Some New Evidence on the Determinants of Large- and Small-Firm Innovation

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ABSTRACT. Empirical analyses presented by Acs and Audretsch suggest differences in the market structure determinants of innovation between large and small firms in U.S. manufacturing. The evidence they offer is ambiguous. By using data for a different country (The Netherlands), a different measure of innovation and a different aggregation level, we offer new evidence, allowing a revaluation of the findings for the U.S. material. Moreover, the influence of the market structure determinants does not appear to differ between a period of sluggish growth (1983) and one of relatively high growth (1989).

1. Introduction

Concern about an ongoing high degree of economic development and vitality led to a vast literature on the identification of the environment most conducive to technological progress. Average firm size, degree of industry concentration, height of entry barriers are among the accepted economic dimensions of this environment (for instance, Cohen and Levin, 1989; and Kamien and Schwartz, 1982). Recently many empirical studies have been done on the relationship between firm size and innovativeness.[1] Most of these studies conclude that small firms can keep up with larger firms in the field of innovation. Generally one could say that they spend relatively more on R&D and prove to be more efficient in using this R&D for innovative output. A full understanding of the engine of innovative activity also requires that we know whether a firm's response to different environments depends on its size. An important contribution to our current understanding of the role firm size plays is provided by Acs and Audretsch (1987a, b, 1988, 1990). They have empirically examined the differences in market structure determinants between large- and small-firm innovation. These studies by Acs and Audretsch are pioneering in this field. This is evident from a survey by Rothwell and Dodgson (1994) focussing on the relation between innovation and firm size. The importance of this market structure influence is also pointed out by Nooteboom (1994) in a theoretical fashion. The Acs and Audretsch results however do not allow us to draw unambiguous conclusions.

Although most papers written by Acs and Audretsch on the subject of innovation in small and large firms focus on different subjects, one can compare them in a way. They all shed light on the question whether small-firm innovation and large-firm innovation are influenced differently by their environment, i.e., by variables capturing the structure of the market. Two approaches are used in four different papers (1987a, b, 1988, 1990). The first approach models the small- and the large-firm innovation rates separately although they are both assumed to relate to the same market structure variables in a linear fashion. The second approach relates the *difference* in innovation rate between large and small firms to market structure variables in a linear model. The innovation rate always is a

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variable at the four digit industry level, defined as the total number of innovations in 1982 in a certain industry divided by some measure of size. Market structure is measured along similar dimensions in the various papers, although the variables used are not always identical.

To compare the results of the two approaches, we will use the following assumption: if in the first approach the coefficient of a market structure variable is significantly different for the small- compared to the large-firm model, this variable is likely to have a significant influence on the *difference* between the large- and small-firm innovation rate in the second approach. However, not all studies using the first approach report on testing the difference in coefficients of market structure variables. Therefore, we use the following approach: a market structure variable influences the small(large)-firm innovation rate positively, negatively or not at all.[2] If its influence differs between small and large firms, we expect this variable to significantly influence the difference between the large- and small-firm innovation rate. Although this method is not as strong as testing the difference in coefficients in a direct fashion, its results are similar to the testing results obtained in Acs and Audretsch (1988). Using this interpretation we are able to establish market structural influences on the difference between large- and small-firm innovation which cover all four papers. The results are to be found in Table I.

Although all Acs and Audretsch papers use a dependent variable based on the same dataset, the results are not identical. For two market structure variables, concentration and technological opportunity, they even find contradictory results. Concentration positively influences large-firm innovation rate minus small-firm innovation rate in Acs and Audretsch (1987a), while in Acs and Audretsch (1990) concentration negatively influences the large-firm innovation rate and does not influence the small-firm innovation rate. Markets with high technological opportunity, as measured by R&D intensity of the industry, positively influence the large-firm innovation rate and do not influence the small-firm innovation rate in Acs and Audretsch (1987b), while in Acs and Audretsch (1987a, 1990) technological opportunity, measured by the same variable, negatively influences the large-firm innovation rate minus the small-firm innovation rate.

