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ENDOGENIZING KNOW-HOW FLOWS THROUGH THE NATURE OF R&D INVESTMENTS

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Abstract

In this paper we carefully link knowledge flows to and from a firm's innovation process with this firm's investment decisions. Three types of investments are considered: investments in applied research, investments in basic research, and investments in intellectual property protection. Only when basic research is performed, can the firm effectively access incoming knowledge flows, and these incoming spillovers serve to increase the efficiency of own applied research. The firm can at the same time influence outgoing knowledge flows, improving the appropriability of its innovations, by investing in protection. Our results indicate that firms with small budgets for innovation will not invest in basic research. This occurs in the short run, when the budget for know-how creation is restricted, or in the long-run, when market opportunities are low, when legal protection is not very important, or when the pool of accessible and relevant external know-how is limited. The ratio of basic to applied research is non-decreasing in the size of the pool of accessible external know-how, the size and opportunity of the market, and the effectiveness of intellectual property rights protection. This indicates the existence of economies of scale in basic research due to external market related factors. Empirical evidence from a sample of innovative manufacturing firms in Belgium confirms the economies of scale in basic research as a consequence of the firm's capacity to access external knowledge flows and to protect intellectual property, as well as the complementarity between legal and strategic investments.

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Introduction

The appropriation of the benefits to innovation is unlikely to be perfect because the results of innovations spill over to other firms, imposing a positive externality on these firms. This public good nature of know-how has profound implications for a firm's innovative activities and for government policies. A large body of theoretical models has developed around the impact of spillovers on firms' incentives to invest in R&D under different investment regimes (see De Bondt (1996) for a review). Empirical studies trying to assess the importance of spillovers have grown accordingly (see Griliches (1992) and Geroski (1996) for a review). Furthermore, public policy makers have recognized the public good character of (technological) know-how and have shifted attention from stimulating R&D expenditures directly to strengthening the diffusion potential of innovation systems.

There are two important features of spillovers that the theoretical models have failed to take into account. First, spillovers as inputs should be distinguished from spillovers as outputs when analyzing appropriation problems. On the one hand, technological spillovers are an input for the innovation process of an innovating firm. Combining this external knowledge with internal knowledge results in innovations—new, higher quality products and processes. On the other hand, innovating firms worry about the applied knowledge that these innovations produce and that spills over to rival firms. Therefore, these innovators try to maximize the benefits from the external knowledge they can access from the environment—the incoming spillovers–and minimize the negative effects from the spillovers generated for imitators—the outgoing spillovers. In almost all theoretical I.O. models, firms generate and receive spillovers to the same extent. But although firms may at the same time benefit from the stock of available external know-how while having their own know-how becoming part of the public domain, these effects are not necessarily symmetric. Martin (1999) similarly distinguishes in a two-firm R&D patent race between input spillovers and post-innovation imperfect appropriability, where he measures appropriability through the size of the license fee that the winner of the innovation race can charge the loser in a compulsory licensing contract. He finds that the value of the firm is typically maximized when there are high incoming spillovers and when appropriability is high.

Second, spillovers are not exogenous. Firms have to make costly investments in order to affect the usefulness of these incoming spillovers or limit the usefulness of outgoing spillovers to rival firms. Hence, firms, through their investment decisions, effectively endogenize knowledge flows between organizations. So far spillovers have mostly been treated exogenously as involuntary flows, which cannot be affected by the firms. In this view, spillovers are determined by the nature of the technology or by market forces. In addition, they are assumed to be industry-specific rather than firm-specific, and, hence, identical for all firms. Recently, some I.O. models have taken into account that firms can indeed manage these spillovers, for instance by voluntarily increasing the spillovers among cooperating partners, as in the Research Joint Venture scenario of Kamien et al. (1992) (see also Katsoulacos & Ulph (1998)). Furthermore, firms can try to increase incoming spillovers by investing in "absorptive capacity", an idea pioneered by Cohen & Levinthal (1989): spillovers are more efficient in reducing own costs when the firm is engaged in own R&D. This notion of absorptive capacity has been integrated in the I.O. models on R&D cooperation by Kamien & Zang (2000). They show that when R&D directions of partners are sufficiently dissimilar, larger spillovers might induce non-cooperative R&D levels to be larger than cooperative R&D levels due to investments in absorptive capacity. But not only will firms have to invest to be able to absorb, firms wanting to protect themselves from appropriation of their innovations by other firms also have to develop explicit (costly) activities designed to manage outgoing spillovers. This is an ignored issue in the theoretical literature, which seems to rely exclusively on legal protection mechanisms. However, empirical evidence suggests that, in this case, complementarity between the legal and strategic protection is quite important.

In this paper we carefully model the interactions between knowledge flows on the one hand and the firm's innovative decisions on the other hand. In doing so, we endogenize both in- and outgoing knowledge flows, taking into account that firms will attempt to affect the impact of knowledge flows to and from the firm through their decisions on the size and nature of R&D activities undertaken. In our model we distinguish between three possible innovation activities: investments in applied research, investments in basic research, and investments in intellectual property protection. Own R&D investment of the basic kind allows the firm to learn more from the information that is freely available, i.e. this investment serves to develop the absorptive capacity of the firm. At the same time a firm that is more sophisticated in its own R&D process is able to improve its appropriability, preventing other firms from learning. Hence, while investments in basic research generate incoming knowledge flows, investments in intellectual property protection prevent outgoing knowledge flows. One possible set-up for our basic and protective investments could come through the labour market for R&D personnel (see Schmutzler & Gersbach (2000), and also Fosfuri et al. (1998)). The offers firms make to attract R&D personnel from outside and the offers made to keep own R&D personnel inhouse can be seen as payments to optimize respectively incoming and outgoing spillovers.

The model focuses on three critical exogenous variables to derive predictions about the relation between know-how flows and technology investments. These variables are the pool of external know-how that the firm can access, the opportunities provided by the market through its size and willingness to pay for quality, and the effectiveness of intellectual property rights protection through legal means. Increases in any of these variables will increase the technology investments by the firm, both in creative and protective investments. Our results indicate that firms need to spend on applied research in order to keep a quality edge over their fringe rivals. At the same time, they need to spend on protection to prevent diffusion of their innovations to these fringe firms. More interestingly, we find that firms with small budgets for innovation will not invest in basic research. This occurs in the short run, when the budget for know-how creation is restricted, or in the long-run, when the market size is too small, when legal protection is not very important, or when the pool of accessible and relevant external know-how is restricted.

Once firms start accessing external know-how by spending on basic research as a way to create effective know-how, the allocation of technology expenditures between basic and applied research will increasingly favor basic over applied as larger budgets become available. This might happen because of a larger pool of accessible external know-how that, overall, will lead to more spending on technology, both in creating internal know-how and in protecting this newly created own know-how base. The external know-how level not only increases internal basic research, which is needed to access this pool of know-how, but will also make applied research more productive and hence boost spending on the latter as well. Similar effects on spending are present in larger markets, markets with a higher willingness to pay for quality, and markets where intellectual property rights protection is tighter. Therefore, our model not only predicts when technology investments increase as a function of market factors, thereby explaining the complementarity between internal and external sourcing. It also explains the increasing returns to basic research as a consequence of these external factors, rather than because of the minimum efficient scale of a research department. The model further incorporates complementarity between strategic and legal protection: when intellectual property rights protection is tighter, firms will have a larger incentive to invest not only in creation of know-how but also in protection of this newly created know-how. Empirical evidence from a sample of innovative manufacturing firms in Belgium confirms the economies of scale in basic research as a consequence of the firm’s capacity to access external knowledge flows and to protect intellectual property, as well as the complementarity between legal and strategic protection.

