggest the opposite, where spillovers stimulate own R&D to efficiently absorb external know-how (see Geroski (1996)). Cohen & Levinthal (1989) however find no convincing evidence for the absorptive capacity effect. Jaffe (1986) finds no significant effect of spillovers on the propensity to patent, nor on profits or market value of the firms, but a positive effect on the productivity of own R&D.

4. Empirical analysis

The theoretical IO literature points to the importance of voluntary, asymmetric flows of knowledge between cooperation partners. Empirical research however has focused thus far merely on the involuntary character of spillovers. Using information on alliances between companies, this paper analyzes the interaction between spillovers and cooperation and its impact on the performance of industries. At the same time, the difference between intra-industry and inter-industry cooperation is explicitly taken into account, as well the international character of spillovers. Furthermore the data allow to differentiate between the impact of R&D-cooperation and other forms of cooperation.

4.1 The K.U.L.-database on alliances

Alliances which appeared in the financial press in the period '86-'96 have been collected and coded on a number of characteristics such as organizational format, activity (production, distribution, R&D), sector in which alliance and partners are active, nationality of the partners... This collection procedure, which is common in other databases on alliances, may cause some misrepresentation, given that the more visible and high impact alliances have a larger probability of being announced in the press. The data collection process may cause also a geographical misrepresentation; given the importance of the Belgian financial press in gathering the data[6]. Belgian companies were clearly more present; and because of the significant differences of Belgian partners on a number of characteristics, these observations were excluded from the analysis.

The K.U.L. database provides a detailed instrument to proxy for the impact of spillovers on the performance of industries, taking explicitly into account the differential impact of intra-industry and inter-industry cooperation[7]. Although the K.U.L-database contains information on alliances in the manufacturing sectors as well as in the services sectors, only the 588 manufacturing-alliances are taken into account in the productivity analysis. A first order analysis points to the importance of intra-industry-alliances: almost 70% of the alliances is set up between sectors active in the same sector. [8] R&D cooperation forms a minority: only 9% of the alliances has been set up solely for R&D-activities; another 17% performs R&D activities in combination with production and/or distribution activities. More than 80% of the alliances is international in scope; i.e. the alliance is set up by partners of different countries.

4.2 Appropriability and alliances

Information about the sector in which the different partners are active, allows to construct an alliance- matrix. With rows and columns representing individual sectors in which alliance partners are active, the matrix proxies for know-how flows between sectors through alliances.

[6] Ghemawat et al (1986) using the Wall Street Journal, end up with a similar overrepresentation in their sample, this time of US companies.
[7] The majority of alliances is between two or three partners (respectively 97% and 3%); alliances with three partners are considered as three alliances between two partners: one alliance between partners one and two, a second alliance between partners one and three, and a third alliance between partners two and three.
[8] Given that sectors had to be defined on a rather aggregate basis, intra-industry alliances may still include vertical alliances as well. A notable example is the car manufacturing, which includes component manufacturers as well as assembly.

To the extent that alliances incorporate spillovers, this matrix identifies transfers of knowledge within and between sectors. On the diagonal are the intra-industry alliances, off-diagonal are the inter-industry alliances[9]. Because alliances are typically characterized by spillovers going both ways [10] ("quid pro quo") the matrix is symmetric with cells above and under the diagonal being equal.

In order to test how alliances are related to appropriability, the sectoral distribution of this alliance matrix is compared with these of the other matrices used in the empirical spillover literature. With input-output matrices and patent-matrices as proxy for involuntary spillovers, the correlation allows to analyze the relationship between the internalization of involuntary spillovers and cooperation