The ambiguity asks for further research. We follow Acs and Audretsch (1987b, 1988, 1990) in

TABLE I

A concise impression of the results Acs and Audretsch obtain in their papers referenced as 1987a,b, 1988 and 1990, on whether a market structure variable influences the difference in innovation rates[a] between large and small firms (i.e., large firm innovation rate minus small-firm innovation rate) using four digit industry data

	1987a	1987a	1987b	1988	1990	1990	1990
Capital intensity	+	0	0	0	+	+	0
Product differentiation	+	0	0	+	+	0	0
Concentration	+	0	0	0	–	0	0
Unionization	+	0	0	0	0	0	0
Market growth	0	0				0	0
Presence large firms	–	–	0		–	–	0
Amount skilled labour	0	–	0	–	0	0	0
Technological opportunity[e]	–	–	+	0	0	–	–
Industry size				–			
Sample size	42[b]	172[c]	247[d]	247[d]	247[d]	42[b]	172[c]

[a] The innovation rate computed as a measure for the number of innovations divided by a measure of size.
[b] Only highly innovative industries are included.
[c] All industries that have some kind of innovative activity are included.
[d] All industries are included.
[e] Technological opportunity is often measured as the total industry innovation rate.
[f] +: significantly positive at the 90% level; –: significantly negative at the 90% level; 0: no significant result; blank: market structure variable not included.

using a separate modelling of large- and small-firm innovation. To provide new and independent evidence, we present an empirical analysis for a country, a measure of innovation, and an aggregation level different from that investigated by Acs and Audretsch. Whereas the number of full-time-employees (FTEs) engaged in research & development (R&D) as a percentage of total employment (henceforth called R&D intensity) of 1878 individual innovating firms in Dutch manufacturing is considered in the current study, Acs and Audretsch examine the number of innovations in (at most) 247 four-digit U.S. industries. Our results can be compared with those of Acs and Audretsch for four important market structure characteristics: capital intensity, market concentration, market growth and skilled labour.

The approach of Acs and Audretsch is a clear reduced form approach with no formal mathematical model lying at the basis of their endeavour. Replication of empirical results is important in the stage of descriptive, non-structural analyses. The search for empirical regularities across countries adds considerably to one country studies because they constitute a fruitful starting point for the construction of structural models. The remainder of this study is set up as follows. Section 2 describes the R&D and market structure data. The six candidate determinants of R&D intensity – the four variables mentioned in the previous paragraph, firm size and profitability – are discussed in section 3. The regression results are presented in section 4. Finally, a concluding comparison of our results to those of Acs and Audretsch is provided in section 5.

2. Model specification

Galbraith (1952) argued that technological innovation is so expensive that only large firms can support it. Large firms possess the advantage of being able to spread the considerable fixed costs over a large sales volume. A second advantage, pointed out by Kraft (1989, pp. 331–332), is that "large firms can undertake more innovation projects of the same magnitude than small firms. If the probabilities of success are uncorrelated for the different projects, the risk from research and development projects decreases with the number of projects, and therefore with *the size of the firm*". The results presented in Scherer (1965) and Soete (1979) suggest that differences exist in the signs of the effects of firm size on R&D intensity between large and small firms. Scherer (1965) shows that the ratio of R&D employment to sales decreases with sales up to a certain sales value but increases for larger values. A similar U-shaped function of sales is found by Acs and Audretsch (1991) for the ratio of innovative output to sales. However, in Soete (1979) the ratio of R&D employment to total employment – our measure of R&D intensity – is found to be a positive function of employment for relatively small values of employment and a negative function for relatively large values.[3]

Schumpeter's (1942) hypothesis is that *market power* is a necessary condition for innovation. Firms should expect some form of ex-post market power which prevents imitation of the new products and processes and thereby allows them to recoup their R&D expenses. Ex-ante market power will also favour innovation, because it reduces the uncertainty undermining incentives to invest in R&D. It will also provide firms with the large monopoly profits that are necessary to finance R&D. The Schumpeterian hypothesis is that large firms having market power are in a better position to innovate than small firms. An alternative hypothesis is that small firms can be more innovative because they are less likely to be bound by tacit agreements deterring non-price competition such as product innovation or, even stronger, they might have to resort to a strategy of innovation in order to remain viable (see Acs and Audretsch, 1988; and Phillips, 1965). Empirical evidence provided by Feldman (1994) shows that geographic concentration of manufacturing activity has a similar, positive effect on small- and large-firm innovation. A well-known measure for the market power the largest firms have is the four-firm concentration ratio.