Section 2 develops a simple analytical model that allows us to distinguish between incoming and outgoing spillovers in order to study the relationship between both types of spillovers and the firm’s innovative activities. We are able to derive analytical results on the allocation of investments in protective activities as well as investments in applied and basic research to optimize effective know-how building by combining internal and external know-how. These results are presented in Section 3. Section 4 contains an empirical investigation which corroborates some of the findings of the theoretical model. A final section concludes.

Model set up

A simple model is used to highlight the nature of the incentives of firms to invest in technology and how firms allocate these investments over different activities such as basic research, applied research and protection.

Market structure

In the output market, consumers decide whether to buy a unit of the product. A consumer who buys a unit of product of quality s at a price p obtains a utility of:

$$U = \theta s - p,$$

where the parameter θ is a measure of taste for quality. A consumer who does not buy obtains a utility normalized to zero. The parameter θ is uniformly distributed among customers between $[\theta_l, \theta_h]$ with $\theta_h - \theta_l = 1$ and $\theta_l \leq 1$.

The market structure is one where a leading firm *(L)* is facing a fringe of followers, producing a product differentiated in quality: while the leading firm L produces a good of quality s_L, the firms in the fringe each produce a good of quality s_F lower than s_L. Only the leading firm is considered to be innovation active. The followers are imitators with respect to the innovations introduced by the leading firm. The unit cost of production is c for all firms, with $c \leq \theta_l s_F$. While this market leader structure allows to keep the model tractable, it is not general and for instance cannot be applied to markets with a small number of equally sized firms such as in the automarket. Nevertheless, a large number of innovative firms seem to perceive their own position as leading, at least in the segments of the markets in which they are active (1).

The firms in the fringe behave competitively, each producing a product of equal quality s_L, and therefore pricing at marginal cost:

$$p_F = c.$$

A consumer with taste parameter θ is indifferent between buying from the leader at the price p_L or from a follower at the price $p_F = c$ if and only if

$$\theta = (p_L - c)/\Delta s \quad with \quad \Delta s = s_L - s_F.$$

The consumers with a taste characteristic higher than that of the indifferent consumer will buy from the leader, while the others will choose the product of the fringe firms. Therefore, the demand for the leading product is (2):

$$D_L\ (p_L) = \left[\theta_h - \frac{p_{L-c}}{\Delta s}\ M,\right]$$

with M a parameter for the size of the market.

The leader firm L chooses the price p_L to solve:

$$\underset{p_L}{Max}\ (p_L - c)\ D_L(p_L).$$

This results in the following expression for the firm's profit function:

$$\Pi_L = N\,\Delta s,$$

with $N \equiv M\ \theta_h 2/4$. That is, N is a measure of both the size of the market and the consumers' willingness to pay for high-quality products. Note that $\Pi_F = 0$, since we have a competitive fringe. For notational simplicity, we will denote $\Pi = \Pi_L$.

The leader's profit function implies that the difference in quality levels between the leader and the follower is crucial in determining profitability. The quality level of the product is determined by the R&D technology in a simple relationship:

$$s_I = X_I,$$

(1) In a Belgian innovation survey, 82% of all 602 innovation-active respondents characterized their competitive position as leaders or at least among the leading companies (Source: IWT (1999)).
(2) The following expression for $D_L(p_L)$ is only valid if $p_L - c \geq \theta_l\, \Delta s$; otherwise, $D_L(p_L) = (\theta_h - \theta_l)M = M$.

with X_I the firm's effective know-how base. Innovative activities that expand the knowledge base of the firm directly improve the quality of the product (3). The previous expression implies that the difference in effective know-how base, $\Delta X = \Delta s$, becomes a crucial variable for the leader's profitability.

Technology Investment

The fringe firms all produce the same product and have zero profits. Hence, incentives to innovate are small. Therefore, we can ignore any investments on their part to build up their effective knowledge base X_F. This allows to concentrate on the leading firm, which, while competing with the fringe firms, has to decide not only on the size of its investment budget, but also on the allocation of this budget to three different generic types of Technology Investment:

A: Budget allocated to Applied R&D or Development,
B: Budget allocated to Basic R&D or Research, and,
P: Budget allocated to Protection.

Each of these types of investment affect the innovation activities in a different way: Applied and Basic R&D are inputs into the innovation process, while investments in protection attempt to protect the output of the innovation process. Technology investments in basic research may generate the capability to absorb external information and improve the productivity of applied R&D:

> "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." (Griliches (1998)).

Survey studies characterizing spillovers find that *independent R&D* is one of the most efficient channels for absorbing external knowledge (see, for instance, Levin et al (1987), Mansfield (1985), and Harabi (1995)). As in the absorptive capacity model of Cohen & Levinthal (1989), firms need to conduct R&D to be able to assimilate spillovers. Diving further in what constitutes "absorptive capacity", Rosenberg (1990) stresses the importance attached to performing *basic research* by companies that see it "as a ticket of admission to an information network":

> "A basic research capability is often indispensable in order to monitor and evaluate research being conducted elsewhere"

Rosenberg suggests that the effective spillover level is an endogenous variable, depending on the basic research capability of an organization. However, a sharp distinction between basic and applied research is very difficult to draw, given the high degree of interaction. Firms often need to do basic research in order to understand better how to conduct research of a more applied nature. Quoting Rosenberg (1990) again:

(3) Product improvement is a major motive for firms to engage in innovative activities, being most typically of the incremental product R&D type. In EUROSTAT/CIS survey results for Belgium (92-93) innovation-active firms ranked improving product quality as the most important objective. This product enhancement is nevertheless typically in line with cost reduction, leaving product and process R&D often combined (Miravete and Pernías, 2000).

> "A basic research capability is essential for evaluating the outcome of much applied research for perceiving its possible implications…"

Therefore, basic research is necessary to be able to absorb external information and can as such increase the efficiency of applied research. Reflecting these different interactions between externally available information and own internal innovative efforts in applied and basic research, the effective knowledge base of a company X_L is modeled as follows:

$$X_L = A^a \, [1 + \beta(B)\, K]^b$$

The parameters a and b, where $a+b < 1$, are a measure of the efficiency of resp. applied and basic R&D technology. The total stock of outside know-how, K, and the firm's incoming spillovers, i.e. the rate of access of a firm to K, $\beta(B)$, influence the effective knowledge base of the leading company. While K captures the quantity or amount of knowledge generated by others, $\beta(B)$ indicates the fraction of knowledge that is captured by the firm. The effective absorption of the external know-how occurs through the basic research effort of the firm as indicated by the dependence of the spillover on basic R&D. For simplicity we will assume a linear relation: $\beta(B) = \beta B$ resulting in

$$X_L = A^a \, [1 + \beta \, B \, K]^b,$$

One would expect that βK depends on firm-specific as well as industry-specific elements. Pavitt's (1984) classification of industries into science-based sectors, supplier dominated sectors or sectors supplying specialized inputs to other sectors indicates the importance of different types of sources of external know-how for different industries. As Henderson & Cockburn (1996) show, the organization of the firm and its strategy might allow it to take more advantage of spillovers.