The benchmark matrices are 6 input-output matrices (USA, France, Germany, Italy, UK and Japan), the technology flow matrix of Yale, and three so-called technology proximity matrices (two matrices based on EPO-information (EPO A and EPO B) and one matrix based on USPO). The input-output matrices show the supply of intermediate products between sectors; (rent) spillovers are going from the generating sector (rows) to the receiving sector (columns). Both the technology flow matrix and the technology proximity matrices are based on patent information. The technology flow matrix (Yale matrix) is based on information directly available in the Canadian patent administration on principal producers (rows, spillover generating) and principal users (columns, spillover receiving) of knowledge. In constructing the technology proximity matrices, Verspagen (1984) used information available in the EPO-administration on main versus supplementary classes of patents for claimable and not-claimable knowledge. Linking classes to sectors by a concordance table, spillovers are going from the main sector (rows) to the supplementary sector(s) (columns). In the USPO matrix patent citations are used; spillovers are going from the cited patent-sector (rows) to the citing patent sector(s) (columns).

Van Pottelsberghe de la Potterie (1997) compared these matrices using factor- and cluster-analysis. The results point to the similarities between the input-output matrices on the one hand, and the technological matrices on the other hand. However, within the latter group of matrices, significant differences exist between the technology flow matrix and the technology proximity matrices.

Since the 'traditional' spillover matrices measure intra-industry spillovers poorly, only the correlations off-diagonal are tabulated. [11] The magnitude and the significance of the

[9] In the construction of the matrix only the number of alliances within and between sectors is considered; no information was available on the value of individual alliances.

[10] Consistent with the last footnote, no judgment is formed about the size of these spillovers. Spillovers may differ in size; dependent on the fact that partners are (not) actively managing spillovers.

[11] The low correlations between intra-industry alliances and the other matrices are explained by the failure of traditional matrices to measure intra-industry spillovers, rather than that it shows that alliances are no good proxy for spillovers within sector.

correlations between the alliance matrix and the other matrices used in the spillover literature, show that alliances are related to appropriability issues. Inter-industry alliances have a higher probability of occurrence when involuntary spillovers exist between those sectors. Not surprisingly, the pattern of inter industry pure R&D-alliances is reflecting the technology proximity matrices of Verspagen; which suggests that R&D-alliances incorporate knowledge spillovers. Also not surprisingly, alliances with exclusively production and/or distribution activities correlate significantly and most strongly with input-output matrices, reflecting the phenomenon of rent spillovers. But table 1 provides ample hints towards alliances capitalizing on a complementarity between rent and knowledge spillovers. This is most straightforward in alliances with a combination of R&D and production/distribution activities. Such inter industry alliances show a high correlation with input-output matrices as well with the more technology-oriented matrices; not surprisingly these alliances seem to be important channels to incorporate rent as well as knowledge spillovers. However, this observation is not exclusively valid for this group of alliances. The significant correlation between production/distribution alliances and technology-oriented matrices demonstrates that knowledge flows are not only important for R&D alliances but also for non-R&D alliances. Studies focusing exclusively on technological alliances are in this respect uncompleted. In addition, R&D alliances correlate with input-output matrices.

Table 1: Correlation between alliance-matrices and 'traditional' spillover matrices[12]

	Alliances exclusively R&D	***Alliances R&D and prod/distr***	***Alliances prod/distr***
Input-output matrices[13]			
IO – USA	0.17**	0.29**	0.26**
IO – FRA	0.02	0.09	0.20**
IO – GER	0.13**	0.25**	0.30**
IO – UK	0.28**	0.27**	0.31**
IO – IT	0.16**	0.24**	0.25**
IO – JAP	0.21**	0.30**	0.26**
Technology flow matrix[13]			
Yale	0.07	0.12**	0.11*
Technology proximity matrices[13]			
EPO A	0.25**	0.32**	0.19**
EPO B	0.25**	0.34**	0.22**
USPO	0.22**	0.29**	0.21**

**: 0.01 significance level;
* : 0.05 significance level;

[12] Because several 0-values are present off-diagonal in the alliance matrix, correlations are computed with 1 – 0 value (1 if alliances are formed between sectors, 0 if no alliances are set up), in order to prevent spurious correlation.
[13] Matrices are normalized by rows.