Aside from the rivalry of firms already in business, potential competition by new firms is relevant. While Schumpeter suggests that barriers to entry favour innovation, they may also weaken incentives for innovation. Dasgupta and Stiglitz (1980) have developed a model in which entry barriers provide little incentive for a pure monopolist to invest in R&D. Kraft (1989) stresses that barriers to entry may reduce the stimulus to be the first in introducing new products. Mansfield *et al*. (1977) argue that entry barriers hamper the entry of new firms which are among the most important contributors to innovation. The *capital intensity* is a proxy for the barrier to new firms. Scherer (1980) suggests there is a positive relationship between scale economies in production and innovative activity. Especially in a capital-intensive industry, the existence of this relationship will mean less small-firm innovation and more large-firm innovation. In a survey Rothwell and Dodgson (1994) conclude that the small firms' innovation share is small in industries characterized by high capital requirements.

Empirical results in Branch (1974) show that there is a tendency for R&D to be influenced by past *profitability*[4] He notes that "Because of the well-known risks and relatively long time horizons associated with R&D, borrowing or the issuance of new equity securities is an unlikely source of funds for the support of R&D projects. . . . We might therefore expect changes in R&D expenditure normally to be positively associated with changes in profits" (Branch, 1974, p. 1001). See also the results and discussions in Coate and Uri (1988), Grabowski (1968), Link (1982) and Van den Berg (1989).

Market growth affects the research opportunities facing a firm. Coate and Uri (1988) note that rapidly growing industries assimilate and promote new innovations. Farrell and Saloner (1985) argue that an industry that is bound together by a standardization will be less innovative. In the growth stages there will be many R&D opportunities, because there is no standardized concept in the market. As noted by Acs and Audretch (1987), because the product design is subject to rapid change and evolution, high levels of skilled labour and labour-intensive production processes characterize the introduction and growth stages. This means that in the early stages small firms are in a better position to exploit the gains yielded from new R&D opportunities. In the mature and declining stages, small firms will be in a worse position because capital intensity becomes then more important than innovation. Two variables are used to model the impact of the life-cycle stages: the growth of sales and a measure for the *skill structure of employees*. We assume that a higher ratio of labour costs to the production value results from the higher salaries of the well-trained employees.

3. R&D and market structure data

The data on the number of FTEs (full-time equivalents) engaged in R&D and the total employment are from the "1984 and 1990 Stichting voor Economisch Onderzoek der Universiteit van Amsterdam (SEO) national survey on R&D and innovation in the Netherlands". We limit our data set to firms that engage in R&D and analyze R&D employment. We are aware of the pros and cons of R&D measures and alternative measures of innovation (see Cohen and Levin, 1989, for a discussion). The 1984 data have also been used in Kleinknecht (1987) to examine the downward biases inherent in measures of small-firm R&D, in Kleinknecht and Reijnen (1992) to examine the reasons for firms to cooperate on R&D and by Den Hertog and Thurik (1993) to focus on differences in market structure determinants between internal and external R&D.

We analyse the 1983 and 1989 R&D intensities for 865 large firms, defined as firms with at least 100 FTEs, and 1013 small firms, which in our case are firms with more than 10 but less than 100 FTEs. For 19 two-digit industries, mean values of total, large-firm and small-firm R&D intensity along with the differences between the large- and small-firm means are reported in Table II (means are presented only for industries for which at least 10 observations are available). The SBI "26" industry, paper and allied products, is found to have the lowest intensities, while "SBI 36", electrical machinery, equipment and supplies, is found to be on average the most innovative Dutch industry.

