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An Empirical Analysis of Knowledge Flows

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The Economics of Knowledge Regulation:

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Abstract. Successful innovation depends on the management of a firm's knowledge base. This paper empirically investigates the determinants of knowledge regulation. Using a unique survey dataset, the analysis suggests that R&D managers do not leak knowledge randomly, but rather regulate knowledge consciously. We find that the source and the channel of knowledge inflows impact knowledge regulation. The findings reveal that the more a firm profits from knowledge inflows from competitors, the fewer actions it takes to regulate outgoing knowledge. We do not find that the extent of knowledge inflows from collaborating firms impacts knowledge regulation. However, the type of channel being used to acquire knowledge matters. Compared to public channels, the different types of private channels used to access knowledge inflow and the type of the competitive relationship influence the firms' decision to regulate knowledge outflow in the following way: concerning relationships with competitors, firms regulate knowledge outflow more when using formal channels, but less when using informal channels (although a significant difference is not found with the latter); concerning collaborative relationships, firms regulate knowledge outflow less regardless of whether they are using formal or informal private channels compared to using public channels. Presumably firms that acquire knowledge from competing firms through formal private channels compared to public channels, try to establish opaque and soundproof fences to surround them, whereas firms that acquire knowledge from collaborating firms through formal or informal private channels do not want to restrict circulation, but rather facilitate inter-firm knowledge exchange. Our results have important implications for academics and R&D managers alike.

JEL classification: O32, L21

Keywords: knowledge management, R&D, biotechnology industry

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1. Introduction

The ‘knowledge society’ and ‘economics of knowledge’ are only two examples of a growing number of catchwords that describe business and today’s society. Over the last decade, business and societal attention has shifted to mainly knowledge-intensive activities, subsequently opening a ‘hunt for knowledge’. Knowledge develops and accumulates with accelerating speed, shortening the time span in which a specific piece of knowledge is ‘state-of-the-art’. With the increasing depth of knowledge specificity, a trend to specialize within corporations as well as between corporations is observed. This results in more diffusely located sources of knowledge, suggesting that complementarities between firms increase (Foray, 2004; Haeussler, 2006).

Therefore, knowledge management emerges as a new organizational practice (e.g., Zander & Kogut, 1995; von Krogh & Roos, 1996; Coombs & Hull, 1998). While much of the existing literature has dealt with the advantage of using external knowledge sources to increase innovative productivity (e.g., Chesbrough, 2003; Laursen & Salter, 2006) and has explored firms’ mechanisms to increase absorption of knowledge (e.g., Cohen & Levinthal, 1989, Rosenberg, 1990), there is very little empirical literature on to what extent firms control knowledge outflow (Liebeskind, 1997; Michailova & Hutchings, 2006).

In general, firms must make a decision (a) to take action to keep knowledge as a private good, (b) freely reveal the knowledge, or (c) stay passive by neither actively preventing nor supporting knowledge outflow.

The literature on knowledge sharing can be separated into two distinct strands. One strand, the older and more traditional, follows the idea that knowledge is only valuable if it is held private and if others are excluded from its usage (Arrow, 1962; Griliches, 1994). Proponents of this strand argue that only asymmetrically distributed knowledge allows the firm that disposes the specific knowledge to appropriate rents. Hence, a firm’s competitive advantage lies in its ability to prevent knowledge from leaking out through potentially porous boundaries. A more recent strand of literature, often referring to the open source phenomenon, argues in favour of knowledge sharing or ‘voluntarily revealing’. Theoretical models suggest that knowledge sharing can be an attractive strategy (Harhoff et al., 2003) even with competing parties (De Fraja, 1993). Empirical studies have provided support for this notion in various regions (Saxenian, 1996) and industries, for example pharmaceuticals (Henderson and Cockburn, 1994), software (Dahl & Pedersen, 2004; Henkel, 2006), semiconductors (Appleyard, 1996), and the specialized steel industry (von Hippel, 1987; Schrader, 1991).

In this paper, we are interested in the determinants of 'firms' secretiveness'. We argue that when the level of external knowledge inflow is considerable, firms regulate knowledge outflow less strongly. Firms that profit from external knowledge are less restrictive regarding outgoing knowledge, in the hope of future benefits. Whereas the notion of reciprocity is well developed in a two-party relationship (e.g., von Hippel, 1987), this paper investigates the interesting case of openness not channelled to a specific firm, but to all firms or a group of them. Ekeh (1974) calls this 'generalized exchange', as opposed to 'restricted or mutual exchange', between two parties. This notion implies that a firm takes the size of external knowledge inflow into account when strategically deciding on the level of knowledge regulation. In addition, we argue that the extent of knowledge regulation depends on the type of knowledge. When knowledge is sufficiently tacit, firms need to engage in private (e.g., informal or formal face-to-face meetings) as opposed to public channels (e.g., patents, newspapers, press) in order to access knowledge (Polanyi, 1962; Zander &Kogut, 1995). We suggest that the more a firm makes use of private channels to acquire knowledge, the less strongly it controls its knowledge outflow.

Using firm-level survey data, this study provides in-depth insights into the control of the knowledge flow practices of 157 German biotechnology firms. The empirical results indicate that the type of competitive relationship and the type of channel used to acquire knowledge govern the knowledge regulation decision. Whereas we find that firms that profit from knowledge inflows from competitors take fewer actions to control outgoing knowledge, we do not find that the extent of knowledge inflows from collaborating firms impact knowledge regulation. However, our results reveal interesting differences with regard to the channel type. Compared to public channels, the different type of private channels matter. Concerning relationships with competitors, firms regulate knowledge outflow more strictly when using formal private channels than when using public channels. This finding suggests that firms which engage in formal interaction with rival firms try to strongly control the knowledge that can be absorbed by the competitor. Concerning collaborative relationships, we find that firms regulate knowledge outflow less, regardless of using a formal or informal channel opposed to a public channel. Hence, firms that acquire knowledge from collaborating firms to a large extent through private channels eliminate obstacles to promote circulation and elaboration of research projects.

