R&D, Firm Size and Branch of Industry: Policy Implications

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SOM theme B: Marketing and Networks

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Abstract

An important conclusion from the study reported on here, is that the ratio of expected returns and risk of R&D is systematically less favorable for smaller firms than for larger ones. The fact that risk is relatively high for smaller firms (compared to expected returns) can at least partially be explained by the presence of a fixed and sunk entry cost, which yields a higher threshold to R&D for smaller firms. This suggests that the most suitable way to promote small firm participation in R&D would be by means of a subsidy in the form of a fixed amount of money, to compensate for fixed entry costs.

Introduction

In the past decades, there have been two different traditions in innovation research, a theoretical and an empirical tradition, which have mostly remained separated. The questions addressed in empirical studies have traditionally been the following. Are large firms (more than proportionately) more innovative than small firms? And secondly, is innovation greater in more highly concentrated industries? These empirical studies have been conducted in a theoretically more loose, ad hoc fashion, and focused mostly on the effects of firm size. Theoretical studies on the other hand, employing the formal analytical tools of decision theory and (after the 1970s) of game theory, focused primarily on the effects of market structure. This paper is based on research that links these two research traditions, by a direct empirical estimation of a theoretical model of Research and Development (R&D), in which effects of firm size and market structure are incorporated. The research project more generally applied to relations between innovation on the one hand, and firm size, risk, market concentration and branch of industry on the other (Vossen, 1996). Here I examine the policy implications.

Industrial Classification

Industries differ widely in the degree to which they engage in innovative activity. Economists agree more and more that these differences can be explained by technological opportunity, appropriability conditions, meaning the ability to capture and protect the results of technical innovations, and market demand conditions (Harabi, 1992). However, these factors are either very hard to conceptualize and give operational definitions, and/or even when a particular variable is well defined, the data necessary for empirical work are often unavailable or unreliable (Cohen and Levin, 1989). Hence if it is not possible to include these factors in an empirical study, it is especially important to control for inter-industry differences.

The number of observations in the present sample was not sufficient to estimate different parameters for all two digit SIC industry classes. Moreover, competition through innovation is not likely to be confined to standard industry classes. As Kamien and Schwartz (1982, p.23) note:

"*Perhaps the most important feature of competition through innovation is that it can come from any quarter. It is not restricted to the firm's acknowledged rivals - the producers of similar goods or services - but includes unknown rivals in entirely different lines of business as well (....)*".

And (p.52):

"(....) industries are usually defined by the Standard Industrial Classification employed by the U.S. Department of Commerce. Although this classification is useful for some purposes, it has an important drawback in the study of competition through innovation. For, as already noted, innovation in one area may arise from an industry in an entirely different area, as defined by the Standard Industrial Classification."

To still allow for inter-industry differences in all parameters I used a classification introduced by Pavitt (1984), specifically based on the characteristics of innovations and of innovating firms, rather than on products and technology of production, as is the case with standard industrial classifications. Pavitt describes and explains sectoral diversity in innovative behavior by identifying four categories of industries with differing technological trajectories, i.e. cost cutting, product design or mixed. He uses data collected by Townsend et al. (1981), on the characteristics of about 2000 significant innovations in Britain between 1945 and 1979. The different technological trajectories are in turn explained by sectoral differences in the sources of technology, type of user, and means of appropriation, and some other characteristics of these trajectories are described. The four categories of firms in Pavitt's taxonomy are Supplier Dominated, Scale Intensive, Specialized Suppliers, and Science Based firms.

Supplier Dominated firms are generally small, with weak in-house R&D and engineering capabilities, and largely non-technical means of appropriation. Technological trajectories are therefore defined in terms of cutting costs, with suppliers as a source of new technology, mostly in production. Innovating Scale

Intensive firms are relatively big and make a relatively large contribution to the innovations in their principal sectors of activity. In contrast to Supplier Dominated and Scale Intensive firms, the main focus of Specialized Suppliers is on product innovations for use in other sectors. These firms are often relatively small. Customers are an important trigger for (or source of) product innovation. In Science Based firms, the main sources of technology are the R&D activities of firms in the sector, based on rapid development of the underlying sciences. These firms are relatively big, and produce a relatively high proportion of process as well as product innovations made in their principal sector of activity (Pavitt, 1984). These four categories of industries can also be viewed as representing classes of technological opportunity. This is an important feature of the environment of a firm that we need to control for, since the opportunity for R&D-based innovations depends on the state of knowledge in relevant fields of science and technology (e.g. Scherer, 1965; 1967). Also, I expect that competition through innovation does indeed not confine itself to SIC classes, but largely takes place within the "Pavitt-categories".

