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The purpose of this paper is to identify those factors shaping the decision to engage in external R & D. We use the lens of institutional economics to link the decision to engage in external R & D to both firm- and industry-specific characteristics. In particular, we find that internal and external R & D tend to be complements in high-technology industries but substitutes in low-technology industries. (JEL: O 3)

1. Introduction

A rather voluminous literature has emerged identifying reasons why firms engage in research and development (R & D).[1] At the heart of this literature is what has become known as the *knowledge production function*, which links knowledge-generating inputs to innovative outputs. That is, firms invest in R & D inputs in order to produce innovative output. As we show in the third section of this paper, a high number of firms undertaking R & D do so by investing in external R & D. Why should firms choose to invest in R & D *external* to the firm rather than *internal* to the firm?[2]

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[1] See, e.g., Griliches [1979] and Audretsch [1995].

[2] We consider external R & D as a form of R & D in which an outside party becomes involved in a certain project. This can be as a cooperative partner or as a subcontractor.

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The purpose of this paper is to shed some light on those factors shaping the decisions confronting firms to engage in external R & D and internal R & D. The traditional literature on the knowledge production function provides virtually no insight into this question. However, when viewed through the lens of institutional economics a number of important factors emerge as shaping the decision of whether R & D is undertaken within the boundaries of an enterprise or externally.

In the second section of this paper we rely upon institutional economics to identify those conditions leading firms to favor external R & D and those conditions leading firms to favor internal R & D. These conditions revolve around well known concepts of institutional economics such as uncertainty, information asymmetries, asset specificity and the principal-agent relationship. In the third section we specify a model linking these factors, and in particular the importance of asset specificity, to the decision to engage in external R & D and the decision to engage in internal R & D. In the fourth section the model is estimated using a data base of 1,106 Dutch manufacturing firms. Finally, in the last section a conclusion and summary are provided. In particular, we find that internal and external R & D tend to be complements in high-technology industries but substitutes for each other in low-technology industries.

2. Internal Versus External R & D

Why would a firm decide to engage in external rather than internal R & D? In a world of perfect information with no knowledge asymmetries, there would be little reason for a firm to outsource R & D activity. As GRILICHES [1979] formalized in his model of the knowledge production function, the firm would then invest in internal R & D to generate innovative activity. Undertaking external R & D would only reduce the control of information. Cooperating with other firms on an R & D project or contracting out R & D inevitably means that others are provided with information about the firm and its products (ARROW [1962]). This would tend to reduce the ability of the firm to appropriate its investment on the (external) R & D.

Similarly, engaging in external R & D inevitably threatens the exclusivity of the resulting new economic knowledge that a firm might rather maintain as proprietory (ARROW [1962]). For example, a firm that has detected a new consumer need after performing market research tries to keep this secret in order to develop the product and enter the market as a monopolist. In addition, internal R & D provides career opportunities for scientists and engineers. As SCHERER [1991] points out, allowing scientists and engineers to pursue their own individual research facilitates the hiring of high-quality researchers, thereby enhancing their career opportunities.

Taken together, these arguments suggest that the firm will tend to shun external R & D in favor of internal R & D in order to best appropriate the economic value accruing from investment in new knowledge.

However, once information is no longer considered to be perfect, the locus of the decision may shift away from internal R & D towards external R & D. As Frank KNIGHT [1921] and later Kenneth ARROW [1962] argued, new economic knowledge is anything but perfect. Not only is new economic knowledge inherently uncertain and therefore risky, but it is also asymmetric and non-exclusive.

ALCHIAN [1950] pointed out that the existence of knowledge asymmetries would result in the inevitability of mistaken decisions in an uncertain world. Later, ALCHIAN and DEMSETZ [1972] attributed the existence of asymmetric information within the boundaries of a firm as resulting in a problem of monitoring the contribution accruing from each employee and setting the rewards correspondingly. This led them to conclude that, "The problems of economic organization is the economical means of metering and rewards" (ALCHIAN and DEMSETZ [1972, 781]).