This study provides several contributions to the literature. First, the study speaks interestingly to the literature on knowledge management. We extend this literature by exploring the link between the sources and channels that firms use to acquire knowledge, and firms' knowledge regulating actions. While the focus of most previous research has been on 'restricted exchange'

between two parties, this study reveals insights into 'generalized exchange' by relating external accessible knowledge to general knowledge regulation actions. Moreover, this elaboration leads directly to a contribution to the open innovation community literature, in which recent studies have investigated the 'architecture' that supports reciprocation (e.g., Baldwin & Clark, 2006). Our findings suggest that even outside of a community, firms that profit from external knowledge inflow from competitors are more open in that they have fewer regulations on knowledge outflow. Finally, we add to the literature on spillover effects (e.g., De Bondt, 1996; Cassiman & Veugelers, 2002; Lhuillery, 2006). Most of this work has related external accessible knowledge to cooperative and non-cooperative R&D investment of firms. We complement this literature by distinguishing between collaborating and competing firms as a knowledge source and by investigating the level of knowledge regulation. Our results have important implications for R&D managers. The study sheds light on the complexity of knowledge regulation and reveals that source and channel are of considerable importance for this decision. Moreover, the results allow us to provide recommendations for R&D managers' knowledge strategy.

2. Conceptual Background

Theoretical models

One strand of the theoretical literature approaches the question of knowledge disclosure mainly by comparing the non-cooperative and cooperative R&D investment of firms competing in a product market (for an overview see De Bondt, 1996). Scholars suggest that different spillover[1] levels exist for the cooperating groups and the competing groups. Cooperation improves knowledge sharing insofar as voluntary spillovers become larger than involuntary ones. In general, the models predict that in the case of coordinated R&D investment, full disclosure of knowledge will maximize profit. Thus, the disclosure rate depends on the R&D cooperation decision. Moreover, the models show that the more differentiated the products of the R&D partners are, the higher are the level of R&D investment and the level of disclosure. Katsoulakos & Ulph (1998) demonstrate that even in a non-cooperative setting, full disclosure can be achieved when firms develop complementary products and operate in different industries.

[1] The economic term 'spillover' is used when firms profit from each other's research without any reciprocation (Griliches, 1992). Hence, spillovers pertain to involuntary knowledge transfer opposed to knowledge flows, which can also occur voluntarily.

Another strand of theoretical literature studies the disclosure of firms in the presence of an invention race. Among others, De Fraja (1993) shows that firms engaged in a patent race may disclose knowledge when they have to share the market with imitators and when the pay-off structure does not allocate the full gain to the winner. Firms may choose to disclose knowledge in order to accelerate the invention race because being second quickly may be a more preferable position, than being first relatively late. Harhoff et al. (2003) suggest in their game-theoretic model that even in a world of self-interested agents producing complementary products, freely revealing knowledge can be profitable. They demonstrate that a firm considered within a group of firms will choose to reveal its innovation to a manufacturer, who will then decide whether or not to improve the product and offer it to the group for sale. The authors support their theoretical findings by presenting four case studies in which users freely reveal innovations, which are adopted by manufacturers and are finally made available via commercial sale.

Empirical studies

Several empirical studies examine the relative importance of certain mechanisms (e.g., secrecy, patents, lead-time advantages) to protect the profits associated with inventions and the determinants of disclosure (Levin et al., 1987; Cohen et al., 2000). In this context, knowledge disclosure is often related to an existing market for knowledge (Arora et al., 2001). However, a number of case studies document that knowledge is also revealed outside the market in a more informal way. Allen (1983) shows that innovative firms in the blast furnace industry enter into 'collective invention' by disclosing technological information to their competitors. Von Hippel (1987) and Schrader (1991) report that employees of mini-mill firms in the specialist steel industry disclose technical information to employees of rival firms through an informal network. Dahl & Pedersen (2004, 1673) report that engineers in a Danish regional cluster of wireless communication firms share 'even quite valuable knowledge with informal contacts'. Spencer (2003) suggests that firms in the flat panel display industry share knowledge to attract other players to their own trajectory. Cockburn & Henderson (1994) find that pharmaceutical companies share complementary knowledge in drug discovery in an attempt to avoid head-to-head competition, rather than engaging in a race characterised by 'tit-for-tat' or simple reaction function models. Several researchers have explained the firms' decision to publish in scientific journals, present research at conferences, and disclose knowledge as an accommodation to its scientific employees (Spencer 2003). Firms may allow scientists to publish in scientific journals in order to recruit new employees and motivate research staff (Henderson & Cockburn,

1994), promote incentives for basic research (Cockburn et al., 1999), or increase absorptive capacity (Cockburn & Henderson, 1994). Several recent papers have pointed to the existence of benefits that firms could derive from contributing to public open source software development (Dahlander & Magnusson, 2005; Henkel, 2006).

While these studies suggest that there is much more disclosure among firms than scholars have probably thought, there are rarely studies trying to explain when disclosure behaviour among firms is more likely with regard to the size of external knowledge inflow. One exception is the analysis of 370 Flemish manufacturing firms by Cassiman et al. (2002). They find that firms that invest more in legal protection are often more effective in appropriating and presumably in preventing competitors from using that knowledge for their own purpose. In addition, they report that when external information is more important, firms are more concerned about protecting 'know how'. Another study of Cassiman & Veugelers (2002) analyzes the relationship between unintentional information leakage and collaboration. Using a sample of 411 Flemish firms, they report that those which are more effective in appropriating the results from their innovation process are also more likely to be actively engaged in R&D cooperation. The results contradict theoretical models in which imperfect opportunity to appropriate returns increases the benefits of cooperative R&D agreements. Recently, Lhuillery (2006) presented an analysis of four French data sets that deals with different determinants of the level of knowledge that leaks out. By using the actions undertaken to prevent knowledge from leaking out, he indirectly measured disclosure. He reports that R&D intensive firms that participate in R&D partnerships and that are operating in the high-technology sector are taking fewer actions to prevent knowledge outflow. In addition, he finds that firms are more prone to disclose knowledge to public laboratories than to the private sector.