Firms were assigned to these categories on the basis of their second digit SIC-codes as shown in table 1. To check for some of the properties ascribed by Pavitt to innovative firms in the different categories, I performed a number of plausibility checks with the industry classification in table 1. First, the average firm size is lowest in the Specialized Suppliers and Supplier Dominated industries, and highest in the Scale Intensive and Science Based industries. Secondly, the average percentage of R&D aimed at product innovation is highest in the Science Based and Specialized Suppliers, and lowest in the Scale Intensive and Supplier Dominated industries, while the opposite is true for the average percentage of R&D aimed at process innovation. Finally, the percentage of firms with a separate R&D department is lowest for the Supplier Dominated industry, followed by Scale Intensive, Specialized Suppliers and Science Based industry. The predicted properties of these industries seem to fit the Dutch situation rather well, as far as I can ascertain on the basis of the available data. De Marchi and Napolitano (1992) also found Pavitt's taxonomy to give a good description of the properties of Italian firms with respect to innovation, and applied it to evaluate Italian innovation policy.

Table 1: Assignment of Industries to Pavitt-categories

Category of Firm	**SIC**	**Description**
Supplier Dominated	22	Textiles
	23	Clothing
	24	Leather
	25	Wood & Furniture
	26	Paper
	27	Printing
	30	Fibers
Scale Intensive	20/21	Food, Beverages, Tobacco
	28	Oil
	31	Rubber & Plastics
	32	Building Materials, Earthenware, Glass
	33	Metals
	34	Metal Products
	37	Means of Transport
Specialized Suppliers	35	Machinery
	38	Instruments, Optical Goods
	39	Remaining
Science Based	29	Chemical
	36	Electrical Goods

The Model

The theoretical model (Nooteboom, 1991) that was the basis for the empirical study, is a "patent race" type of model, where R&D is a race between n competitors, the winner of which can make monopoly profits for a certain period of time. The race is stochastic in the sense that for each contestant, development time follows a negative exponential distribution, and the race stops as soon as one of the contestants wins. The model I employed adds several elements, so that it contains four types scale effects. First, there is a possibility that there is a fixed and sunk entry cost associated with conducting R&D, which is independent of firm size.

This would imply that participation in the R&D race is relatively expensive for small firms. Second, the assumption is that the profitability of an innovation increases with the level of R&D expenditure, but with decreasing returns to scale. Third, there may be an effect of firm size on R&D efficiency. That is, smaller firms may be more or less efficient with respect to the profit/cost ratio of R&D than larger firms. The model explicitly considers not only the expected returns to an investment in R&D, but also the risk involved, defined as the probability that the investment yields negative returns. The fourth possible effect of scale consists in the property that this risk is dependent on firm size.

Another important feature of the model is that with respect to R&D, a systematic distinction is made between participation (does a firm conduct any R&D at all), and intensity (how much is spent in case of participation). The decision on intensity is modeled as a maximization of expected profits, in case of participation. The participation decision is modeled as a more diffuse political process of weighing expected profits against risk. This process is stochastic, with a certain probability that a firm enters the race, which increases with expected profits and decreases with risk, weighed with a 'risk aversion parameter'.

Without going into too much detail, the basic model is represented in the following two equations. For the exact mathematical formulation of the model, and for a detailed account of estimation methods and results, I refer to Vossen (1996, 1998a). Here, the focus is on the discussion of some of the results and their implications for innovation policy.

Annual R&D expenditure (in case of participation):

$$K = a/\Theta + \kappa S^{1+\mu} \tag{1}$$

where K = expenditure per unit of time

a = fixed and sunk entry cost

Θ = time period over which the fixed entry cost a is spread

S = firm size

κ and μ are functions of other model parameters

Probability of participation:

$$P = \frac{-a + hS^{1+m}}{-a + hS^{1+m} + r\, r(S)} \qquad (2)$$

where P = probability of participation

ρ = risk aversion parameter

r(S) = risk as a function of firm size

h and μ are functions of other model parameters

In equation (2), the numerator (and the first part of the denominator) represents the (optimal) expected net present value of returns, as a function of firm size.