4.3 Performance and alliances

Building further on the theoretical and empirical link between alliances and spillovers, this paper proposes to use alliances as an alternative channel to access external know-how. Alliances with external partners can be used to weight the impact of know-how from external sources, not only since cooperation constitutes a mechanism for voluntary transfers of know-how, but also since alliances are linked to involuntary spillovers. To facilitate comparison with other studies using more traditional spillovers on the basis of input output relations or technology flows, the model uses a productivity growth model, which is standard in this literature, to include the impact of external know-how.

4.3.1 Empirical model and data

To asses the impact of R&D and spillovers on industry performance, an extended Cobb-Douglas production function is specified; this functional form is taken as a first approximation to a potentially much more complex relationship (Griliches (1979)):

$$Y = c\, K^{\alpha} L^{\beta} R^{\delta} e^{\lambda t + u} \qquad (1)$$

where Y is a measure of output, K and L are the traditional inputs capital and labor, R is a measure of cumulated knowledge; c is a constant, t is a time trend, e is the base of natural logarithms and u stands for all unmeasured factors.

After taking the logarithms and differentiating, a growth equation is obtained which will be estimated using OLS; α, β, λ and γ will be the estimated coefficients:

$$d\log Y = \lambda + \alpha\, d\log K + \beta\, d\log L + \gamma (RD/Y) + u \qquad (2)$$

In expression (2) the research efforts –term is written in intensity form by using the definition $\delta = dY/dR = \gamma(Y/K)$ and approximating $d\log R/dt$ by RD/Y with RD being R&D investments[14]. This assumes that depreciation is close to zero (which is a tenable assumption on industry level) and is consistent with a constant return of R&D instead of a constant elasticity. In order to control for heteroscedasticity, (2) is written in labor-intensive form (3):

$$d\log Y - d\log L = a + \alpha(d\log K - d\log L) + (\alpha+\beta-1)d\log L + \gamma(RD/Y) + u \qquad (3)$$

with λ representing the disembodied technical change and $(\alpha+\beta-1)$ being an indication of the level of scale economies.

Most variables are drawn from OECD databases, more specifically the STAN and ANBERD databases which are compatible. The analysis is done on a pool of 308 observations, made up of 22 manufacturing industries (defined on the ISIC Rev2 classification) for 14 OECD countries. Value added is taken as a measure of output (Y); gross fixed capital formation is used to compute the stock of capital (K) with the perpetual inventory method, labor (L) is the number of employees[15], RD is R&D-investments. All variables (except number of employees) are expressed in constant 1990 national currencies. Value added is deflated by industry and country specific deflators, capital investment by the country specific 'gross fixed capital price index, and R&D with the country and sector specific value added deflator[16].

In order to control for business cycle and capacity utilization fluctuations[17], all variables are averaged for the whole period; this at the same time mitigates the effects of not taken into account lagged effects of R&D, since the R&D-intensity is relatively stable over (a short period of) time.

Spillovers are included in the analysis by decomposing the knowledge term into own R&D investments and R&D-investments of other industries received as spillovers. While other studies use input-output matrices, technology oriented or trade matrices as weights in the construction of the external R&D-pools, this study proposes the use of alliance matrices to weigh external know-how. By engaging in alliances with external sources, industries can access external know-how to improve own productivity. At the same time, alliances open up own know-how in reciprocity.

In contrast to other spillover studies on industry level, which focus exclusively on inter-industry spillovers, the available information on alliances allows to analyze both inter-industry as well as intra-industry. Furthermore, in constructing the external R&D pools, the international dimension is taken explicitly into account, by aggregating industry R&D investments across countries. More specifically the intra-industry spillover-pool for a specific sector in a particular country consists of all R&D-investments of that specific industry summed across all countries except for that particular country; this pool is weighted by the international diagonal (i.e. total alliances – national alliances) of the alliance matrices. The inter-industry spillover-pool for a specific sector in a particular country is constructed by summing up all R&D-investments of the other sectors over all countries and this weighting by the off-diagonal elements in the alliance matrices.