Asymmetric knowledge under uncertainty in the context of decision making within a bureaucratic organization leads to a host of agency problems, spanning incentive structures, monitoring and transaction costs (MILGROM and ROBERTS [1987]). The basic agency problem (ALCHIAN and DEMSETZ [1972]; JENSEN and MECKLING [1976]; HOLMSTROM and MILGROM [1987]; HOLMSTROM and TIROLE [1989]; and MILGROM [1988]) arises in the context of an organization responding to an agent who possesses potentially new economic knowledge. In fact, it may even be the task of that agent within the context of the bureaucratic organization to search out, either through production or acquisition, such new economic knowledge, as in the case of a scientist or engineer. Because the principal is not able to directly observe either the efforts or the outcome of the agent, both monitoring and incentive problems, as well as possible hostage problems emerge. For instance, this may lead to a situation where the agent will have a clear incentive to exaggerate the expected value of a potential innovation along with the amount of effort required by him to develop and implement it.

Although outsourcing R & D is considered positive if the "principal-agent" argument is applied, the "asset specificity" argument can hamper outsourcing. WILLIAMSON [1989] mentions that idiosyncratic human capital, which in this case is the specific asset, can sometimes build up during the course of employment. He quotes MARSCHAK [1968, 14] saying that "there exist almost unique, irreplaceable research workers, teachers, administrations; just as there exist unique choice locations for plants and harbors." Especially a *highly skilled* labor force tends to be specific to the individual enterprise, meaning that the value of the R & D is greater when it is undertaken in conjunction with the firm-specific human capital rather than independent of the firm-specific human capital.

By contrast, a highly capital intensive firm will tend to produce a relatively standardized product, which can only be copied with great difficulty by another firm. Thus, *ceteris paribus*, external R & D is expected to be more prevalent in firms which are capital intensive in terms of *physical* resources, but less prevalent in firms which are capital intensive in terms of *human* resources.

3. Model

3.1 Specification

A model is used to test what factors shape the decision to engage in external and internal R & D. The dependent variable is whether or not a firm engages in external R & D. This enables us to apply a PROBIT model. Our particular interest is whether the degree of asset specificity influences the decision. The extent to which the firm utilizes firm-specific human capital is represented by the share of the firm's labor force accounted for by Skilled Labor. This is measured by the ratio (percentage) of labor costs to the value of industrial production. It is expected that the R & D will more likely be undertaken within the boundaries of the firm, because human capital tends to be firm specific.

Firms exhibiting a high Capital Intensity, measured by the ratio of the cumulative investment in physical plant and equipment during the preceding seven years to the value of industrial production, are generally producing a standardized product based on standardized, albeit capital intensive, production processes. The ability to produce is dependent on physical capital rather than on human capital and therefore likely to be less firm-specific. Additionally, the high barriers to entry reduce the likelihood that the firm investing in the R & D will not be able to appropriate the returns from its investment. Thus, a firm which is relatively capital intensive in terms of *physical* resources is expected to have a greater likelihood of deciding to engage in external R & D, whereas a firm which is relatively capital intensive in terms of *human* resources is expected to have a lower likelihood of engaging in external R & D.

In addition, as Coase [1937] suggested, larger firms are more likely, *ceteris paribus*, to incorporate additional transactions internally. This would suggest that Firm Size, measured in terms of employment should have a negative impact on the likelihood of an enterprise engaging in external R & D. Of course, it is also well known that larger firms have a greater propensity for engaging in R & D in general (Scherer [1991]; and Audretsch [1995]). We also include the number of scientists and engineers involved in R & D to control for the extent to which the firm is involved in R & D. Both R & D and Firm Size are expressed in terms of logarithms.[3]

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[3] Expressing R & D and Firm Size in terms of logarithms enables a test on linear restrictions. For instance, it can be tested whether the effect of R & D and Firm Size originates from an effect of R & D Intensity, defined by the ratio of R & D and Firm Size. This would be the case if the coefficients of R & D and Firm Size are about equal and bear the opposite sign. It appears that is not the case for our data set.

Industries experiencing a high growth rate are more likely to be in the early stages of the industry life cycle, where no dominant product design has yet emerged. Such a lack of product standardization elevates the cost of transacting information between firms and should lead to a lower likelihood of firms engaging in external R & D. In addition, firms will tend to be more protective of their innovative ideas. Thus, Market Growth, measured as the percentage change in total (deflated) industrial sales is expected to be negatively related to the likelihood of a firm engaging in external R & D.