The productivity of absorbed knowledge results from the interaction between basic and applied research. Applied R&D is specific to the firm's business and, hence, necessary to develop an effective knowledge base that serves to improve the firm's position. Basic research, B, is necessary to be able to absorb outside know-how and to add it to the effective knowledge base of the firm. Without basic research externally available know-how cannot become part of the effective knowledge base of a company. Basic research is as such complementary to own applied R&D. Note that in our model basic research only serves to absorb external know-how. In case K=0, there is no value to investing in B.

The effective knowledge base of a company cannot be kept fully proprietary. Once developed it will become part of the public domain. These outgoing spillovers will directly affect the firm's competitive position when they can be accessed by its competitors, i.e. the competitive fringe (4). While the pool of publicly available know-how requires basic research in order to be able to effectively translate this into quality improvements, and as such is not accessible to the fringe firms, the effective know-how base of the leader is already sufficiently product specific that it can be absorbed by the fringe firms without any own innovative activities. Absorptive capacity through basic research is hence only considered for accessing external know-how which is not yet product specific. The process of competitive diffusion is characterized as follows:

$$X_F = \alpha \, X_L,$$

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(4) See Amir & Wooders (1998) for a model with endogenous innovator-imitator roles where spillovers flow from the high R&D intensive firm to the low R&D intensive firm. In our model, we assume the leader-follower relation exogenously.

where α measures the process of diffusion (ease of imitation) to rivals. This process of diffusion is partly exogenous, affected by the effectiveness of legal protection or the appropriability degree of the technology. But the firm can also influence the ease of imitation by investing in protection. This type of technology investments should be distinguished from applied or basic R&D expenditures, which are inputs into the innovation process. The firm can make strategic investments to increase the complexity of the product or process design or to improve secrecy. Or, when tacit knowledge is embodied in human capital, protective investments may take the form of attractive wage packages to keep key R&D personnel (see Schmutzler & Gersbach (2000)). Even if an intellectual property protection system is available, the firm typically has to make investments to take advantage of the possibilities provided by the legal protection system. Patent rights are typically not self-enforcing and require costly expenditures by patent-holders to exercise their rights. Survey evidence has indicated that all these strategic protection efforts are rated more important by firms, as compared to legal protection mechanisms (Cassiman & Veugelers (1999)) (5). This interaction between legal and strategic protection to influence the diffusion process is formalized as follows:

$$\alpha(P) = 1 - [(R + 1)\, P^p]$$

with $p < 1 - (a + b)$. The loss of appropriation depends on the level of investment in protection, P, and level of legal rights protection, R. The efficiency of the strategic protection technology is represented by p. (6) Both R and p are assumed to be exogenous to the firm's investment decision.

This formalization allows to capture the importance of strategic protection. Without protective investments P, α=1. In addition, legal protection mechanisms cannot substitute for these protective investments: R serves as a complement to strategic protection. Firms need some investment P in order for them to be able to benefit from any legal protection mechanism. (7)

Due to diffusion, the firm can only keep part of its know-how proprietary. The ratio of protected know-how to actual know-how, i.e. $(1 - \alpha)$, can be influenced by the firm through its investments P. The stock of protected know-how, $(1 - \alpha)X$, is in our model equal to the difference in quality Δs:

$$\Delta s = (1 - \alpha(P))\, X = [(R + 1)\, P^p]\, X.$$

If the firm fails to invest in strategic protection, i.e. $P = 0$, the diffusion of know-how to fringe competitors will eventually wipe out the profitability of the leading firm. In our model this implies that $\Delta s = 0$ and hence $\Pi = 0$.

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(5) In a sample of innovating Belgian manufacturing firms, we find that 401 out of the 411 firms rate strategic protection through secrecy, complexity or lead time at least as effective as patent protection (for a description of the sample see Section 4).

(6) The parameter p only measures the efficiency of strategic protection Note that the model can easily be transposed into $\alpha(P) = 1 - [P\,(R + 1)]^p$ with p measuring the overall strength of the appropriation regime, replacing in the further discussion $(R + 1)$ by $(R + 1)^p$.

(7) The data from the survey confirm the importance of strategic investments as the most necessary protective mechanism. First, only 63 out of the 411 firms in the sample rate strategic protection as not relevant. Second, of these firms, only 9% (or 6 sample firms) rate legal protection to be of minor importance, while the other 91% also rate legal protection to be irrelevant. Hence, the few firms that do not invest in strategic protection, seem to be ignoring strategic protection for other reasons than the possibility of substituting it with legal protection. To compare: on average, 73% of responding firms in the sample rate legal protection to be irrelevant, 22% of slight importance, 5% of moderate importance.

In summary, the model deliberately distinguishes between incoming spillovers, $\beta(B)$, and outgoing spillovers, $\alpha(P)$, endogenizing both. On the one hand, the incoming spillovers $\beta(B)$ indicate the access the innovating firm has to external knowledge through investments in basic research *B*. On the other hand, the outgoing spillovers $\alpha(P)$ represent the loss of returns because of information flows to imitators. Investments in protection, *P*, affect these flows. Furthermore, the model allows us to discuss the decision on the size of the budget and its allocation over *A*, *B*, and *P* in different steps. First, we look at the optimal total budget to spend on Technology *T*. Second, given T, how much to spend on the creation of know-how, *I*, and on the protection of this know-how, *P*. Third, given the investments accruing to know-how creation, *I*, how does the firm allocate it between applied and basic research, *A* and *B*, with the latter allowing the firm to access external know-how (8). The following table summarizes the model set-up:

(1) $\max_{T} \Pi(T)$

s.t. $T \geq 0$,

where $\Pi(T) = N\,\Delta s(T) - T$.

$\Delta s(T)$ is the value function of (2):

(2) $\max_{I,P} \Delta s(I, P)$

s.t. $I + P = T;\ I, P \geq 0$,

where $\Delta s(I, P) = (1 - \alpha(P))\,X(I) = (R + 1)\,P^{p}\,X(I)$.

$X(I)$ is the value function of (3):

(3) $\max_{A,B} X(A, B)$

s.t. $A + B = I;\ A, B \geq 0$,

where $X(A, B) = [A^{a}\,(1 + \beta K B)^{b}]$.

Model Results

Applied versus Basic Research

We start with the discussion on the allocation of the R&D budget between basic and applied research, *A* and *B*, for a given budget size *I*. Although the resulting expressions for levels of *A* and *B* are not yet equilibrium levels before we have solved all steps of the model (see Section 3.3), they are nevertheless interesting to discuss since they reflect the short-term position of a research department when faced with a budget constraint.

(3) $\max_{A,B} [A^{a}\,(1 + \beta K B)^{b}]$

s.t. $A + B = I;\ A, B \geq 0$.

(8) A possible interpretation of the model set-up, consistent with the decentralization within large companies, is the following. The HQ decides on the total expenditure on technology. Next, the strategic decision on the share between creation of know-how and its protection is taken. Finally, the R&D department decides the best allocation between applied and basic research. Note that this is only an interpretation, the resolution of the previous three steps provides the optimal decisions on *A*, *B*, and *P* in the maximization program where the firm chooses (simultaneously) optimally *A*, *B* and *P*.