The present study extends and complements these aforementioned studies by relating the whole pool of incoming knowledge – distinguishing between source and channel – to various actions to regulate knowledge outflow.

Hypotheses

Recent studies emphasize that firms have incentives to manage knowledge flows, which occur 'to and from' firms, by attempting to maximize incoming knowledge and minimize outgoing knowledge (e.g., Cassmian & Veugelers, 2002; Belderbos et al., 2004). Firms can follow an 'egotistical' approach – they try to absorb knowledge from other firms, incorporate it, and take actions to 'draw the curtains close'.

However, this notion neglects that firms might be more open in pecuniary and social interest. We argue that firms that profit from external knowledge inflows are aware of this benefit and choose actions as to how restrictive they will act regarding outgoing knowledge. We presume that firms choose a lower level of control if they benefit from knowledge inflows. This notion of reciprocity is clearly illustrated in a two-party relationship (e.g., von Hippel, 1987; Fehr & Schmidt, 1999). Providing a party with a favour obliges that party to reciprocate in order to maintain the balance of benefits and contributions. Schrader (1991) suggests that not being willing to return a favour may induce feelings of guilt and a poor reputation (Takahashi, 2000). In the game theoretical literature, trust and gift-exchange games show that actors even accept material losses to reward others who are perceived as being generous (e.g., Fehr et al. 1993; Falk & Fischbacher, 2004). This 'quid pro quo' mechanism works well when the parties know each other so that trust can be developed quickly and also when the firms are able to evaluate what they get from each other and when they will get it.

However, a particularly interesting case is the one in which knowledge flow cannot be completely channelled to a specific firm. A large part of knowledge outflow is publicly beneficial and beneficial to other (competing) firms. Hence, the discussion about incoming knowledge and subsequent actions to more strongly or less strongly regulate knowledge outflow is, to a large extent, between a firm and a group of possible 'profiteers'. Ekeh (1974, 55) calls this type 'generalized exchange', as opposed to 'restricted exchange' between two firms. An important characteristic is that the group does not operate as a unit, as not all firms profit equally from the knowledge that a firm has brought into the 'common pool'. According to Ekeh (1974), the law of extended credit ensures that "… the receipt of a benefit by any one party is regarded as a credit to that party by all other parties and therefore its reciprocation is regarded as a credit to all of them." This univocal reciprocity is more difficult to achieve than mutual reciprocity, in which the two firms are able to directly respond to the level of disclosure of the other party (Franke & Shah, 2003).

Why do firms participate in this 'common pooling' and disclose knowledge to the group when they profit from knowledge inflows? The answer is related to both institutionalized norms and incentives. The norm of 'openness' is supported when most firms in the group, which profit from external knowledge inflow, respect the norms of univocal reciprocation (Levi-Strauss, 1969; Ekeh, 1974). But besides the social aspect, it is important to understand that open knowledge exchange does not mean the absence of a firm's individual incentives. Individual economic pay-off is the precondition for firm participation (see also von Hippel &

von Krogh (2003) for individuals contributing to open source communities). The individual calculation for participation is designed to show profit from expected future knowledge inflows, at the cost of giving knowledge to the common pool. The idea of generalized knowledge exchange was already extensively debated during the early meetings of the Institute of Metals, founded in England in 1908. Though all institute members were competing against each other, the members discussed the desire to disclose trade secrets (Allen, 1983). The members who freely revealed posed the following arguments: "Each individual has some cherished bit of knowledge, some trade secret which he hoards carefully. Perhaps by sharing it with others, he might impart useful information; but by an open discussion and interchange he would, almost for certain, learn a dozen things in exchange for the one given away. General increase of knowledge would give general improved practice, most likely a larger use of the materials in which a manufacturer is interested."[2] Allen (1983) classifies this behaviour as 'collective invention'. In general, there is one important similarity and one important difference between Allen's idea of 'collective invention' and this study. Similar to Allen, we are also interested in the openness towards the whole innovation system and not just to a selected few firms; while, however, in Allen's study the collectively produced new knowledge is a by-product of normal business operation, we investigate knowledge that is directly related to the R&D of firms (Allen, 1983; Henkel, 2006).

Moreover we differentiate between two sources of horizontal knowledge inflows: (1) collaborating firms that are active in the same field, and (2) competitors. In general, we expect that the positive relationship between external knowledge inflow and 'openness' is found, regardless of whether collaborators or competitors play a role as sources of knowledge.

From the above, we hypothesize:

H1: When the level of external knowledge inflow from ***collaborating firms*** *is considerable, firms take fewer actions to regulate knowledge outflow.*

H2: When the level of external knowledge inflow from ***competing firms*** *is considerable, firms take fewer actions to regulate knowledge outflow.*

Furthermore, we perceive that the relationship is more pronounced when a firm profits from competitors, because this firm behaviour may reduce the danger of a knowledge race. Our argument builds on the findings of Schrader (1991) and von Hippel (1987). After analyzing information transfer decisions in the US specialty steel and mini-mill industry, Schrader reports

[2] Muntz (1909, 291) cited from Allen (1983, 19).

that collaboration and exchange of information among firms has increased considerably with the entrance of new competitors. Similarly, in his study about the US steel mini-mill industry, von Hippel (1987) reveals informal knowledge trading to be common between competing firms.[3]

Two drivers of organizational behaviour induce less 'secretiveness' among competing firms: First, firms tend to weigh potential losses heavier than gains (e.g., Kahneman et al., 1982). The danger of losing access to the competitor as a knowledge source galvanizes firms to be more open. Second, the success of every single firm depends on how it competes in the market. The danger of entering into a costly, existence-threatening knowledge race or patent race with another competitor may lead to lower knowledge regulation (De Fraja, 1993).