In order to control for industry-specific influences, we include three variables that reflect the underlying structure of each particular industry. These influences are captured by including the four-firm concentration ratio, C4, of the industry within which the firm is operating, as well as the Price Cost Margin measured as the ratio of the value of industrial production minus labor and material costs, divided by the value of industrial production. An additional measure reflecting the degree to which the firm-size distribution is dominated by large enterprises is the Small Business Presence, defined as the number of employees working in firms with fewer than 100 employees, divided by total industry employment. See HERTOG and THURIK [1993] for a discussion of the possible influence of these variables.

3.2 Measurement

The firm-level data used to estimate the above PROBIT model are from the 1984 Stichting voor Economisch Onderzoek der Universiteit van Amsterdam (SEO) national survey on R & D and innovation in the Netherlands. We are able to construct a consistent data base of 1,106 Dutch manufacturing firms engaging in R & D. Each firm is classified according to the three-digit SBI code.[4] The data set contains information for 1983 on whether or not the firm engages in external R & D, whether or not the firm engages in internal R & D, as well as on firm size (in terms of employment), the SBI code, and the number of scientists and engineers engaged in R & D. As table 1 shows, the percentage of firms engaging in external R & D ranges from 32% for the smallest firms to

Table 1

Percentage of Firms Engaging in External R & D per Size Class*

Sizeclass (fte's)	0–1	2–4	5–9	10–19	20–49	50–99	> 100	Total
Total Number of Firms	154	232	181	112	73	91	263	1106
Percentage of Firms With External R & D	32%	33%	44%	52%	49%	53%	63%	46%

* The sample consists of Dutch manufacturing firms engaging in R & D in 1983.

[4] SBI is the industrial classification system used for Dutch manufacturing.

63% for large firms. There is a clear trend linking firm size to an increased likelihood of engaging in external R & D.

The industry-specific variables, except for Small Business Presence, were computed using three-digit SBI data from the DUMA (Dutch Manufacturing) data set of the EIM Small Business Research and Consultancy in the Netherlands. To compute Small Business Presence, we used a data set identifying the firm size distribution in each industry, which is also located at EIM. All industry-specific variables are constructed as the mean of the 1981, 1982 and 1983 values. This is done because R & D decisions are not just based on contemporaneous factors, but also originate from strategic plans made during the preceding years.

4. Empirical Results

The PROBIT regression results from estimating a firm's decision to engage in external and in internal R & D are shown in table 2. As the positive and statistically significant coefficient of R & D indicates, the likelihood of a firm engaging in external R & D tends to rise as the R & D effort of the firm rises. In fact, despite the obvious simple positive relationship between firm size and the propensity to engage in external R & D exhibited in table 1, after controlling for R & D effort along with the other factors, Firm Size is found to exert no statistically significant influence on the decision to engage in external R & D. Thus, there is no evidence supporting the hypothesis that large firms have a higher propensity to engage in external R & D.

The negative and statistically significant coefficient of Skilled Labor suggests that firms utilizing a high degree of skilled labor are less likely to engage in external R & D. This is consistent with the idea motivated above that high levels of human capital tend to be a firm-specific asset and dictate that R & D be undertaken within the boundaries of the enterprise. The positive and statistically significant coefficient of Capital Intensity implies that the likelihood of engaging in external R & D tends to rise as the capital intensity of the firm rises. This is consistent with the hypothesis that capital intensive firms tend to produce standardized products using standardized technology and are less concerned with appropriating the returns from external R & D. The coefficients of C4, Small Business Presence, Price Cost Margin and Market Growth cannot be considered statistically significant.

The model is extended in two ways. First, an equation is included for internal R & D similar to the external R & D equation. External and internal R & D need not be substitutes for each other. As Dosi [1988, 1132] points out about external research projects, "They do not stand as an all-or nothing substitute for in-house research."[5] Similarly, Gambardella [1991, 391] observes that,

[5] Dosi [1988, 1134] points out that the outcomes of R & D projects are subject to considerable risk and uncertainty, so that "firms tend to work with relatively general and event-independent routines (with rules of the kind ... spend x% of sales on R & D)."