The optimal value for the endogenous variables *A(I)* and *B(I)* and the value function *X(I)* can take two expressions depending on the level of the budget I:

(A) if $I \leq a/(b\beta K)$:

$$A(I) = I, \quad B(I) = 0, \quad X(I) = I^a;$$

(B) if $I > a/(b\beta K)$:

$$A(I) = \frac{a(\beta KI + 1)}{(a+b)\beta K}$$

$$B(I) = \frac{b(\beta KI + 1)}{(a+b)\beta K} - \frac{1}{\beta K}$$

$$X(I) = \frac{(\beta KI + 1)^{a+b}}{(\beta K)^a} \frac{a^a b^b}{(a+b)^{a+b}}$$

Note that *X(I)* is twice differentiable in *I* (although the second derivative is not continuous at the point $I = a/(b\beta K)$).

A firm with a small budget *I* cannot afford to spend on basic research. This follows from the complementary nature of basic research. On its own, basic research will not result in effective know-how, giving rise to improvements in product quality. Building up effective know-how always requires applied research. If the budget is too small, the priority goes to applied research. If, however, the firm's budget on *I* is sufficiently large, the firm will be able to devote resources to basic research which will allow it to tap the pool of relevant external know-how available, βK. The larger this pool of relevant external know-how, the smaller the threshold level of investments *I* required to start spending on basic research.

Interesting to note is that the ratio of basic to applied research will increase with the budget *I*, once the firm starts investing in basic research. The more the firm spends on R&D, the larger the share that goes to basic research. This result is in line with the empirical observation that basic R&D is typically more associated with big firms with large R&D budgets (see also Section 4). Basic research, as a way of accessing external know-how, becomes increasingly more productive when combined with larger amounts of applied research. Although applied research also becomes more productive when combined with larger amounts of basic research, this effect is less predominant than the previous one, given the head-start for applied research.

When the pool of accessible and relevant external know-how, βK, becomes larger, firms will have a larger incentive to invest in basic research. Although this increases the efficiency of applied research, the expenditures on applied research will go down within a fixed budget. In total, a firm's effective know-how base, *X*, will go up when a larger external know-how base is available, for a given budget *I*.

Protection versus Creation of know-how

A next step in the analysis is the allocation of the total budget on Technology Investments, between the creation of know-how through basic and applied research, and the protection of this know-how, i.e., the allocation between *I* and *P*, given *T*. The optimal decision is considered in the following program:

$$(2) \qquad \max_{I,\,P} \; (R + 1)\, P^{p}\, X(I) \qquad \text{s.t.} \quad I + P = T; \quad I, P \geq 0.$$

Denoting $T^* \equiv (a + p)/b\beta K$, again we have two cases:

(A) if $T \leq T^*$:

$$(T) = \frac{a}{(a+p)} T \; ,$$

$$P(T) = \frac{p}{(a+p)} T \; ,$$

$$Ds(T) = (R+1) \frac{a^a p^p}{(a+p)^{a+p}} T^{a+p} \; .$$

Note that in case (A), $I \leq a/b\beta K$, c.f. section 3.1. In particular, the optimal investments in applied and basic research in this case are:

$$\mathrm{A(T)} = \frac{\mathrm{a}}{(\mathrm{a}+\mathrm{p})} \mathrm{T} \quad \text{and} \quad B(T) = 0.$$

(B) if $T > T^*$:

$$I(T) = \frac{a+b}{(a+b+p)} T - \frac{p}{(a+b+p)} \frac{1}{\beta K} \; ,$$

$$P(T) = \frac{p}{(a+b+p)} T + \frac{p}{(a+b+p)} \frac{1}{\beta K} \; ,$$

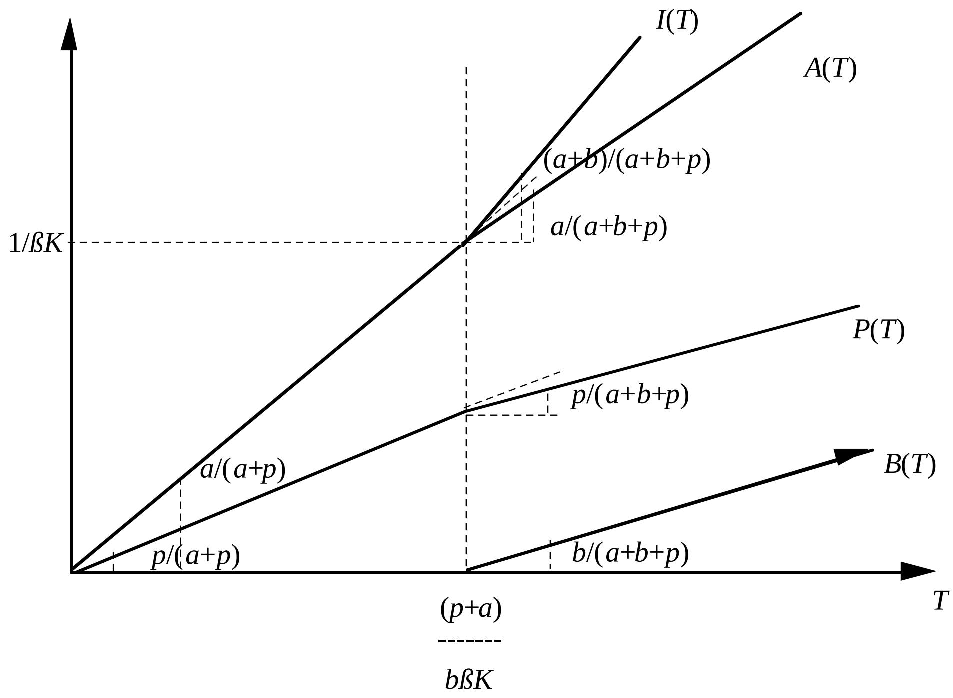
$$\Delta s(T) = (R+1) \frac{a^a b^b p^p}{(a+b+p)^{a+b+p}} \frac{(\beta K T + 1)^{a+b+p}}{(\beta K)^{a+p}} \; ,$$

The optimal investments in applied and basic research in case (B) are:

$$A(T) = \frac{a}{(a+b+p)} T + \frac{a}{(a+b+p)} \frac{1}{\beta K} \; ,$$

$$B(T) = \frac{b}{(a+b+p)} T - \frac{(a+p)}{(a+b+p)} \frac{1}{\beta K} \; ,$$

Figure 1. Optimal allocation of Technology Investment *T* into *A*, *B*, *P*



Up to the critical budget level *T**, firms don't spend on basic research. If a larger budget for technology investment becomes available, firms increase their expenditures on creation of know-how (through applied research only) and on protection of know-how in a linear fashion, keeping the ratio between both constant, as long as $T < T^*$.

Once the budget for technology investment grows beyond the critical level *T**, firms start spending on basic research. Beyond *T**, larger budgets will lead to increases in applied and basic research, as well as in investments in protection. Applied research will increase less with increasing budget *T* in case (B) than in case (A), but total investments in the creation of know-how *I*, including basic research, will increase more with larger budgets in case (B) than in case (A) $((a+b)/(a+b+p) > a/(a + p))$. The opposite holds for expenditures on protection of know-how: beyond *T** expenditures on protection *P* will increase with larger budgets available to a smaller extent than before *T**. All this implies that the allocation of expenditures on Technology between creation and protection will increasingly favor creation over protection with larger budgets available.