H3: The proposed effect of H2 is stronger than the proposed effect of H1.

Last of all, we focus on the channel through which external knowledge is accessed. Access to knowledge can occur either through public channels: patents, publications, press; or through private channels that demand some interaction with the knowledge source: face-to-face meetings, telephone calls, e-mails (Appleyard, 1996). The channel used to access external knowledge reveals information on the form of knowledge transferred. Knowledge that can be expressed in written form – so called 'codified knowledge' – is in an appropriate form for its diffusion (e.g., publication, computer program) and is often accessible through public channels. When knowledge is completely codified, it is easy to interpret and easy to use for experts and practitioners, but it is impossible for the firm that produced it to control it.[4] However, in practice, critical knowledge is far more often bound to the practical experience of people. Knowledge that cannot be formalised, but that resides in the heads of people, institutions or routines is tacit. Knowledge at the frontier of cutting-edge science has often a strong tacit dimension (Nelson and Winter 1982). This implies that firms have to get in contact with the person or the laboratory possessing the knowledge in order to gain access to the benefits of this knowledge. The tacit dimension of new scientific knowledge implies natural excludability (Zucker et al., 1998). Von Hippel (1994) emphasizes that the more tacit the knowledge is, the more important is personal interaction. The group perspective of the exchange relationship diminishes in favour of a more personal relationship between interacting firms. Face-to-face interaction feeds

[3] While innovations have enabled the US steel mini-mill firms to compete effectively against the major integrated US steel producers, von Hippel's study (1987) does not suggest that this is the primary motivation for the knowledge exchange between rivals."

[4] Exceptions are patent protected inventions. Although patents demand disclosure, they limit the usage of the patented invention by external parties.

trust and reciprocity (Ostrom, 1998). For example, Sally (1995) finds that face-to-face communication in one-shot experiments increases cooperation rates by more than 45%.

We hypothesize:

H4: The larger the share of knowledge acquired through private channels opposed to public channels, the less strongly firms regulate knowledge outflow.

4. Field of Analysis, Data, and Method

4.1. The human biotechnology sector and the survey

The research setting of this study is the bio-pharmaceutical industry. Given the heterogeneity of the biotechnology industry, only biotechnology firms active in the human biotechnology sector, which is related to medical purposes, are included in this study (refer to OECD, 2005 for the definition).

The innovation process of biotechnology is characterized by high-knowledge intensity, due to the complexity of R&D. In comparison with other industries, the biotechnology industry has a relatively large number of inter-firm collaborations (Hagedoorn, 1993; Haeussler & Zademach, 2007) but is also one of the industries that is highly preoccupied with the protection of knowledge (Cohen et al., 2002). However, testing differences between industries regarding the level of disclosure, Lhuillery (2006) reports the pharmaceutical industry to be classified within the groups that have a high level of disclosure. The apparently conflicting findings imply that several effects compete, rendering it impossible to have an undifferentiated conclusion, whereby the literature agrees in classifying the biotechnology industry as one with strong incentives to manage knowledge flows (Foray, 2004).

The data used in this study is based on a survey that was developed and administered in the German biotechnology industry in 2006. The study's population consists of all core biotechnology firms in Germany. Firms not founded in Germany, firms that are subsidiaries of foreign firms, and firms solely offering services or supplying products without conducting research were excluded from the sample. Our sample was identified from several industry (e.g., Biocom, Dechema) and Internet searches. We ended up with 346 German firms that fulfilled the criteria in 2005 and had been active for a minimum of one year. Each firm received a personalized letter, addressed to the head of management, inviting them to participate in the survey. Prior to the field stage, we interviewed industry experts from biotechnology associations

and firms, which helped us to design the survey instrument. In addition, 12 pre-test interviews were conducted to test the questionnaire; this procedure led to some revisions, mainly in the reformulation of questions. We decided to conduct face-to-face interviews as biotechnology firm managers have said that they are reluctant to participate in mail and on-line surveys but are open to face-to-face interviews. In their opinion, an in-person interview demonstrates authentic interest in their firms. We and interviewers from TNS Global filled out the questionnaire during the interviews. We conducted 162 interviews with managers of German biotechnology firms on the pre-formatted and tested questionnaire. The response rate of 47% provided us with an unusually comprehensive sample of German firms. For this study, five interview-questionnaires had to be excluded due to missing variables. The interviews have been conducted with the top management of the relatively young firms (median firm age: 5.8 years). The overall majority of interviewees have been firm founders and scientists and therefore especially able to answer the questions relevant for this study.

4.2. Variables

Dependent variable

In this paper, we use the actions that a firm takes to regulate knowledge outflow as our dependent variable. Such actions are mostly organizational rules and can be in the form of "do's" or "don'ts" for employees. Prior to the study, we carried out several interviews to research the management actions that firms implement in order to keep knowledge within the firm. We find the standard behaviour in the industry is to contractually bind researchers to secrecy, and restrict researchers from publishing and presenting research-related knowledge that is unpublished, not yet protected by a patent, or that cannot be patented. Hence, asking firms about their standard regulations won't enable us to gain a deep insight into the level of disclosure. However, we identified three non standard regulations, that allow us to detect heterogeneity in firm behaviour: (1) The employment contract of employees in research and development includes a non-competition clause, (2) the channels of communication of employees in research and development with external parties are explicitly regulated (e.g., employees need to have explicit permission to talk about the firm's R&D projects), and (3) the company has a unit or management function that is responsible for keeping research-related knowledge within the company. The interview partners emphasized that these rules are regularly adapted when changes occur in the firms' strategy (e.g., new competitor emerges, new collaboration deal signed) or environment. We asked the interviewees to what extent the three rules are used on a five-point Likert scale. For the empirical analysis, we combined these answers by summing up

the scores on each of these questions to generate the 'ACTIONS' variable.[5] We used the summation method because there was no indication for heterogeneity in the importance of the three "actions".