Although many determinants of innovation have been proposed as candidates in previous empirical studies of R&D, the following six are usually considered: firm size, market concentration, capital intensity, profitability, market growth and skilled labour. We measure firm size by the total number of FTEs, market concentration by the four-firm concentration ratio, capital intensity as the ratio of the cumulative investments in the preceding seven years to the industrial production value, skilled labour by the ratio of labour costs to the industrial production value, profitability by

TABLE II
Dutch R&D intensities for small firms, large firms and all firms for 19 two digit industries. The differences between small and large firm R&D intensities is also given[a]

Two digit[b]	Industry	Small firm R&D intensity	Large firm R&D intensity	Difference large vs. small firms	All firms R&D intensity
20	Food and kindred products	0.0291	0.0097	0.0194	0.0208
21	Tobacco manufactures	0.0450	0.0080	0.037	0.0257
22	Textile mill products	0.0713	0.0109	0.0604	0.0439
23	Apparel and other finished products made for fabrics and similar materials	0.0506	0.0111	0.0395	0.0384
24	Leather and leather products	0.0433	0.0071	0.0362	0.0406
25	Lumber and wood products, furniture	0.0467	0.0063	0.0404	0.0406
26	Paper and allied products	0.0396	0.0073	0.0323	0.0205
27	Printing, publishing and allied industries	0.0879	0.0069	0.0810	0.0660
28	Petroleum refining and related industries	0.0544	0.0240	0.0304	0.0406
29	Chemicals and allied products	0.0868	0.0375	0.0493	0.0585
31	Rubber and miscellaneous plastics products	0.0711	0.0241	0.0470	0.0551
32	Stone, clay, glass, and concrete products	0.0446	0.0075	0.0371	0.0343
33	Primary metal industries	0.1009	0.0145	0.0864	0.0447
34	Fabricated metal products, except ordnance, machinery and transportation equipment	0.0611	0.0101	0.0510	0.0475
35	Machinery, except electrical	0.1094	0.0198	0.0896	0.0791
36	Electrical machinery, equipment and supplies	0.1158	0.0282	0.0876	0.0792
37	Transportation equipment	0.0592	0.0122	0.0470	0.0390
38	Instruments, photographic and optical goods, watches and clocks	0.0630	0.0482	0.0148	0.0586
39	Miscellaneous manufacturing industries	0.0909	0.0186	0.0723	0.0635

[a] The R&D intensities are mean values for all available companies in the industry. R&D intensity for a single company is defined as the number of full time employees engaged in R&D activities divided by the total number of full time employees.
[b] Dutch SBI classification number.

the price-cost margin (the ratio of the industrial production value minus labour and material costs to the industrial production value),[5] and market growth as the percentage change in deflated industrial sales. We know the size of all 1878 firms. For the other explanatory variables, we use three-digit data from the DUMA (Dutch Manufacturing) data set of EIM Small Business Research and Consultancy in the Netherlands. Note that these industry-level variables describe the whole industry, including firms which are not engaged in R&D. The variables explaining the 1983 R&D intensities are averages of 1981, 1982 and 1983 values. The decision to start R&D projects will often be made in the preceding years and thefore the market structure conditions for these years are used explaining the R&D intensities in succeeding years. Extrapolations of the data for 1986 had to be made to calculate the 1989 explanatory variables. The 1983 and 1989 data are combined into one dataset. For all explanatory variabels, the stability over time of the regression coefficients is investigated using a T-test.

4. Results

The cross section regression results are presented in Table III. They are shown for analogous regressions where the R&D intensity of all firms, the large firms and the small firms are the dependent variables. Including a dummy variable in the model for the R&D intensities of all firms, we obtain estimates of the differences in coefficients between large and small firms. The test for heteroskedasticity proposed by White (1980) shows that homoskedasticity cannot be rejected. We have tested whether the coefficients on the market structure variables for the 1983 R&D intensities differ from those for the 1989 intensities. The T-test statistics for these tests are reported in Table IV. Only the coefficient of profitability appears to have changed over time. All three

TABLE III
Regression results of R&D intensity[a] on firm size and a number of market structure variables[b]