Even if the ratio *P/I* between the expenditures in protection and creation decreases with the budget *T*, the ratio between protected know-how and created know-how $\Delta s/X$ (which is the complement to the diffusion rate $(1 - \alpha(P))$) increases with the budget. That is, a larger budget favours actual protection over actual creation.

Optimal Technology Investments

We finally turn to the decision on the optimal size of the budget for technology investments, *T*. This is a strategic decision a firm faces in the medium to long-run, when investment budgets become choice variables. The firm solves:

$$(1) \qquad \max_{T} \ \{N\, \Delta s(T) - T\} \qquad \text{s.t.} \quad T \geq 0.$$

Note that the objective function $\Pi(T) = N\, \Delta s(T) - T$ is continuously differentiable, and it has a negative second derivative (the second derivative is discontinuous at the point T^*).

Again we have to distinguish two cases. Depending on whether T is smaller or larger than T^*, we have a different expression for the value of $\Delta s(T)$ (see section 3.2). The optimal total investment T, as well as the optimal values of the different investment decisions of the firm, are the following:

(A) if $N\,(R + 1)\, a^{\mathrm{a}} b^{1-a-p}\, p^{p}\, (\beta K)^{1-a-p} \leq 1$:

$$T = (a + p)\left[N(R+1)a^{a}p^{p}\right]^{\frac{1}{1-a-p}} \quad ,$$

$$A = I = a\left[N(R+1)a^{a}p^{p}\right]^{\frac{1}{1-a-p}} \quad ,$$

$$B = 0,$$

$$P = p\left[N(R+1)\,a^{a}\,p^{p}\right]\,\frac{1}{1-a-p} \quad ,$$

(B) if $N\,(R + 1)\, a^{\mathrm{a}} b^{1-a-p}\, p^{p}\, (\beta K)^{1-a-p} > 1$:

$$T = (a+b+p)\left[N(R+1)a^{a}b^{b}p^{p}(\beta K)^{b}\right]^{\frac{1}{1-a-b-p-}} - \frac{1}{\beta K} \quad ,$$

$$I = (a+b)\left[N(R+1)a^{a}b^{b}p^{p}(\beta K)^{b}\right]^{\frac{1}{1-a-b-p}} - \frac{1}{\beta K} \quad ,$$

$$A = a\left[N(R+1)a^{a}b^{b}p^{p}\,(\beta K)^{b}\right]^{\frac{1}{1-a-b-p}} \quad ,$$

$$B = b\left[N(R+1)a^{a}b^{b}p^{p}(\beta K)^{b}\right]^{\frac{1}{1-a-b-p}} - \frac{1}{\beta K} \quad ,$$

$$P = p\left[N(R+1)a^{a}b^{b}p^{p}(\beta K)^{b}\right]^{\frac{1}{1-a-b-p}} \quad ,$$

A firm needs to spend on applied research to keep a quality edge over its rivals in the fringe. At the same time it needs to spend on protection to prevent diffusion to these fringe firms. Whether or not firms spend on basic research depends on the size of the market (9), on the effectiveness of legal protection, and on the pool of accessible and relevant external know-how.

In Case (A)—no spending on basic research—the increase in market attractiveness *N* will boost technology spending *T*, both on the creation and on the protection of know-how. Better legal protection provides a similar incentive for more spending on *T* (both *A* and *P*). Both of these drivers will not change the ratio of spending on creation versus protection, as long as the firm is not accessing external know-how (10).

When the firm starts accessing external know-how (Case (B)), the allocation decisions look different. Firms will start spending on basic R&D, which allows them to internalize the pool of accessible external know-how. Market attractiveness *N* and legal protection *R* will stimulate technology spending on creative as well as on protective investments, as in case (A). But we now also have basic research as a complementary way to create effective know-how. The ratio of basic to applied research in creating own know-how will be larger when firms face more attractive markets or better legal appropriation regimes (11). An increase in *N* or *R* furthermore leads to a higher ratio of actual protection, Δs, over actual creation, *X*, while increasing the value of investment in *P* (12). Our model thus generates complementarity between exogeneously given legal protection, *R*, and optimal investments in strategic protection, *P* (13).

The availability of external know-how will only influence the firm's investment decision once it invests in basic research, i.e. in case (B). It is clear that in our model a larger pool of accessible external know-how (either by a larger pool, *K*, or a more accessible pool, β) will lead to more spending on technology, both in creating internal know-how and in protecting this newly created own know-how base. The increase in expenditures on the creation of own know-how suggests that internal and external know-how are complementary. External know-how not only stimulates internal basic research, which is needed to access the pool, but will also make applied research more productive and hence increase spending on the latter as well. Hence, expenditures on basic research will be larger, the larger the pool of accessible know-how, βK, not only because of its access-function but also because of its function of leveraging the efficiency of applied research. All this implies that the ratio of spending on basic versus applied research is typically larger when larger pools of accessible know-how are available, although at a decreasing rate. The increase in spending on basic research also induces the ratio of spending on creation versus protection to increase with the pool of accessible know-how. However, because of the effect of *X* on Δs, the ratio of protected versus created know-how also increases with βK.

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(9) Note that market size *N* has two components: the size of the market in terms of number of customers, *M*, and the willingness to pay for quality (increments), θ_h.

(10) This ratio is only affected (positively) by the efficiency parameter of the R&D technology $a+b$ and (negatively) by the parameter of the efficiency of the protection technology *p*. $(I/P = (a+b)/p)$

(11) This increase in the *B/A* ratio is decreasing in *N* and *R*, given a negative second order effect.

(12) It can be shown that the increase of investments in *P* due to *R* (or *N*) is larger in case (B) than in case (A).

(13) Including in the model the possibility that legal protection *R* would without strategic investments *P* at least partially be able to prevent diffusion, i.e. $\alpha(P) = 1 - [(1+R)(1+P)^{p}]$, seriously complicates the model but would still generate a positive effect of *R* on *P*. It would however be able to generate optimal investment levels for *P* which can be zero for small values of *N, R* and βK.

Some results from selected scenarios

a) Intellectual property rights protection

An important technology policy instrument in many countries is the protection of intellectual property rights through the patent system. The aim of the patent system is to stimulate inventions and investments to develop and commercialize innovations. This is also the result in our model. A legal system that is more efficient in protecting intellectual property, i.e. a larger *R*, will stimulate technology investments, *T*. But more interestingly, the model also allows us to discuss the effect on the allocation of these investments. First, there is a positive effect on defensive investments to protect know-how, which are more efficient the better the legal system. Although these defensive investments may not be interesting from a technological progress point of view, they are nevertheless important. Indeed, because of the better appropriability, firms will also invest more in the creation of know-how, not only through own applied research, but firms will also have a larger incentive to tap into existing know-how by investing in basic research. Our results seem to suggest that the effect on the creative investment is more important than on the protection investment. The creation of know-how will be biased towards basic research, at least for firms/economies that are sufficiently innovation-active, in that they are capable of accessing external know-how through basic research.