Another difference with other spillover studies is that the weights are not computed by row-normalizing the alliance matrices. Because (the size of) spillovers from one industry to another industry depend not on (the size of) spillovers from that same industry to a third industry, this paper uses a different approach. The number of alliances between industry 1

[14] This implies that knowledge is only accumulated through R&D-investments.
[15] As such, the quality of the labor force (e.g. education level) is not taken into account.
[16] No R&D-deflators were available; the country and sector specific value added deflator may be the most appropriate given that R&D-investments include labor costs as well as capital investments.
[17] These same reasons motivate why value added and not total factor productivity is used in the regressions.

and industry 2 is weighted by the value added of industry 1, instead of the total number of alliances formed by industry 1[18].

As already mentioned, the K.U.L-database makes it possible to disentangle the individual effects of pure R&D alliances, combined R&D alliances and the non R&D alliances, as distinct channels to access external R&D. As such, 3 variables of intra-industry spillovers are constructed and another 3 variables of inter-industry variables; as opposed to one spillover variable used in other spillover studies. Table 1 summarizes the expressions of the spillovers or external R&D pools.

Table 1: Definition of spillover-variables

Spillovers (intra, R&D exclus.) of sector i in country l (n = 58)	$Spill(intra, eR\&D)_{il} = \frac{\text{alliances (intra, eR\&D, internat)}_{ii}}{Y_{i,l}} * \frac{\Sigma_k RD_i}{\Sigma_k Y_i}$ $(l \neq k)$
Spillovers (intra, R&D combined) of sector i in country l (n = 104)	$Spill(intra, cR\&D)_{il} = \frac{\text{alliances (intra, cR\&D, internat)}_{ii}}{Y_{i,l}} * \frac{\Sigma_k RD_i}{\Sigma_k Y_i}$ $(l \neq k)$
Spillovers (intra, non-R&D) of sector i in country l (n = 540)	$Spill(intra, nR\&D)_{il} = \frac{\text{alliances (intra, nR\&D, internat)}_{ii}}{Y_{i,l}} * \frac{\Sigma_k RD_i}{\Sigma_k Y_i}$ $(l \neq k)$
Spillovers (inter, R&D exclus.) of sector i in country l (n = 52)	$Spill(inter, eR\&D)_{il} = \Sigma_j \frac{\text{alliances (inter, eR\&D)}_{ij}}{Y_{i,l}} * \frac{\Sigma_k RD_j}{\Sigma_k Y_j}$ $(i \neq j)$
Spillovers (inter, R&D combined) of sector i in country l (n = 70)	$Spill(inter, cR\&D)_{il} = \Sigma_j \frac{\text{alliances (inter, cR\&D)}_{ij}}{Y_{i,l}} * \frac{\Sigma_k RD_j}{\Sigma_k Y_j}$ $(i \neq j)$
Spillovers (inter, non-R&D) of sector i in country l (n = 318)	$Spill(inter, nR\&D)_{il} = \Sigma_j \frac{\text{alliances (inter, nR\&D, nat)}_{ij}}{Y_{i,l}} * \frac{RD_j}{Y_j} +$ $(i \neq j)$ $\Sigma_j \frac{\text{Alliances (inter, nR\&D, internat)}_{ij}}{Y_{i,l}} * \frac{\Sigma_k RD_j}{\Sigma_k Y_j}$ $(i \neq j)$ and $(l \neq k)$ with i, j = 1,...22 sectors and k, l = 1,...14 countries

Because of the multicollinearity between the exclusively R&D and combined R&D intra-industry alliances, only two intra-industry spillover variables were included in the analysis: one based on R&D alliances (which is the sum of the variables ***Spill(intra, eR&D)***$_{il}$ and ***Spill(intra, cR&D)***$_{il}$) and the other based on non R&D alliances (variable ***Spill(intra, nR&D)***$_{il}$). In the case of

[18] Ideally, the number of firms active in industry 1 would be used. Because these data were not

inter-industry alliances, the limited number of R&D alliances however did not lead to multicollinearity; as such 3 inter-industry spillover variables were used as defined in Tabel 1. Because of the significant differences between national and international inter-non-R&D-alliances, a distinction is made between national and international inter-industry spillovers. For the inter-R&D- alliances (exclusively and combined) national and international alliances showed the same sectoral distribution.