Variables	All Firms	Large Firms	Small Firms	Difference Large vs. Small Firms[c]
Full-time Equivalents	–0.00003	0.00007	–0.036**	0.037**
	(–0.33)	(0.79)	(–6.28)	(6.57)
Concentration[d]	0.043**	0.050**	0.043**	0.0075
	(8.63)	(7.80)	(5.70)	(0.76)
Capital Intensity[e]	–2.779**	–1.160	–4.809**	3.595*
	(–3.02)	(–0.87)	(–3.84)	(2.07)
Profitability[f]	0.071**	0.075*	0.0610	0.018
	(2.70)	(2.27)	(1.56)	(0.76)
Market Growth[g]	9.149**	16.38**	0.455	15.76**
	(3.16)	(4.48)	(0.10)	(2.95)
Skilled Labour[h]	4.796**	2.470	4.855*	–2.438
	(3.19)	(1.31)	(2.11)	(–0.84)
Dummy Profitability[i]	7.452**	8.136**	8.496**	
	(3.47)	(2.98)	(2.64)	
Intercept	0.560	–0.362	3.757**	–4.151**
	(1.15)	(–0.53)	(4.46)	(–4.123)
Sample Size	1878	865	1013	
R-Squared	0.063	0.125	0.084	

** Significant at the 99% level.
* Significant at the 95% level.
[a] R&D intensity is defined as the number of employees engaged in R&D activities divided by the total number employees.
[b] The data-set consists of data for both 1983 and 1989. Firms with less than 100 employees are considered small. T-values are within parentheses.
[c] This column reports on the coefficient of an explanatory variable in the large-firm-regression minus the coefficient of this variable in the small-firm-regression. The t-statistic reporting on significance of this difference is reported between brackets.
[d] Concentration is defined as the market share of the four largest companies in the industry.
[e] Capital intensity is defined as the ratio of the cumulative investments in the preceding seven years to the industrial production value.
[f] Profitability is defined as the ratio of industrial production value minus labour and material costs to the industrial production value.
[g] Market growth is defined as the percentage change in deflated industrial sales.
[h] Skilled labour is defined as the ratio of labour costs to the industrial production value.
[i] The profitability dummy has the value of the profitability in the 1983 observations and zero for the 1989 observations.

regression models include a dummy variable to allow for the different coefficient for this variable. The coefficients for total employment, four-firm concentration ratio, capital intensity, market growth and the skill structure of employees prove not to be different between our two time periods for the three models.

When we consider all firms, firm size does not appear to be a determinant of R&D. However, the results for this explanatory variable illustrate the better insights the data can provide when we distinguish between large and small firms. The positive coefficient for large firms is insignificant, but the coefficient for small firms is negative and significantly different from zero. The difference between these two coefficients is significant at the 95% level. The insignificant coefficient for large firms contradicts the Schumpeterian and Galbraithian hypotheses. Acs and Audretsch (1991) and Scherer (1965) show that R&D intensities decrease with sales up to a certain level but subsequently increase for larger values. The

TABLE IV
Test statistics on the difference in regression coefficients for the 1983 and the 1989 data[a]

Explanatory variable[b]	T-test on difference in 1983 and 1989
Full-time equivalents	0.62 (0.5325)
Concentration	0.66 (0.5106)
Capital intensity	–1.22 (0.2194)
Profitability	3.01 (0.0026)
Market growth	–1.10 (0.2705)
Skilled labour	–1.64 (0.1009)
Intercept	1.00 (0.3194)

[a] For all explanatory variables the stability over time of the regressioncoefficient is tested with a T-test, p-values are within parentheses.
[b] See Table III for the definition of the explanatory variables.

significantly negative coefficient for small firms confirms the negative function of firm size for small firms. For large firms, however, we can neither reject nor confirm a progressive relationship between size and R&D.

Market concentration appears to have a significantly positive effect on the R&D intensity of both large and small firms. The difference in the coefficient on this market structure variable between large and small firms is not significant. The positive coefficient for large firms supports the Schumpeterian hypothesis that the ex-ante and ex-post market power of large firms in concentrated markets provide them with a considerable innovative advantage. An explanation for the positive coefficient for small firms may be that small firms rely on innovation to offset their size disadvantage and to survive in an industry dominated by large firms (see Acs and Audretsch, 1987; and Caves and Pugel, 1980).

Using data from all our 1878 firms, capital intensity is found to have a significantly negative effect on R&D. However, like firm size, capital intensity affects small-firm R&D but not large-firm R&D. The difference between the two coefficients is significant. The insignificant coefficient for large firms does not support the Schumpeterian hypothesis that barriers to entry favour innovation, on the other hand it does not support a weakening of incentives for large firms to innovate either. Mansfield *et al.* (1977) explain the negative impact for small firms by the fact that a high capital intensity hampers the entry of new, small and innovative firms.