The patent system, by granting temporary monopoly rights to the innovator, is not only designed to stimulate innovations. At the same time, it invigorates diffusion by specifying property rights and making the technical information embedded in the patent publicly accessible (14). In terms of the model specification, this would imply a larger accessible external know-how base through β. A better diffusion power of the patent system will only have an impact on firms' innovative strategies if they are investing in basic research to access external know-how. In this case any improvement in the distributive power of the patent system will again result in more spending on basic and applied research as well as on protection. Nevertheless, investments in basic research will be favored in relative terms.

b) R&D Cooperation

When devising their innovation strategies, organizations rely increasingly on cooperative R&D agreements. Firms expose, transfer, and develop valuable know-how within these cooperative R&D ventures. The relationship between R&D cooperation and R&D spillovers is relatively well developed in theoretical models (see Cassiman & Veugelers (1999) for a review). While most models study how the level of spillovers influences the decision of a firm to cooperate in R&D, the decision to cooperate also affects the level of spillovers in an important way. On the one hand, a cooperative agreement increases incoming spillovers. This might be the result of information sharing between partners, as in the RJV scenario in Kamien et al. (1992). Cassiman & Veugelers (1999) provide empirical evidence for the positive association of incoming spillovers and R&D cooperation. On the other hand, a cooperative agreement increases the probability of spillovers to other firms because of this information sharing. However, Cassiman and Veugelers (1999) find that partners in a cooperative agreement also have more effective protection against outgoing spillovers. They thus find evidence that firms actively manage information flows through cooperation, i.e. maximizing access to external information sources as well as protection of own information.

(14) Indeed patent information is one important source of publicly available information, cf infra.

Furthermore, the type of research partner is important in understanding these effects. In cooperative agreements with research organizations or universities, the level of *incoming* spillovers is a determining factor. When cooperating with suppliers or customers, partners worry more about minimizing the *outgoing* spillovers.

Incorporating these results into our model allows us to study how R&D cooperation, through its impact on in- and outgoing knowledge flows, will influence the nature of the firm's innovation strategy. First, it is important to note that in our model, there is no incentive for the leading firm to team up with competitors in a cooperative R&D agreement: fringe rivals are not innovation active and their know-how base is completely derived from the firm's own know-how base. We will hence ignore cooperation with competitors (15). The impact of joint ventures can be interpreted as a comparative statics exercise on the accessibility of external know-how βK. Either know-how is transferred among cooperating partners or the efficiency of research is increased through realizing economies of scope in innovation by combining complementary innovative capabilities. Therefore, the model predicts that collaborating firms will spend more on protecting know-how, as well as on creating know-how, both through more applied research and through more basic research. Furthermore, the ratio of basic to applied research, and the ratio of creation versus protection investments, will be larger for cooperating firms. In addition, the ratio of protected over created know how will be larger for cooperating firms.

Different types of partners –suppliers or customers versus research institutes– will imply a different impact of R&D cooperation on the relationship between knowledge flows and the firm's innovative decisions. By collaborating with research institutes, firms can improve the technological know-how transfer, increasing the (efficiency of the) pool of accessible external know-how βK and/or the parameter b, the efficiency of basic research. Teaming up with clients or suppliers allows the firm to tap more efficiently into a highly relevant source of external know-how. Given the nature of these cooperative agreements, they could also increase the R&D efficiency of applied research, a, rather than the basic research efficiency, b. But a joint venture with vertically related partners will not only allow to increase the (efficiency of) know-how, it also introduces a danger of reducing appropriability. This is reminiscent of the idea that competitors learn about their rivals through common suppliers or customers. It implies that firms cooperating with common suppliers or customers might find it more difficult to appropriate their know-how, i.e. there is more diffusion of know-how, through a lower value for the p-parameter. Typically, innovative investment will decrease with lower values of p, both in the protection and in the creation of know-how (16).

Empirical Evidence

The purpose of this section is to provide empirical evidence consistent with the model presented in the previous sections. The aim is not to formally test the model, since our data are not quite suited for this task. The data used for this research are innovation data on

(15) Note that in empirical observations, cooperation with competitors is only a minor phenomenon as compared to cooperation with suppliers, customers or independent research institutes (see Cassiman &Veugelers (1999)).

(16) Reduced appropriability when captured through the p-parameter would reduce the incentives for firms to invest in protection. However, reduced appropriability through a higher level of exogenous diffusion, as captured by an exogenous shift in α, would increase the necessity for protective investments.

the Belgian manufacturing industry that were collected as part of the Community Innovation Survey conducted by Eurostat in the different member countries in 1993. A representative sample of 1335 Belgian manufacturing firms was selected resulting in 737 usable questionnaires. About 60% of the firms in the sample claim to innovate, while only 40% do not innovate. First, we analyze the effect of market size, the effectiveness of legal protection and access to external know-how, on the total investments in technology by the firm. Next, we restrict the analysis to the innovative firms in the sample. These firms introduced new or improved products or processes in the last two years and returned a positive amount spent on innovation. Due to missing data, we end up with 370 firms in this innovation sample. For these firms, information is available on the nature of their innovative activities.

Unfortunately, the data do not provide us with quantitative data on technology expenditures in each category, i.e. on applied and basic research, and on investments made on protection. However, the data set does provide indirect evidence on the importance of each of these aspects in the innovative strategies of the firms. We therefore construct variables which we expect to be strongly correlated with the firms' expenditures. The questionnaire measures the importance of different information sources for innovation. We assume that the sources that are more important attract higher investments in knowledge creation. More particularly, to construct the ratio of applied-to-basic research, the importance of universities and research institutes as sources of information for innovation is used as a proxy for basic research, while the importance of suppliers and customers as sources of information for innovation is used as a proxy for applied research. We use measures on the effectiveness of protection as a proxy for the ratio of protected-to-created knowledge, i.e. a measure of appropriation of knowledge. For the exogenous variables of interest, *ßK*, *N* and *R*, we use the survey information on respectively the firm's importance of publicly available information as a source for innovation, the inverse of lack of customer responsiveness to its new products as barrier to innovation, and the effectiveness of patent protection to appropriate the benefits of innovation (17). Table 1 presents the variables used.

(17) Although the survey provides firm level information on the effectiveness of legal mechanisms such as patents, trademarks, copyrights, we choose to include the firm level information in our measure of protective investments, reflecting the private investments firms have to incur to be able to use these legal mechanisms. We use the aggregation of the variable at the 2-digit NACE level as our exogeneous industry specific measure of *R*.

Table 1. Construction of empirical proxies

VARIABLE LABEL	VARIABLE DESCRIPTION	ASSOCIATED THEORETICAL CONSTRUCT
INNOVCOST	Total Expenditures by the Firm on Innovation in BEF/10^8.	T
VERTINFO	Importance of supplier and customers as information sources for the innovation process (sum of scores, each rated on scale of 1(=not important) to 5(=crucially important).	A
RESINFO	Importance of universities and research institutes as information sources for the innovation process (sum of scores, each rated on scale of 1 to 5).	B
LEGPROT-IND	Mean measure of effectiveness of patents, registration of brands, copyright as a protection measure of innovation at the level of the 2 digit NACE.	R, p
PROT	Mean score of the effectiveness to the firm of (legal and strategic) protection measures of innovation, STRATPROT + LEGPROT, where LEGPROT is defined as the above industry measure, but at the firm level, and STRATPROT is a mean measure of effectiveness of secrecy, lead time and complexity as a protection measure of innovation	$\Delta s/X = 1-\alpha$
PUBINFO *PUBINFO-IND*	Importance of patent information, conferences and publications, and expositions as information sources for the innovation process (mean score rated on scale of 1 to 5).	βK
COOPRES	0/1 if the firm has a cooperative R&D agreement with a university or research institute.	βK, b
COOPVERT	0/1 if the firm has a cooperative R&D agreement with suppliers or customers.	$\beta K, p, a$
MARKET *MARKET-IND*	Inverse of score on importance of lack of customer interest for new products as barrier hampering innovation.	N
	Control variables	
SIZE *SIZESQ*	Sales of the firm in BEF/10^{10} and its square	
COST	Mean score of importance of high innovation costs, lack of financing and long pay-back time as a barrier for innovation	
INDUSTRY DUMMIES	0/1 for industries defined at NACE 2-digit level.	