Table 2

Estimation Results of the PROBIT Model Where the Dependent Variable Equals Zero in Case the Firm Does not Engage in External R & D and Equals one in Case the Firm Does Engage in External R & D*

Dependent Variable	ln (R & D)	ln (Firm Size)	C4	Small Business Presence	Capital Intensity	Price Cost Margin	Market Growth	Skilled Labor	Intercept	n (n1–n2)[c]
External R & D	0.27[a] (0.0001)	0.052 (0.2483)	–0.0014 (0.5726)	–0.00037 (0.9278)	0.011[a] (0.0013)	–0.013 (0.2065)	0.0033 (0.7294)	–0.011[b] (0.05781)	–0.28 (0.3874)	1106 (514–592)

* The model is estimated for Dutch manufacturing firms that engaged in R & D in 1983. (p-values in brackets, ratios are expressed as a percentage.)

[a] Statistically significant at a 5% significance level.

[b] Statistically significant at a 10% significance level.

[c] n1 is the number of firms engaged in the form of R & D concerned, n2 is the number of firms not engaged in this form of R & D.

"firms have to undertake their own basic research in order to understand and utilize external science. In-house basic research is the price to plug into the outside information network." [6]

To examine the extent to which internal and external R & D compete, the above model for external R & D is analogously estimated for internal R & D. Differing knowledge conditions underlying an industry, which shape the degree to which knowledge asymmetries exist in the industry, could shift the coefficients systematically. That is, estimating both the decision to engage in external R & D as well as the decision to engage in internal R & D could result in one out of two outcomes: *(i)* The predicted opposite effects *are observed* for each explanatory variable. In this case it can be inferred that internal and external R & D tend to serve as substitute forms of R & D, because a change in any given explanatory variable would induce an increase in the likelihood of one type of R & D at the expense of a decrease in the other form. In such a case external and internal R & D would be exchangeable. *(ii)* The predicted opposite effects *are not observed* for each explanatory variable. In this case internal R & D and external R & D are not considered to be substitutes but are considered to be complements.

Second, the influence of different technological environments is taken into account. SCHERER [1965] introduced this influence on the relationship between size and innovativity of a firm. In their literature review BALDWIN and SCOTT [1987, 75] mention "the need for empirical models with variables that capture the significant aspects of this technological environment, elaborating on the technological opportunity classes in Scherers 1965 and 1967 empirical studies." ACS and AUDRETSCH [1990] divide the industries according to mean R & D intensity [7] into low- and high-technology industries. In the present study the approach of Acs and Audretsch is followed. A test on the relevance of this division is performed using a likelihood ratio test. Indeed, a significant difference between high and low-tech industries for both internal and external R & D at a 5% level is found.

The estimation results of the PROBIT model for internal and external R & D for both low- and high-tech industries are to be found in table 3. From this table one can conclude that the asset specificity argument applies to low-tech industries and not to high-tech industries. For low-tech industries a higher level of Capital Intensity and a lower level of Skilled Labor favor external R & D and hamper internal R & D. This effect is significant at a 5% significance level. In high-tech industries the level of Capital Intensity and the presence of Skilled

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[6] GAMBARDELLA [1991] provides evidence of the link between internal and external R & D from several case studies on a few large U.S. pharmaceutical companies. He finds that, on the one hand, external R & D is not a full substitute for internal R & D. On the other hand, by engaging solely in internal R & D a firm cannot benefit from the *integration* of knowledge, which he claims is characteristic of external R & D.

[7] R & D intensity is defined as number of full-time-equivalents engaged in R & D divided by total number of full-time-equivalents.

Table 3

Estimation Results of the PROBIT Model Used to Establish the Determinants of Both Internal R & D and External R & D*