Independent variables

Two sets of independent variables are included: the level of external knowledge inflow, depending on the source and the channel through which knowledge is accessed (differentiating between sources).

To measure the level of incoming knowledge, we asked the respondents to rate the importance of knowledge inflows from collaborating firms (INFLOWS Collaborating Firms) and from competing firms (INFLOWS Competing Firms) for the advantage of their research and development activity on a five-point Likert scale (Cohen et al., 2000). In this paper – derived from the business behaviour in the bio-pharmaceutical industry – collaborating firms are firms with which a firm collaborates on projects and which are not perceived to be competitors. For example, collaborating firms might develop the same or similar approach in detecting or handling diseases, but focus on different indication areas. Using the same approach makes collaboration and knowledge exchange attractive. In contrast, firms using and promoting different approaches to cure the same disease are seen as competitors.

In characterizing the level of interaction to access external knowledge, we distinguish between private and public channels of knowledge, whereby no interaction with the knowledge source is necessary with the public channels (e.g., analyzing patent data, scientific publications, other publications, newspaper, web page, press releases) while using private channels makes personal interaction necessary (e.g., face-to-face contact, the telephone). The latter can be further differentiated into knowledge acquired through formal private channels (e.g., official collaboration projects (FORMAL CHANNEL)) versus informal private channels (e.g., chat at a conference (INFORMAL CHANNEL)).[6] The respondents are asked to report how much of the total external knowledge is acquired through each type of channel, with the total sum adding up to 100 percent. This is undertaken separately for channels to acquire knowledge from collaboration firms and from competitors. In the estimation, we only include the two private channels. Hence, the reference group consists of knowledge acquired through public channels.

5 We tested for independence between the three actions. Kendall's Tau indicated no independence between the actions.

6 Rogers (1982, 115) argues that although formal and official channels exist for exchanging information, the "… most valuable information is communicated via informal channels."

Control variables

Some of the variables that are included are known or expected to influence the level of outgoing knowledge, though they are not involved in the hypothesis discussion.

- Differentiation by innovative product/technology (INNO). The respondents are asked to rate, on a five-point Likert scale, how strongly the firm differentiates itself from competitors by offering an innovative product/technology. We expect that a firm that differentiates itself through the introduction of innovative products/technologies regulates outgoing knowledge more strongly.

- Protection by patents (PROT by PATENTS): We derived a direct measure of the firm's management belief regarding the importance of patents to protect their innovations. Previous empirical literature does not provide a clear-cut prediction on the effectiveness of protecting actions (e.g., collaborations). Some studies report that a lower appropriability resulting in larger (involuntary) spillovers increases the incentives to cooperate, whereas other studies find the opposite effect (Schmidt, 2005).

- Protection by complexity (PROT by COMPLEXITY): Firms rated the effectiveness of product complexity for strategic protection on a five-point Likert scale. We believe that firms that produce an extremely complex product will need to implement fewer regulations to control their knowledge.

- VC financed firms': dummy variable (VC) – Venture capitalists are often involved in management practices. We presume that VC financed firms are advised or pressured to take more actions in order to keep research-related knowledge in-house than non-VC financed firms.

- Firm age (AGE): Age is measured by days from a firm's inception to December 31, 2005. We perceive that older firms are more likely to implement management practices in order to control outgoing knowledge (Lhuillery, 2006).

Concerns: causality of knowledge inflows and regulation

The study raises the issue concerning 'the causality of incoming and outgoing knowledge'. We perceive that the level of knowledge inflows influences the control of knowledge. To the best of our knowledge, all studies that emerged in the field within the last years studied the effect of knowledge inflows on actions to prevent outgoing knowledge by using the fact of entering collaboration as a proxy for controlling knowledge (e.g., Belderbos et al., 2004). In

addition, in-depth discussion with experts convinced us that the size of external accessible knowledge influences knowledge regulation by firms. Firms will first get a taste for the advantages of incoming knowledge profits and will then take actions. Moreover, firms regularly need to adapt their actions in accordance with the changes in their strategy and environment. For example, W. Alexy, a manager of a user group of Computer Associates, stated in an interview: "It is clear that give follows take; firms start out and check what is in it for them, regularly evaluate that, and then decide to reveal knowledge. People that profit a lot from our exchange are also the ones that contribute a lot." In their study of Freenet, von Krogh et al. (2003) report that people start contributing to the community after a significant period of observation ('lurking'). Nevertheless, to control for potential causality and endogenous consequences, we include the knowledge inflow variable in one model as non-instrumented and in another model as an instrumented variable.

Empirical approach and instrumental variables

Cassiman & Veugelers (2002) and Cassiman et al. (2002), among others, provide arguments for the endogenous character of incoming knowledge. Following the studies by Cassiman & Veugelers (2002) and Schmidt (2005), we introduce a two-step procedure to take the endogeneity of the variable into account. In the first step, we regress the potential endogenous knowledge inflow variable on all the other independent variables, along with some additional exogenous instruments. The predicted values are then used in the second stage regression. We use robust ordered probit regressions, given that the knowledge inflow variable (for the first stage) and the action variable (for the second stage) are ordinal. We use the following four exogenous variables as instruments for the incoming knowledge flow variable in the first step regression: The field[7] level of incoming knowledge flows (INFLOWS Collaborating Firms (field level); INFLOWS Competing Firms (field level)) is included, following the notion of Cohen & Levinthal (1989) and Cassiman & Veugelers (2002). Moreover, the breadth of a firm's R&D approach (as estimated by the number of biotechnological technologies used) serves as an instrument (TECHNOLOGICAL BREADTH). The more biotechnological technologies a firm works with,[8] the more profit that firm is perceived to gain from knowledge outflows from other firms, compared to those concentrating on a single technology. Cohen & Levinthal (1989), among others, argue that the type of R&D influences the capacity for absorb-

[7] Fields are: therapeutics, vaccines, diagnostics, and platform technology. The mean of field average is used for firms active in more than one field.