Table 2 shows the simple correlations between the variables of interest. Table 3 presents the means of our dependent variables for cooperating firms, while Tables 4 to 6 present regression results for the expenditures on technology (INNOVCOST), the ratio between applied and basic research (VERTINFO relative to RESINFO), and the ratio of protected to created knowledge (PROT) respectively.

Table 2. Correlation matrix

	INNOVCOST	Vertinfo	Resinfo	Vertinfo/ ResInfo	Prot
Pubinfo	-	0.333***	0.435***	-0.247***	0.337***
Pubinfo-ind	0.136***	0.038	0.123**	-0.115**	0.237***
Protleg-ind	0.089**	0.059	0.161***	-0.108**	0.295***
Market	0.036	-0.071	-0.12**	0.08	-0.098*
Market-ind	0.0021	0.057	-0.0042	0.045	0.084

***significant at 1%, **significant at 5%, *significant at 10%.

From the closed form solution of the model in Section 3.3, the theoretical predictions of the model are clear cut: the optimal levels of *I, A, B,* and *P* are increasing in *N*, *R* and (weakly) increasing in *βK*. Therefore, total investment in technology should be positively related to these variables. As expected, we find in Table 2 that the importance of public external information, as proxied by PUBINFO and PUBINFO-ind, is positively and significantly correlated with total technology investments, and, with both of the applied and the basic knowledge variables, as well as with the effectiveness of protective mechanisms. This result confirms the complementarity between internal and external sourcing. Legal protection, LEGPROT–ind, is also positively associated with investments in know-how creation, but this is only significant for basic research. There is however a strong positive correlation with our measure of effectiveness of protective investments, PROT, confirming the complementarity between legal protection and strategic investments. Our measure for market opportunities seems to correlate poorly with total investments. Furthermore, the evidence seems to suggest a negative correlation with basic and protective investments.

Cooperating firms have a significantly higher score on basic research and the ratio of applied-to-basic research is significantly lower for both cooperation with research institutes and vertical cooperation (see Table 3). In all cases the importance of protective investments is significantly higher for cooperating firms. These results are consistent with the positive effect cooperative agreements would have on accessibility of external information. As derived in the theoretical model, this should negatively affect the ratio of applied-to-basic research investments, while positively affecting the ratio of protected-to-created knowledge.

Table 3. Cooperation in R&D and Innovative Investments

		Vertinfo	Resinfo	Vertinfo/Resinfo	Prot
Coop res	*No*	13.2	5.60***	2.73***	2.52***
	Yes	13.4	7.88***	1.82***	2.94***
Coop vert	*No*	13.0***	5.99***	2.54**	2.55***
	Yes	13.9***	6.94***	2.28**	2.85***

Differences in means across classes is ***significant at 1%, **significant at 5%, *significant at 10%.

Effects on investment levels

Table 4 presents a Tobit regression of the total investment in innovation by the firms. These data are obviously left censored for firms not spending on innovation. Due to missing values for non-innovating firms, we are restricted to industry level variables for legal protection and access to external information. After accounting for missing values, we are left with 565 observations. Controlling for firm size (SIZE, SIZESQ) and the costliness of innovation as an obstacle to innovation (COST), we find strong positive effects of access to external knowledge on innovation expenditures, again confirming the complementarity between external and internal sourcing. Also market opportunity, at least at the firm level, stimulates innovative expenditures. The effectiveness of legal protection is positive but only marginally significant.

Table 4. TOBIT Regression of INNOVCOST

	INNOVCOST
Constant	-16.76*** (3.15)
Size	2.72*** (0.298)
Sizesq	-0.12*** (0.016)
Cost	0.917*** (0.303)
Pubinfo-ind	3.66*** (1.16)
Protleg-ind	1.20* (0.74)
Market	1.80** (0.81)
Market-ind	-2.63 (3.23)
	N=565 267 left-censored Chsq=129.6***

***significant at 1%, **significant at 5%, *significant at 10%.

Effects on the applied-to-basic investment ratio

The theoretical model presents some clear predictions on the ratio of expenditures of applied R&D to basic R&D. To recall, the ratio of applied-to-basic research was found to decrease in the volume of accessible external information, the tightness of the legal appropriation regime, and the size of the market. In particular, the most obvious prediction is on access to external information. For large values of this variable, the firm's basic research should be relatively more stimulated than its applied research expenditures. In the correlation table, we already found PUBINFO (and PUBINFO-ind), as well as LEGPROT-ind to be negatively and significantly correlated to the ratio VERT/RES-INFO.

Table 5. Econometric results on ratio Applied-to-Basic R&D: VERTINFO/RESINFO

	(1)	(2)
PUBINFO	-0.327*** (0.082)	-0.270*** (.079)
PUBINFO-ind	0.072 (0.306)	0.144 (0.289)
LEGPROTind	-0.231 (0.187)	-0.066 (0.179)
MARKET	0.167 (0.194)	-0.013 (0.185)
MARKET-ind	1.036 (0.824)	0.832 (.780)
SIZE	-0.119* (0.068)	-0.049 (0.068)
SIZESQ	0.004 (0.003)	0.002 (0.003)
COOPRES		-0.906*** (0.135)
COOPVERT		0.272** (0.134)
Constant	2.988*** (.745)	2.699*** (.708)
	n=370 F(7, 362)=4.46*** adj R-sq=0.0615	n=370 F(9, 360)=8.93*** adj R-sq=0.162

***significant at 1%, **significant at 5%, *significant at 10%.

The OLS regression results reported in Table 5, column (1), show that the effects of PUBINFO on the applied-to-basic ratio remain strongly significantly negative at the firm level in a multivariate analysis. This confirms that firms with access to external know-how are relatively more oriented towards basic reseach. The regression results further confirm that legal protection, LEGPROT-ind, is more important for basic research expenditures relative to applied research, but this effect is not significant. Also our proxy for market attractiveness fails to generate a significant effect both at the industry and the firm level. Note that the conventional wisdom that basic research is more related to large firms is also confirmed, with size negatively, but only marginally significantly, affecting the applied-to-basic spending ratio.

The comparative statics results show a discontinuity at a cutoff which determines whether or not the firm invests in basic research. The cutoff is more likely exceeded for higher values of βK, N and R. We therefore split the variables PUBINFO, LEGPROT-ind and MARKET into high and low values (18). According to the theory, we should find a more important (or significant) effect of these variables on the ratio applied-to-basic for higher levels of these variables. For high values for PUBINFO a strongly significant negative effect on the applied-to-basic ratio emerges, while the coefficient for low values for PUBINFO is only marginally significant. But since F-tests on whether split coefficients are individually or jointly significant cannot be rejected at conventional significance levels, results are not reported.

(18) The cutoff between high and low is constructed using information on the modus for firms who rate resinfo as not important: firms belong to the high category if they have a value for the variable which is equal to or higher than the modus value within the sample of firms who rate resinfo as not important (=2 for PUBINFO, 1 for MARKET and 1.99 for LEGPROTind).