Data

The model was estimated with three data sets. The first contains data from a national innovation survey conducted in the Netherlands in 1989 (with data on 1988), funded by the Netherlands' ministry of economic affairs (Kleinknecht et al., 1990). The other two data sets are part of the Community Innovation Survey (CIS) project of the European Community (DG13), making use of a harmonized EU/OESO questionnaire for innovation surveys. I have made use of the Dutch and German surveys, with data on 1992 (Brouwer and Kleinknecht, 1994; Felder et al., 1994).

Results

The empirical results showed that smaller firms systematically participate less in R&D than larger firms. Larger firms are more innovative in the sense that they have a higher probability of conducting any R&D, because their ratio of expected returns to risk is more favorable than for smaller firms. This can at least partly be explained from the existence of a fixed and sunk entry cost, which can act as a threshold to R&D, particularly for small firms. For the Dutch data, I found a significant entry cost in the Supplier Dominated, Scale Intensive, and Specialized Suppliers industries. For the German data, no significant values were found. It is possible that this is because in Germany, substantial investment subsidies have been granted, notably to (smaller) firms from the former East Germany.

Nevertheless, smaller firms that do participate in R&D, do so at higher relative levels of intensity than larger firms in the same three out of four sectors. That is, in these industries smaller firms spend more on R&D per unit of firm size. According to the underlying model the implication is that smaller firms are more R&D efficient. This conclusion is supported by other studies that found that smaller firms are more than proportionately responsible for significant innovations (e.g. Acs and Audretsch, 1990). Only in the Science Based industries no significant difference in relative R&D spending was found between small and large firms.

No effect of firm size was found on the risk factor (the product of risk aversion and risk). It is plausible that for larger firms the risk is lower, because they can diversify it over several simultaneously carried out R&D projects, and because the presence of a fixed and sunk entry cost yields a higher risk for smaller firms. If risk itself is smaller for larger firms, then the result implies that larger firms are more risk averse, since the product of risk aversion and risk is does not vary with firm size. This is theoretically easily accounted for, as in large firms a proposal passes through more hierarchical layers in the process of project screening, with the ensuing higher chance of rejection.

In a comparison between Pavitt-sectors, the pattern is the same for participation and spending: lowest for the Supplier Dominated industries, followed by the Scale Intensive, Specialized Suppliers, and Science Based industries, respectively, as one might expect beforehand. In addition, an effect of market concentration was included. As in most other studies, a consistent positive effect on the intensity of R&D expenditure was found. The interpretation of this result is however not unambiguous. It would go beyond the scope of this paper to devote a full discussion to the arguments pro and contra a positive effect of market concentration on innovation here (see Vossen, 1998b). Here I only mention that I checked whether the effect of concentration applied equally to small and large firms. A notable result was that the positive effect of concentration on R&D was strongest for the smallest of four size-categories of firms, and got weaker for larger size classes. This is surprising, because the most prominent argument in favor of a positive effect of concentration is that firms with large market shares are better able to guard innovations from imitation, if patent protection is inadequate. The results mentioned in this section are consistently robust, in the sense that they are similar for the different data sets.

Policy Implications

Larger firms are more innovative than small firms in the sense that they are more likely to engage in innovative activity. Not many small firms are particularly innovative. However, the percentage of firms participating in R&D rises quickly at quite moderate levels of firm size. The percentage hardly increases for firms with more than 300 employees. Moreover, there are a number of indications that the smaller firms that do engage in R&D, do so more efficiently than larger firms. This suggests that very large firm size is not at all a necessary condition for innovativeness. There is also no evidence that high market shares are in any way conducive to innovation. This does not mean that large company size or high industry concentration are necessarily bad things, in the sense that they are not conducive to innovation and can only have a negative effect on allocative efficiency. First of all large firms may very well have an advantage in specific kinds of innovations (Nooteboom, 1994), and their innovations may on average be of higher quality (cf. Cohen and Klepper, 1992). Secondly, there is empirical evidence that large firm R&D laboratories produce knowledge spillovers that help small firms to be the efficient innovators that they are (Acs et al., 1994). I would agree with Scherer (1992) that the more important condition for technological progress seems to be to keep markets open for new entrants with novel ideas.