[8] Biotechnological technologies are: DNA, proteins and molecules, cell and tissue cultures, process biotechnologies, sub cellular organisms, bioinformatics, and nanobiotechnologies.

ing external knowledge. In the questionnaire we asked interviewees about the founding of their firm. We use the dummy variable whether the firm is a spin-out of a university or a research institute as an indication for basicness of R&D (SPINOUT UNI). Rosenberg (1990, 170) puts forward that "... basic research is a ticket of admission to an information network". He argues that firms involved in basic R&D absorb knowledge from other firms more easily than firms focusing on applied R&D. Therefore, we presume spin-outs from universities or research institutes will profit more from knowledge outflows from other firms than firms that are de novo start-ups, corporate start-ups, or firms founded as a result of a merger with another company.

Finally, we include the speed with which a field develops as a measure for knowledge cycle time (SPEED of FIELD). We presume that in areas of high speed, firms profit less from incoming knowledge. The variable is measured by asking respondents to indicate on a five-point Likert scale whether the rate at which new technologies are developed in their field is very high.

5. Multivariate Analysis

5.1. Summary statistics

Table 1 shows summary statistics of the variables.

[Table 1 about here]

The ACTION variable – measures how strongly firms regulate research related knowledge – shows a mean of 9.96. This higher-end value implies that firms control knowledge relatively strongly.

The incoming knowledge flow variables show that, on average, firms profit more from knowledge inflow from collaborating firms than from competitors (a mean of 3.16 versus a mean of 2.85). Over 50% of the knowledge that is acquired from collaborating firms is gained through private channels: on average 30% of the knowledge is obtained through formal private channels and 24% through informal private channels. In contrast, only 32 % of the knowledge acquired from competing firms is gained through private channels: on average 3.5% through formal private and 28% through informal private channels.

The average score for which a firm competes over differentiation is relatively high, scoring 4.71 on a five-point scale. The measure of appropriability based on the importance of pat-

ents to protect their innovation is on average 4.07. The measure for the importance of product complexity to protect their innovation scores slightly higher with 4.37. 36% of the firms in the sample being financed by a venture capitalist (this number corresponds with Ernst & Young 2005). The median age of the firms is 5.8 years. The bivariate relationships among the independent and the control variables are available from the author upon request.

5.2. Regression for actions to control knowledge outflows

Table 2 reports the results for the determinants of actions to regulate knowledge outflow. The dependent variable 'ACTIONS' measures the actions taken to regulate knowledge, ranging between 3 and 15. We use a robust ordered probit regression, given that the dependent variable is ordinal. Model (2) presents the results, taking the endogeneity of the knowledge inflow variables into account. Whereas Model (1) uses the direct answers from the survey for the incoming knowledge variables, Model (2) uses the predicted values of the first stage regression. Model (2) demonstrates that the correction of endogeneity of the incoming knowledge variables does not change our findings on signs, and only slightly changes the degree of significance of a few coefficients.[9]

A main objective of this paper is to investigate the relationship between the importance of the external knowledge base for R&D and actions taken to control knowledge outflow, whilst taking into account different sources and channels to acquire external knowledge. The coefficient of the variable knowledge inflows from collaborating firms (INFLOWS Collaborating Firms) is positively related to the actions taken to regulate knowledge (model 1 and 2). Firms tend to gravitate to more controlling mechanisms if they benefit from knowledge from collaborating firms. Presumably, firms try to exclude non-collaborating firms from profiting from their knowledge base. However, both coefficients are not significant. The results show remarkable differences when competing firms are considered as knowledge sources. The coefficient of the variable knowledge inflows from competing firms (INFLOWS Competing Firms) is significantly negative. This confirms the notion of endogenous leakage occurring not only in a collaborative setting, but also in a competitive setting. Firms profiting from their competitors are regulating knowledge outflow less strongly, and thus are more prone to release information.

[9] A table reporting the first step regression results from which the predicted values for knowledge inflows from collaborating and competing firms for the main regression in table 2 are obtained, is available upon request. The first step regression reveals that two of the exogenous instruments, technological breath of a firm's activities and the aggregated field level knowledge inflows, have a significantly positive influence on knowledge inflows. Moreover, a firm that uses external collaborations to a larger extent as a channel compared to other channels, shows a higher level of knowledge inflows.

An investigation of the impact of various channels on the strength of regulating knowledge outflow provides interesting insights. We differentiate between private and public channels to acquire knowledge. Whereas the percentage of knowledge acquired through public channels is the reference group, we further differentiate between two private channels: informal private channels (e.g., chats at conferences) and formal private channels (e.g., official joint projects).

The coefficients of both channel variables for acquiring knowledge from collaborating firms (Formal CHANNEL_Collaborating Firms and Informal CHANNEL_Collaborating Firms) are notably negatively related to the actions taken. Firms that acquire knowledge from collaborating firms through private channels are less concerned about knowledge outflow compared to those firms using public channels. Firms do not want to restrict circulation and elaboration of joint research projects, but they rather want to facilitate co-operation among researchers.

Interestingly, the results differ when the channels to tap knowledge from competing firms are analyzed (Formal CHANNEL_Competing Firms and Informal CHANNEL_Competing Firms). Whereas the variable measuring the level of knowledge accessed via informal private channels shows a negative and non-significant coefficient, the coefficient concerning formal private channels is significantly positive. Hence, firms that gain knowledge from competitors via entering into formal personal interaction employ more management techniques to control knowledge outflow. Two explanations may apply: (1) firms entering a formal exchange partnership with a direct competitor establish an exclusive arrangement. The exclusivity between the two parties is realized by drawing the curtains closed; (2) although a firm enters a formal private exchange with a competitor, it is still competing in other areas. Therefore, the firm establishes ways to control its boundaries to keep projects secret into which no other firm should gain any insight.