One of the main reasons why firm size and market concentration affect innovation is that they are important determinants of a firm's financial position. However, after controlling for the influences of firm size and market concentration, the profit measure is still found to be positively and significantly related to large-firm R&D. For small firms the coefficient on the profit margin is not significant.

In the previous section we suggested that small firms have an innovative advantage in rapidly growing markets. Our empirical results, however, suggest that large firms have this advantage. The growth of sales does not significantly affect the small-firm R&D intensity. It is possible that in our data set the industries with a relatively high market growth are not in the introductory or growth stages but already in the mature and declining stages. Small firms have the innovative advantage in the former stages and large firms in the latter. More consistent with our hypotheses is that (skilled) labour-intensive industries are particularly favourable for small-firm innovation – the coefficient of our measure of skilled labour is significant for small firms and insignificant for large firms.

In summary, the distinction between large- and small-firm R&D can provide better insights into the impact of market structure characteristics on innovation. If we would not account for this distinction we would conclude that firm size does not affect R&D, while all our other five determinants do. But presenting a separate modelling for large and small firms we find that they have only one determinant in common, viz. market concentration. Profitability and market growth only affect large-firm R&D, whereas firm size, capital intensity, and skilled labour only determine small-firm R&D.

5. The concluding comparisons

We compare our results for market concentration, capital intensity, market growth and skilled labour to those presented in Acs and Audretsch. The contradiction between the 1987a and the 1990 paper caused by the variable *concentration* cannot be resolved. We find no evidence for a different effect of this variable on the large- compared to the small-firm-innovation rate. Our result supports the view that both the positive sign of 1987a and the negative sign of 1990 were accidental, i.e., concentration influences both innovation rates in a similar way and does not stimulate one compared to the other. The variable *skilled labour* does not show a different influence on both innovation rates either. Hence, we find no support for the 1987a and 1988 finding that skilled labour favours small-firm innovation more than large-firm innovation. The other two variables, *market growth* and *capital intensity*, do influence small-firm innovation differently than large-firm innovation in our study. Both variables seem to stimulate large-firm innovation compared to small-firm innovation. Although this effect has never been found by Acs and Audretsch for market growth, the capital intensity effect has been found in both the 1987a and the 1990 paper.

We should also pay attention to yet another important comparison: the situation in 1983 and 1989. Our results indicate stability of the Dutch results for the different time periods. We have used an F-test to show that there is no significant difference in the impact of most explanatory variables for the 1983 and 1989 data. The only explanatory variable which seems to have a different effect in the different time periods is profitability. This may be caused by the difference in the economic situation in 1983 and 1989. The year 1983 is part of a period of recession in the Netherlands, while 1989 is a year of high economic growth. From the regressions we find that industry profitability in times of recession has a stronger positive effect on the innovation rate for both the large and the small firms in the industry. This result is probably due to the fact that in times of recession firms feel more limited by small budgets as a result of a lower profit level, when deciding upon R&D activities. Recession causes firms to underestimate the necessity of research as a long-term investment, thinking that "R&D can be postponed". The government might want to consider to focus on stimulating R&D in these periods. Further research has to be done on this topic to fully understand the influence of recession on R&D expenses for both small and large firms.

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Notes

1 See for example Rothwell (1989), Kleinknecht (1989), Santarelli and Sterlacchini (1990), Link and Bozeman (1994), Hansen (1992), Acs and Audretsch (1987a, b, 1988, 1990) and a survey by Rothwell and Dodgson (1994).

2 A level of significance of 90% is maintained.

3 For a review of the literature on the relationship between firm size and innovative activity we refer to Baldwin and Scott (1987), Cohen and Klepper (1991) and Rothwell and Dodgson (1994).

4 Branch discusses three ways in which profitability and R&D may be related. "First, profits may influence subsequent R&D. Second, R&D mayinfluence subsequent profits. And third, it is possible that R&D and profits are influenced simultaneously by some third factor. For example, government support or exogenous surges in demand could increase both at the same time" (Branch, 1974, p. 999).

5 Our definitions of "profitability" and "skilled labour" may lead to introducing problems caused by multicollinearity. The correlation coefficient in our case however, is very low, 0.25. This will not cause any multicollinearity problems.

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