In order to stimulate innovative efforts, one would increase expected rewards and/or lower the risks of engaging in such activity. An important conclusion from the study reported on here, is that the ratio of expected returns and risk is systematically less favorable for smaller firms than for larger ones. The fact that risk is relatively high for smaller firms (compared to expected returns) can at least partially be explained by the presence of a fixed and sunk entry cost, which yields a higher threshold to R&D for smaller firms, especially in the technologically less progressive industries. In view of the indications that smaller firms are more R&D efficient, it may be advisable to promote their participation. The above suggests that the most suitable way to do this would by means of a subsidy in the form of a fixed amount of money, to compensate for fixed entry costs. This seems to be confirmed by the fact that no empirical evidence for a fixed and sunk entry cost could be found for the German data, where large R&D and investment subsidies are granted, especially to (smaller) firms from the former East Germany.

Much has been written in the past about the relatively low R&D intensity in the Netherlands. It has been suggested that this is, at least partially, a consequence of the sectoral structure of the Dutch industry. The service industry is relatively large compared to the manufacturing sector, among other things as a result of the function of the Netherlands as a distribution country ('gate to Europe'). But it goes beyond that. Also within the manufacturing industry, the Netherlands has a relatively high share of sectors which in my analysis were shown to have both low R&D participation and low R&D intensity. The Netherlands has an especially high share of Scale Intensive sectors[1], such as process industry and assembly. In the Specialized Suppliers category, where R&D participation and intensity are found to be relatively high, it is not so well represented. The Netherlands is to a lesser degree than for instance Switzerland, Denmark, Sweden, Germany, or the United Kingdom, a nation of machinery and instrument makers, although it does have a certain potential in that area. The Netherlands is also under-represented in the R&D intensive Science Based sectors.

Also interesting is the result that between 1988 and 1992 there has been a sharp decrease in the percentage of firms performing any R&D, and that this can be attributed almost entirely to an increase in the risk factor (risk times its weight). Apparently firms perceive the risk of performing R&D to be higher, or are less willing to take a risk (are more risk averse), or both. This has a large effect on the probability of participation, particularly for smaller firms, where the relative weight of the risk factor is higher. The intensity of R&D expenditure of firms participating

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[1] About 55% of firms in the manufacturing industry fall in the Scale Intensive category, which is one of the highest shares in the European Community (based on Eurostat, 1988, *Structure and Activity of Industry*).

in R&D showed only a very modest decrease (Brouwer and Kleinknecht, 1994). In other words, the decrease is the consequence of an increase in (perceived) risk or in risk aversion, which is probably attributable to a falling off in the business cycle in those years. This is reassuring in a way, because it appears not to be a matter of structural decline in innovative effort, but more of risk perception related to the phase in the business cycle.

The service sector is taking an increasingly dominant position in modern economies (Bartels, 1995). The Netherlands has one of the most service oriented economies, with a 25% share of the manufacturing industry in total added value (SER, 1995). This is not problematic in itself. One could say that the Netherlands walks in front in that respect. In addition, the most technology intensive sectors have relatively low shares within the Dutch manufacturing industry. Taking account of the structure of the Dutch economy, the Netherlands seems to be performing reasonably well with respect to innovation. An important element where the Netherlands does lag behind internationally is the participation of small firms in the innovation process. The European "Community Innovation Survey" shows that less smaller Dutch firms conduct any R&D, than smaller firms from other countries (Kleinknecht, 1995). There is general agreement that direct subsidization of R&D in firms is not the way to go, with the significant exception of the support of innovative activity in smaller firms (cf. Metcalfe, 1995). The type of subsidy proposed here, in the form of a fixed amount to compensate for entry cost which are relatively high for smaller firms, may help to catch up arrears. The current policies are principally aimed at augmenting the availability of risk capital, or a compensation of the flow cost of R&D, but not for threshold costs. Pavitt (1998) concludes that the European Union's innovation policy should give high priority to closing technology gaps within Europe, through training and exchange programs, and help to small firms. The current study suggests that a comparative investigation of innovative performance of countries should account for differences in the sectoral composition of the respective economies. And it should include an analysis of which firms (sizes) lag behind internationally, and in what respect (participation and/or intensity).

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