Dependent Variable	ln (R & D)	ln (Firm Size)	C4	Small Business Presence	Capital Intensity	Price Cost Margin	Market Growth	Skilled Labor	Intercept	n (n1−n2)[c]
External R & D	0.31[a]	0.012	−0.0020	0.0051	0.017[a]	−0.036[a]	−0.011	−0.020[a]	0.21	550
Low-tech	(0.0001)	(0.8516)	(0.6948)	(0.3669)	(0.0003)	(0.0066)	(0.4611)	(0.0259)	(0.6385)	(262−288)
Internal R & D	0.59[a]	−0.097	0.019	−0.009	−0.020[a]	0.064[a]	0.035	0.044[a]	0.45	550
Low-tech	(0.0001)	(0.4475)	(0.1975)	(0.3965)	(0.0328)	(0.0372)	(0.3392)	(0.0289)	(0.6341)	(520−530)
External R & D	0.26[a]	0.089	−0.0035	−0.0080	−0.00027	0.037[b]	−0.0054	−0.016	−0.66	556
High-tech	(0.0001)	(0.1807)	(0.2730)	(0.2801)	(0.9730)	(0.0686)	(0.7836)	(0.2193)	(0.2677)	(252−304)
Internal R & D	0.45[a]	0.16	0.013	0.043	−0.021	0.022	−0.052	−0.011	0.99	556
High-tech	(0.0001)	(0.3729)	(0.1568)	(0.1413)	(0.3044)	(0.6957)	(0.3060)	(0.7766)	(0.5624)	(539−517)

* The dependent variable equals zero in case the firm does not engage in external (internal) R & D and equals one in case the firm does engage in external (internal) R & D. The model is estimated for low and high-tech industries separately. The sample consists of Dutch manufacturing firms that engaged in R & D in 1983. (p-values in brackets, ratios are expressed as a percentage.)

[a] Statistically significant at a 5% significance level.

[b] Statistically significant at a 10% significance level.

[c] n1 is the number of firms engaged in the form of R & D concerned, n2 is the number of firms not engaged in this form of R & D.

Labor do not seem to influence the decision on internal and the decision on external R & D. Not only are the effects insignificant, they also do not seem to have a different effect on internal and external R & D, since the signs of the effects are the same. As the table indicates, there is some evidence that external and internal R & D are substitutes in low-technology industries but not in high-technology industries. That is, in the low-technology industries the coefficient of Capital Intensity is positive for external R & D but negative for internal R & D. Similarly, the coefficients of both the Price Cost Margin and Skilled Labor are negative for external R & D but positive for internal R & D. The consistent emergence of opposite signs for the coefficients of these explanatory variables is consistent with the interpretation that internal R & D is a substitute for external R & D in low-technology industries. In high-technology industries, by contrast, there is no tendency for the regression coefficients to have opposite signs. It may be that, in high-technology industries external R & D serves as a complement to, rather than as a substitute for, internal R & D.

By and large our empirical findings lead to the following conclusions. Firms seem to realize that it is efficient to engage in both types of R & D. Internal R & D enables the firm to translate external knowledge into innovation opportunities for the firm. External R & D facilitates spillovers from the outside information network to the firm's specific knowledge stock. To engage in both kinds of R & D there seems to be a need for a critical mass. Either the firm needs to develop a certain amount of R & D effort, or the firm needs to be in an environment with ample technological opportunities. The results show that the more R & D employees a firm has, the higher is the probability that the firm engages in *both* internal and external R & D.[8] The results also show that in high-tech industries internal and external R & D tend to be complements and in low-tech industries they tend to be substitutes.

5. Conclusions

The traditional model of the *knowledge production function* has typically viewed R & D as an input into the process of generating innovative output. But why should such knowledge-generating inputs be external to the firm rather than internal? Here the traditional model sheds virtually no light on the decision of firms to engage in external R & D.

In viewing the firm through the lens of institutional economics, two concepts appear to be useful in explaining the decision between internal and external R & D. First, *asset specificity* implies that a low level of Skilled Labor and a high level of Capital Intensity in an industry lead to a higher probability that

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[8] This is a statistical result implied by the two individual results of the internal R & D model and the external R & D model.

firms engages in external R & D. Estimates using a sample of Dutch manufacturing firms and a PROBIT model confirm this hypothesis in an empirical fashion. Second, the principal-agent theory implies that firms are not eager to restrict R & D to internal R & D. For the Netherlands we find that high-technological R & D opportunities in the industry and/or a considerable R & D effort by the firm, lead the firm to engage in *both* internal and external R & D.

Perhaps the most striking finding of our investigation implies that external R & D is complementary to internal R & D in high-technology industries but not in low-technology industries, where external R & D apparently tends to be a substitute for internal R & D.

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