[Table 2 about here]

Regarding the control variables, we find that the coefficient of the dummy variable indicating VC financed firms is negative but does not show any significance. Similarly, the variable measuring firm AGE is also negative and shows no significance. Hence, the age of the firm and the financing source does not affect the knowledge regulation strategy of firms. The variable INNO, which measures the degree of differentiation between competitors via an innovative product, shows a positive and highly significant coefficient. Firms that compete by bringing innovative products or processes on the market take more actions to control knowl-

edge. The variable PROT by COMPLEXITY, which measures how important the product complexity is to protect the innovation of the firm, is negatively but not significantly related to the action variable. The variable PROT by PATENTS, which measures the importance of patents to protect the innovation, is positively related to the actions taken to regulate knowledge.

6. Discussion and conclusion

This paper has explored the relationship between the existence and importance of the external available stocks of knowledge and the extent of knowledge regulation by firms. Our empirical findings indicate that the type of competitive relationship together with the knowledge source and the type of channel through which knowledge is accessed govern the knowledge regulation decision. Table 3 summarizes our empirical results.

[Table 3 about here]

While we did not find that the extent to which firms profit from collaborating firms impacts the control of knowledge, we found that firms profiting from external knowledge from competitors regulate knowledge outflow less strongly. We further investigated the channels firms use to acquire knowledge, that is, whether they engage in private interaction or use public channels to access knowledge. Our empirical investigation revealed that, concerning relationships with collaborating firms, firms take less action to regulate knowledge the more knowledge is acquired through formal or informal private channels opposed to public channels. Concerning relationships with competitors, firms regulate knowledge outflow more strongly when using formal channels, but less strongly when using informal channels (the latter not significantly) opposed to public channels. Presumably, firms that acquire knowledge from competitors through formal interaction are less open in order (i) not to benefit competitors with whom they are not in formal exchange, and (ii) to better control the boundaries of the rivals with whom they are in exchange, in order to keep specific project details or whole projects secret.

This paper makes several contributions to the literature. First, we add to the literature on knowledge management by providing a detailed analysis of the determinants of firms' knowledge regulation. Previous research has documented that a firm's sharing behaviour differs between industries (Lhuillery, 2006) and countries (Appleyard, 1996). We find that the extent to which a firm profits from external knowledge influences how strongly the firm regulates knowledge outflow. Our research indicates that firms profiting from competitors expand the area of voluntarily shared knowledge. While previous literature has suggested that firms try to

maximize knowledge inflow while they minimize knowledge outflow (Cassiman & Veugelers, 2002), we provide the notion and empirical evidence for a less 'egoistic' firm behaviour.

Second, whereas previous research on knowledge transfer is mainly focused on 'restricted exchange' between two parties (e.g., von Hippel, 1987; Dahl & Pedersen, 2004; Appleyard, 2004), we examine 'generalized exchange', which is not restricted to a specific firm. That is, we relate the extent of the stocks of accessible external knowledge to general knowledge control mechanisms of firms. Even then, we find that firms that profit from competitors regulate knowledge outflow less strongly. This elaboration leads directly to a third contribution: extending the literature on how communities work. Previous research suggests that knowledge sharing is related to the membership of a community or exchange network (Brown & Duguid, 2001; Franke & Shah, 2003). In the Open Source Software context, for example, individuals improve software within groups. They receive free assistance from other group members and are in turn expected to freely share the product of their effort (Henkel, 2006). We show that there does not have to be an official community membership, but rather that outside a community, the existence and importance of the external available stocks of knowledge induce firms to be open and 'leak' knowledge to others. This finding complements the theoretical model of Baldwin and Clark (2006), which suggests that the larger the option value from early code releases in open source development process is, the higher is the probability of participating and sharing knowledge among developers. Furthermore, we find that the channel, be it private or public (formal or informal), through which knowledge is acquired determines knowledge regulation. In this respect, we complement works exploring the mechanisms that firms use to obtain externally generated knowledge (e.g., Oxley, 1999; Alcácer & Chung, 2007) and to increase knowledge sharing. We highlight that the influence of the channel on the firms' level of knowledge regulation depends on the type of knowledge source.

Our study allows us to provide implications for R&D management. The empirical results reveal insights into the complexity of R&D managers' decision on how strongly they regulate knowledge. The results suggest that knowledge regulation depends on the type of competitive relationship and the type of channel, private or public (formal or informal), through which knowledge is acquired.

In general, the results provide good news for R&D managers who engage in 'generalized exchange' and follow the open innovation model. Firms that profit from knowledge from competitors are, in turn, revealing knowledge to the group. Although our investigation does not allow us to analyse whether managers that follow the open model of innovation are more suc-

cessful, the results suggest that there is a self-sustaining mechanism for this model. Hence, R&D managers should be less concerned that 'free-riding' of competing firms in 'generalized exchange' is common firm behaviour.

However, managers should also consider the channel through which knowledge from competitors is accessed in their knowledge regulation decision. The finding that a firm controls knowledge more strongly the more it acquires knowledge from competitors through private formal opposed to public channels, reveals that entering into formal private exchange with competing firms is accompanied by the danger that competitors gain access to information that threatens a firm's competitiveness. This concern might cause firms to be more sensitive about what information should be provided to the competitors, even while accepting that a stronger regulation of knowledge flow reduces the free flow of information between firms. For R&D managers, this implies that they should be careful when acquiring knowledge through formal exchange with competitors. On the one hand, they should take into account that the information they get from competing firms might be highly filtered. On the other hand, they should also try to find a way to encourage fruitful knowledge exchange. They could for example engage a gatekeeper who is a member of the project team and who has the task to foster knowledge exchange while also carefully deciding on on the type of information that the competitors are provided with in formal exchange. Recently, Hermann Requardt, chief of R&D strategy of Siemens AG, underlined this notion by saying: "While we have closed the door in the past to mitigate copying, today we open our doors [to competitors], let many in, but control the information they can access".[10]

With regards to exchange with collaborating firms, our findings suggest that the more a firm acquires knowledge through (formal and informal) private channels as opposed to public channels, the more important it is for R&D managers to foster open knowledge exchange.