4.3.2 . Results and discussion

The discussion will focus on the effects of the intra and inter-industry R&D-pool on the growth in productivity. Basically there are two reasons why the intra-pool for a specific sector in a particular country can be large. Either because the sector has many intra industry R&D and/or non-R&D alliances that allow to access this know-how base, or because the country has a larger *accessible* know how base, which typically holds for follower countries with a smaller *own* know-how base in the particular sector. Similarly, the inter-pool will be large for sectors that have many inter-industry alliances or a larger *accessible* know-how base, which is more likely to hold for low-tech industries. High-tech industries will typically have a lower total inter-industry know-how base to access.

The pool of externally accessible know-how will have a positive effect on own productivity growth; however a positive (negative) effect for the inter variables on productivity growth will only occur when inter industry alliances have a positive (negative) effect on own productivity. Based on the results of earlier studies and given the internalization issues of R&D-cooperation, it can be expected that inter-industry alliances have a positive effect on productivity. The theoretical IO-literature has pointed to the higher profits and thus larger incentives for firms in inter-industry cooperation, which results in higher R&D investments and higher output levels. Furthermore information sharing between partners enhances incoming spillovers, as such firms cooperating with firms in other industries should a fortiori benefit from the knowledge developed by these other firms/industries.

This is different for intra-industry spillovers; as made clear by the theoretical IO-literature. In horizontal alliances, the competitive effect is stronger. The internalization effect will only dominate if spillovers are high enough. Differences in R&D efficiency and/or absorptive capacity, possibly reinforced by free riding by partners, will be reflected in the different size of the spillovers going from one partner to the other. This may lead to a negative effect on the industry output level and productivity for those follower countries that have a lower own R&D base, and hence a larger external accessible base as compared to the

available, value added is used.

leader countries. [19].[20]. With follower countries standing more to loose from intra-industry alliances because of a lower absorptive capacity, the follower countries however have at the same time a larger know how base to access and may still be far from diminishing returns to knowledge creation. All this makes the expected effect of intra-industry alliances ambiguous. Furthermore, especially for intra-industry alliances a different effect can be expected between R&D alliances and non-R&D alliances. Production and/or distribution alliances formed by partners in the same industry are typically set up to enhance efficiency (economies of scale, rationalizations of overcapacity...) or are motivated by market power reasons.

Table 2: Estimation results

Variables	*Regression (1)*	*Regression (2)*	*Regression (3)*
Intercept	0.011**	0.044	0.014
Capital	0.124**	0.116**	0.127**
Labor	- 0.792**	0.804**	0.839**
R&D	0.104**	0.126**	0.054
R&D²	- 0.042	- 0.053*	- 0.008
Spill(intra, R&D)	- 0.13E08	- 0.13E08**	- 0.78E08**
Spill (intra, nR&D)	0.48E07**	0.49E07**	0.51E07**
Spill (inter, eR&D)	0.14E08	0.11E08	- 0.57E08
Spill (inter, cR&D)	- 0.49E08*	- 0.56E08*	- 0.75E08**
Spill (inter, nR&D)	- 0.061	- 0.512	- 0.144
		Country dummies	Sector dummies
R² adj	64.14%	64.68%	73.02%

**: 0.01 significance level;
* : 0.05 significance level;

The results contain some interesting observations (regression (1)). First, the coefficient of the labor term points to decreasing returns to scale, which can be explained by the fact that R&D-investments are not segregated out the conventional input factors labor and capital. Second, the results confirm the importance of (own) R&D in productivity growth, however the negative quadratic term (significance = 0.06) point to the decreasing marginal return of R&D. R&D investments have an excess return[21] of 11%, which is in line with other industry studies, but is lower than studies focusing on the firm level. So far, the results seem to confirm existing "know-how" on drivers for productivity growth.