As expected, cooperation with research institutes, providing access to external information and at the same time possibly increasing the efficiency of basic R&D, has a (significantly) negative effect on the ratio of applied-to-basic research. Cooperation with vertical partners, however, is significantly positively related to the applied-to-basic ratio. Cooperation with research institutes is strongly positively correlated with vertical cooperation. Controlling for cooperation with research institutes now reverses the simple correlation result of Table 3, where vertical cooperation seems to have been picking up the effect of research cooperation on access to external information. This indicates that these types of vertical cooperative agreements might actually boost the efficiency of applied R&D relative to basic R&D rather than affect access to external information (see column (2)) (19).

Industry level variables, including LEGPROT-ind (20), fail to contribute significantly to explaining the applied-to-basic ratio. When industry dummies at the NACE-2 digit level are included, again no industry dummy is significant. The results on access to external information remain unaffected when including industry dummies.

Results on the effectiveness of protection

Regressing the PROT variable on the same set of explanatory variables allows us to check to what extent exogenous factors such as the effectiveness of the protective system, the availability of external information, and market opportunities influence the ratio of protected knowledge to created knowledge (1 - $\alpha(P)$). Table 6 presents the results of these OLS regressions.

Table 6. Econometric results on ratio Protected-to-Created Knowledge

	(1)	(2)
PUBINFO	0.371*** (0.056)	0.360*** (.057)
PUBINFO-ind	-0.149 (0.206)	-0.160 (0.207)
LEGPROTind	0.533*** (0.126)	0.505*** (.128)
MARKET	-0.227* (0.133)	-0.202 (0.134)
MARKET-ind	0.893 (0.567)	0.918 (.568)
SIZE	0.080* (0.046)	0.066 (0.049)
SIZESQ	-0.004* (0.002)	-0.003 (0.002)
COOPRES		0.105 (0.096)
COOPVERT		0.012 (0.096)
Constant	.570 (.521)	0.626 (.525)
	n=368 F(7, 360)=13.67*** adj R-sq=0.195	n=368 F(9, 358)=10.79*** adj R-sq=0.194

***significant at 1%, **significant at 5%, *significant at 10%.

(19) There might exist a tautological relation between cooperation and the construction of the ratio of applied-to-basic research. Firms that cooperate with research organizations, suppliers or customers will find these organizations to be an important source of information for the innovation process. This is exactly our proxy for applied and basic research. See also Table 1 for a definition of the variables.

(20) Including legal protection at the firm level fails to generate a significant effect, suggesting this variable is only relevant at the industry level.

In line with the theoretical model, a more efficient legal protection system, measured through LEGPROT at the industry level, results in a significantly higher ratio of protected-to-created knowledge (21). This confirms the complementarity between the efficiency of legal protection and the incentives for firms to engage in strategic protection. The results further reveal a link between incoming and outgoing knowledge flows: firms for which external information is more important will rate protecting their know-how as more important as indicated by the very significant positive coefficient of PUBINFO. This is in line with the theoretical model that predicts a positive effect from βK on P and, hence, on the ratio of protected-to-created knowledge, Δs/X or 1-α(P). The importance of size for protective investments is confirmed by the positive coefficient on size, with a non-linearity in the size relationship. But after correcting for access to external know-how and intellectual property protection, firm size remains only marginally significant. MARKET seems to have a negative impact on the effectiveness of protection, which is contrary to expectations, but again the effect is only marginally significant and not robust across alternative specifications.

The regression results in column (2) further show a positive effect from vertical cooperation and cooperation with research institutes on the ratio of protected-to-created knowledge (PROT). While consistent with the model predictions, these effects are not significant (22).

Conclusions

In this paper we carefully model the interactions between knowledge flows on the one hand and firms' innovation decisions on the other hand. Firms will attempt to affect the impact of incoming and outgoing knowledge flows to and from the firm through their decisions on the size and nature of R&D activities undertaken. Three innovation activities are distinguished: investments in applied research, investments in basic research, and investments in intellectual property protection. The market structure is one where a firm is facing a fringe of followers, producing a product differentiated in quality. The effective knowledge base of a firm is used to improve the quality of the product. This knowledge base is built by combining internal and external know-how. Only when basic research is performed can the stock of relevant and accessible outside know-how be used effectively. It may then serve to increase the efficiency of own applied research. The process of diffusion is partly exogeneous, affected by the effectiveness of legal protection or the appropriability degree of the technology. But the firm can also influence the ease of imitation by investing in protection.

The theoretical model shows that firms with small budgets for innovation will not invest in basic research. This occurs in the short run, when the budget on know-how creation is restricted, or in the long-run, when market size is too small, when legal protection is not

(21) The same result holds when the dependent variable would be strategic protective measures STRATPROT, in which case including legal protective measures at the firm and industry level results in a strong significantly positive coefficient of LEGPROT at the firm level, further supporting the strong complementarity between legal and strategic protection.

(22) Performing a similar split on PUBINFO, MARKET and LEGPROTind into low and high values allows us to check any non-linearity in the relationship. While the coefficients on PUBINFOhigh and PUBINFOlow as well as LEGPROTind-low & LEGPROTind-high, all remain significantly positive, a test for equal coefficients again cannot be rejected in both cases. Also a joint F-test on the equality of the high-low coefficients for PUBINFO, LEGPROTind & MARKET cannot be rejected. Hence results are not reported.

very important, or when the pool of accessible and relevant external know-how is restricted. Once firms start accessing external know-how by spending on basic research as a way to create effective know-how, the ratio of basic to applied research will increase, the more firms spend on R&D. This could happen because of a larger pool of accessible external know-how that, overall, will lead to more spending on technology, both in creating internal know-how and in protecting this newly created own know-how base. Similar effects are present in larger markets or markets with a higher willingness to pay and in markets where intellectual property rights protection is tighter. Therefore, our model can explain the complementarity between internal and external sourcing, through the interactions between basic and applied research, as well as the complementarity between legal and strategic protective technology investments. In addition, it establishes increasing returns to basic research as a consequence of external factors such as the size of the market, the extent of the pool of external knowledge available to the industry, and the effectiveness of intellectual property rights protection, rather than the more traditional explanation of economies of scale in basic research because of the minimum efficient scale of a research department. Consistent with the theoretical predictions, we find that, for a sample of Belgian manufacturing firms, large firms in industries with sufficient access to external information and good legal protection mechanisms, when confronted with market opportunities, will invest more in innovation. Furthermore, we find that larger firms that have better access to external information sources and enjoy better legal protection spend more on basic R&D relative to applied R&D. Our empirical evidence thus confirms the existence of economies of scale in basic research as a consequence of access to external information and protection of intellectual property. In addition, there seems to exist a strong complementarity between legal protection and the level of protective investments. A firm that is larger, which exploits a diversity of internal and external sources and enjoys sufficient legal protection seems to be more effective in appropriating and preventing others (competitors) from learning.

The simplifications in the current model allow to trace explicit analytical results on optimal technology budget allocations, while generating predictions that seem to corroborate with some stylized facts. It remains to be investigated whether the results extend to more general settings, for instance with respect to market structure and diffusion regimes. Since the integration of protective and creative motives in innovation strategies is underdeveloped in the literature, we hope, by presenting our theoretical model and some empirical results, to stimulate further research in this topic.

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