All in all, this study should make R&D managers aware that the regulation of knowledge is highly strategically dependent on who provides the firm with valuable knowledge and how this knowledge is acquired.

The study has been undertaken in the German biotechnology industry. Caution must always be exercised when generalizing from a single industry. In the biotechnology industry, firms may be more prone to openness, since most scientists of firms emerge out of university laboratory paths, respecting the norms of science (David, 2004; Cockburn et al., 1999). Re-

[10] Translated from German (Sentker & Schnabel, 2008).

search results are often a product of people employed by various institutions, since science exists because of the interaction and exchange of knowledge. However, we believe that the basic processes we have observed operate in other contexts as well. Evidence is left to future research.

We hope this study fuels the scholarly and practitioner's debate and understanding of how firms manage knowledge and about the actual mechanisms by which knowledge is disseminated in the biotechnology industry. This paper provides several avenues to further the understanding of the mechanisms at work. The suggestions that result from the finding that managers do not leak knowledge randomly, but rather regulate knowledge consciously, deserve analysis. Two subsequent areas of investigation are: (1) how do firms direct 'research related knowledge' to collaborating firms, but restrict knowledge to competing firms? (2) How do firms maintain secrecy in specific areas, but openness in other areas?

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Tables

Table 1: Summary statistics (n=157)

Variable	Mean	Std. Dev.	Min	Max
Dependent Variable				
ACTIONS	9.96	2.99	3	15
- Non-competition clause	3.70	1.50	1	5
- Channels of communication are regulated	3.80	1.28	1	5
- Unit or management function for keeping knowledge in-house	2.46	1.51	1	5
Knowledge Inflows				
INFLOWS Collaborating Firms	3.16	1.25	0	5
INFLOWS Competing Firms	2.85	1.24	0	5
Interaction level				
Formal CHANNEL_Collaborating Firms	30.36	30.67	0	100
Informal CHANNEL_Collaborating Firms	23.51	26.07	0	100
Formal CHANNEL_Competing Firms	3.47	8.20	0	50
Informal CHANNEL_Competing Firms	28.11	25.41	0	100
Control variables				
INNO	4.71	.63	1	5
PROTECTION BY PATENTS	4.07	1.24	1	5
PROTECTION BY COMPLEXITY	4.37	.71	2	5
VC	.36	-	0	1
AGE (in days)	2131♦	2086	364	18992

♦ Median.

Table 2: Robust Ordered Probit Regression

	ACTIONS	**ACTIONS Two-Step regression**
	(1)	**(2)**
INFLOWS Collaborating Firms	0.121	0.295 **(I)**
	(0.093)	(0.210)
INFLOWS Competing Firms	-0.234***	-0.226** **(I)**
	(0.084)	(0.096)
Formal CHANNEL_Collaborating Firms	-0.011***	-0.012***
	(0.004)	(0.004)
Informal CHANNEL_Collaborating Firms	-0.006*	-0.008**
	(0.004)	(0.004)
Formal CHANNEL_Competing Firms	0.025***	0.026**
	(0.009)	(0.010)
Informal CHANNEL_Competing Firms	-0.003	-0.003
	(0.004)	(0.004)
VC	-0.237	-0.314
	(0.180)	(0.209)
INNO	0.446***	0.418***
	(0.132)	(0.146)
AGE	-0.000	-0.000
	(0.000)	(0.000)
PROT by COMPLEXITY	-0.101	-0.138
	(0.137)	(0.149)
PROT by PATENTS	0.103	0.101
	(0.074)	(0.075)
Observations	157	157
Pseudo R-squared	0.06	0.05

Robust standard errors in parentheses. (I) Instrumented.
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: Summary of empirical findings

	Intensity of Knowledge Regulation	
	Coefficient	Significance
Collaborating Firms as source of knowledge The more important collaborating firms as source of knowledge…	more (+)	non sign.
The larger the share of knowledge acquired through formal private channels opposed to public channels…	less (-)	sign.
The larger the share of knowledge acquired through informal private channels opposed to public channels…	less (-)	sign.
Competing Firms as source of knowledge The more important competing firms as source of knowledge…	less (-)	sign.
The larger the share of knowledge acquired through formal private channels opposed to public channels…	more (+)	sign.
The larger the share of knowledge acquired through informal private channels opposed to public channels…	less (-)	non sign.

Appendix

Appendix A. Correlation matrix of the independent and control variables (n=157)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) INFLOWS Collaborating Firms	1									
(2) INFLOWS Competing Firms	0.46	1								
(3) Formal CHANNEL_Collaborating Firms	0.25	-0.02	1							
(4) Informal CHANNEL_Collaborating Firms	0.13	0.16	-0.30♠	1						
(5) Formal CHANNEL_Competing Firms	0.18	0.25	-0.03♠	-0.03♠	1					
(6) Informal CHANNEL_Competing Firms	0.10	0.03	-0.03♠	0.41♠	-0.05♠	1				
(7) INNO	0.13	0.05	-0.00	-0.11	-0.06	-0.19	1			
(8) PROTECTION BY COMPLEXITY	0.07	-0.10	-0.00	-0.04	0.08	-0.10	0.13	1		
(9) PROTECTION BY PATENTS	0.06	-010	-0.01	-0.13	0.03	-0.09	0.35	-0.03	1	
(10) VC	0.21◊	0.09◊	0.22♦	-0.12♦	0.05♦	-0.11♦	0.14◊	0.15◊	0.33◊	1
(11) AGE	-0.02	-0.09	-0.13♠	0.03♠	-0.00♠	0.02♠	0.01	0.02	0.04	0.09♦

Note: Spearman rank correlation coefficient unless otherwise stated; ◊ Cramers' V; ♠ Pearson product moment correlation; ♦ Point biserial correlation coefficient.