More interesting are the results for the intra and inter R&D pool. The positive effect of the *non-R&D intra-industry* pool can be explained by the positive impact of intra-industry

[19] The smaller output will directly result in a lower productivity per employee given the rather inflexibility of the labor market in most of the 14 countries. The high cost of hiring and firing employees will inhibit companies to instantly reduce the employment.
[20] Inter-industry alliances are in themselves asymmetric given the different industries of the partners; however the smaller competitive effect mitigates the potential negative effect of this asymmetry.
[21] Excess return because of the double counting of R&D-investments in the R&D-variable as well in the traditional input factors.

alliances set up for production and or distribution activities on industry output and productivity. This result is consistent with efficiency motivations in setting up alliances. The negative coefficient for the *R&D-intra-pool* confirms the adversial impact R&D cooperation can have on the productivity of the individual partners, and on aggregate for the whole industry. A first explanation for this negative sign may be the size of the spillovers: in low spillover industries, cooperation in R&D results in lower R&D-investments and lower output levels compared to independent R&D. However, the negative effect can also indicate that advantaged partners succeed more successfully in absorbing the knowledge of the disadvantaged partner via the alliance, maybe at the same time concealing its own technological expertise. Smaller countries with lower own R&D (and hence a large intra accessible R&D base to tap on) may experience a more negative effect of engaging in alliances with leader countries that are more apt to absorb any know-how, thus eroding their own competitive advantage. This matters especially in intra-industry transactions.

This negative effect of R&D-alliances may also explain why the number of intra-industry R&D alliances is rather limited. In the K.U.L. alliance database only 25% of the intra-industry alliances include R&D-activities (exclusively or in combination), while in inter-industry-alliances 38% are of the R&D-type (difference significant at the 0.001 level). Firms are aware of the potential pitfalls and will prefer not to set up alliances with firms of the same industry.

Contrary to expectations, inter-industry R&D alliances have no significant positive effect on industry output and productivity: firms do not seem to benefit from the knowledge accumulated in other industries, accessed through R&D or non-R&D alliances. However, inter-industry alliances that combine R&D with production/distribution activities have a significant negative effect on productivity growth. This again can be explained by competitive issues made earlier in the discussion with respect to the intra-industry alliances. The only difference is that in inter-industry alliances no actual competitor but potential competitors may weaken your competitive position. Given that not only knowledge is shared but also some operational activities implies that especially these types of vertical alliances, can accommodate entry by partners in the own industry. This observation is especially valid for industries which because of the convergence of certain technologies, becomes increasingly integrated with other industries. Traditional studies that measure involuntary inter-industry spillover through other means than alliances, are not likely to pick up this negative effect.

Including country dummies (regression 2) and sector dummies (regression 3) do not alter the estimation results fundamentally. The impact of intra-industry spillovers in R&D-alliances remains negative, as opposed to the positive influence of intra-industry spillovers in non-R&D-alliances. Inter-industry spillovers only matter in alliances where R&D-activities are combined with production/distribution. Including sector-dummies lowers the coefficient of the own R&D-variable, to the point of no longer being significant. This result is consistent with other studies.

The robustness of the results (Table 3) is further demonstrated by defining the intra- and inter spillovers solely as accessible know how base (i.e. without weights, assuming perfect non-rivalry of knowledge). Regressions including spillovers defined in this manner (regression (4)) show no impact on productivity growth, which demonstrates that it is not only absorptive capacity which explains the negative impact of intra- and inter R&D-alliances. Similarly, regressions including solely the sectoral distribution of alliances as spillover variables have no explanatory power. The results are also confirmed by using the 'traditional' spillover matrices (input output matrix USA, Yale matrix, matrix A of Verspagen), consequently only focusing on inter-industry spillovers. The results reported in Table 3 show that involuntary inter-industry spillovers do not have a positive influence on productivity growth; as such the results of other studies pointing to a positive impact of inter-industry spillovers are not confirmed here. While these latter studies only analyzed national spillovers, explicitly modeling international does not lead to significant findings: productivity growth does not benefit from national as well as international inter industry spillovers (regressions (5) (6) (7)).

All this suggests that especially in alliances the larger capabilities of advantaged firms in absorbing know how is important. The two-way transfer of knowledge in alliances through sharing and exchanging information between typically heterogeneous partners specifically increase the importance of the absorption potential, leading to the prevalence of asymmetric spillovers, which in turn may negatively affect productivity growth. Only taking into account accessing inter-industry know-how through alliances leads to significant negative effects on own productivity growth.

Table 3: Robustness checks

Variables[22]	*Regression (4)*	*Regression (5)*	*Regression (6)*	*Regression (7)*
Intercept	0.013**	0.015**	0.013**	0.011**
Capital	0.145**	0.153**	0.147**	0.143**
Labor	- 0.763**	- 0.755**	- 0.759**	- 0.757**
R&D	0.026	0.024	0.025	0.024
Know how base (intra)	- 0.0000427			
Know how base (inter)	- 0.0000011			
IO matrix USA national		- 0.029		
IO matrix USA internat.		- 0.00009		
Yale matrix national			- 0.022	
Yale matrix internat.			0.00002	

[22] A first regression was run with all 6 spillover variables included; however because of multicollinearity, the effect of the intra-spillovers variables was not clear.

Verspagen matrix A nat. Verspagen matrix A int.				0.057 - 0.001
R^2 adj	60.07%	60.25%	59.94%	60.22%

**: 0.01 significance level;
* : 0.05 significance level;

5. *Conclusion*

The theoretical literature has pointed to the importance of R&D-cooperation for spillovers, suggesting that spillovers induce cooperation as a means to internalize these involuntary effects, while cooperation at the same time enhances voluntary spillovers through information sharing. The empirical results in this paper show that R&D cooperation is indeed strongly correlated with the occurrence of involuntary spillovers, based on input-output relations and technology proximity. But not only R&D-cooperation corresponds to (the lack of) appropriability; the evidence shows that also non-R&D alliances are associated with transfers of knowledge.

Following the association of alliances with spillovers, this paper analyses the impact of external know-how on the performance of industries in OECD-countries where external know-how is weighted by the occurrence of alliances with the external source, based in the same industry or in other industries. The differential impact of intra-industry alliances versus inter-industry alliances, as well as of R&D-alliances versus non R&D-alliances is clearly illustrated. Intra-industry R&D alliances give rise to transfers of knowledge which have a negative impact on productivity growth, while for inter-industry alliances this only is true when R&D activities are combined with production/distribution activities. Non-R&D alliances have a positive influence because of its efficiency enhancement in intra-industry settings.

The results of the paper support the insights that cooperation is a mechanism to manage transfers of knowledge: alliances are an effective channel to get access to external knowledge especially for advantaged partners. Because of their larger absorptive capacity, advantaged partners are more able to effectively learn from others, while at the same time protecting their own expertise. The asymmetric spillovers that result may lead to a negative influence on productivity growth for the disadvantaged partners. The specific character of alliances as spillover channel, may thus give rise to transfers of knowledge that may negatively affect industry productivity. This especially holds in intra-industry alliances where partners are direct competitor. In inter-industry alliances, this competitive effect is less apparent; however alliances which combine R&D and production activities can turn partners in potential competitors by accommodating their entry.

The results of the paper should incite further theoretical and empirical research on the role of alliances in diffusing know-how, carefully indicating circumstances in which an innovation system should nurture alliances and networking to increase the productivity of improvements in know-how. Such results are not only important for firm strategies vis-à-vis cooperation, but also to governments considering stimulating cooperation as part of their innovation policy.

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