Firms Size and R&D Spillovers: Evidence From Italy

David B. Audretsch
Marco Vivarelli

ABSTRACT. The recent emergence in the industrial organization literature of a wave of studies identifying small firms as more innovative than their larger counterparts poses something of a paradox? Where do small firms get their knowledge generating inputs? The purpose of this paper is to link innovative inputs to innovative outputs. This enables the identification of the extent to which spillovers exist from major sources generating new economic knowledge, such as the research and development (R&D) laboratories of private and public firms, as well as universities, to the innovative activity of large and small enterprises. Based on twenty Italian regions over a period of nine years, the empirical evidence suggests that, while firm R&D expenditures contribute to the generation of innovative output for all firms, as well as for large and small firms, the spillovers from university research are apparently more important for small-firm innovation than for large-firm innovation.

I. Introduction

At the heart of his prognosis for the demise of capitalism, Schumpeter (1942, p. 132) identified the fatal flaw as the innovative superiority of large corporations vis-à-vis their smaller counterparts, "Innovation itself is being reduced to routine. Technological progress is increasingly becoming the business of teams of trained specialists who turn out what is required and make it work in predictable ways". The ultimate result of the inherent innovative advantage bestowed upon giant corporations would be an inevitable concentration of economic power, "Since capitalist enterprise, by its very achievements, tends to automize progress, we conclude that it tends to make itself superfluous – to break to pieces under the pressure of its own success. The perfectly bureaucratic giant industrial unit not only ousts the small- or medium-sized firm and 'expropriates' its owners, but in the end it also outs the entrepreneur and expropriates the bourgeoisie as a class which in the process stands to lose not only its income but also, what is infinitely more important, its function" (Schumpeter, 1942, p. 134).

Not only have the developed economies experienced a process of deconcentration and decentralization rather than one of concentration and centralization over the past two decades,[1] but a wave of empirical studies have recently emerged identifying small firms as the engines of technological change and innovative activity, at least in certain industries.[2] These findings pose something of a paradox, because it is a well-known observation that the bulk of research and development (R&D) is concentrated among the largest industrial corporations (Scherer, 1991). And, according to one of the most prevalent models of technological change (Griliches, 1979), innovative output is the product of knowledge generating inputs, most notably R&D. That small enterprises are the engine of innovative activity in certain industries despite an obvious lack of formal R&D activities raises the question, "Where do small firms get the innovation producing inputs?"

The purpose of this paper is to shed some light on this question. We suggest that, while the model of the knowledge production function may be valid, the unit of observation may be somewhat broader than at the level of an individual enterprise, but rather may span both a product and spatial dimension. Placing the knowledge production function in such a context allows for the

Final version accepted on August 18, 1995

Centre for Economic Policy Research (CEPR) and Wissenschaftszentrum Berlin für Sozialforschung, Reichpietschufer 50, D-10785 Berlin 30, Germany

and

Universita Cattolica di Piacenza, Italy

Small Business Economics 8: 249–258, 1996.

possibility of knowledge spillovers, where the investment in R&D made by private and public firms as well as universities *spills over* for economic exploitation by third party firms.

In the second section of this paper we identify the new learning emerging from the recent wave of studies identifying the relative innovative roles of large and small enterprises. The knowledge production function and recent evidence from a series of studies undertaken in the United States are introduced in the third section. Measurement issues arising from linking innovative inputs to innovative outputs are discussed in the fourth section. Based on the patent activity of all firms, large firms, medium-sized firms, and small firms within the twenty distinct Italian regions, and spanning nine years, pooled ordinary least squares regression results are presented in the fifth section. Finally, a summary and conclusions are presented in the sixth section. In particular, we find that while R&D inputs, both from private and public firms as well as from universities contribute to the generation of innovative output, the spillovers from universities are apparently more important for small-firm innovation than for their larger counterparts. Not only does this confirm similar findings for the United States, but it also suggests that an environment with a high endowment of knowledge based workers and skilled engineers is particularly conducive to the innovative activity of small firms.

II. Small firms and innovation: The new learning

Some three decades ago it seemed unlikely that small firms would emerge as the engine of technological change. A prevalent assumption, for which there was considerable support, was that technological change requires increasingly large quantities of research and development resources compiled and organized by giant corporations. With the greater internationalization of markets, this conventional wisdom predicted that small firms would recede in importance as they became overwhelmed by large enterprises able to exploit economies of scale.[3] At the heart of this conventional wisdom was the belief that monolithic enterprises exploiting market power were better endowed to generate innovative activity. Thus, Schumpeter (1942, p. 6) was moved to declare, "What we have got to accept is that the large-scale establishment has come to be the most powerful engine of progress". John Kenneth Galbraith (1956, p. 86) echoed Schumpeter's sentiment, "There is no more pleasant fiction than that technological change is the product of the matchless ingenuity of the small man forced by competition to employ his wits to better his neighbor. Unhappily, it is a fiction".

As scholars began challenging the validity of this so-called *Schumpeterian Hypothesis*,[4] they had to overcome severe measurement constraints. The first type of measure to historically evolve proxied the degree of inputs into the innovative process, such as R&D expenditures, or else the share of the labor force accounted for by employees engaged in R&D activities.[5] A severe limitation in using R&D activity as a proxy measure for technological change is that R&D reflects only the resources devoted to producing innovative output, but not the amount of innovative activity actually generated. That is, R&D is an input and not an output in the innovation process.

A plethora of studies have almost unanimously shown that R&D is positively related to firm size.[6] These results are not surprising, since Scherer (1991) points out that about ninety percent of all private R&D expenditures in the United States are undertaken by 400 of the largest corporations. As Scherer (1982, pp. 234–235) concludes, the results "tilt on the side of supporting the *Schumpeterian Hypothesis* that size is conducive to vigorous conduct of R&D".

However, development of more direct measures of technological change, such as the numbers of patented inventions and counts of new products and processes actually introduced in the market threw considerable ambiguity into the debate linking firm size and innovation.[7] Studies linking patent activity to firm size do not generally support the *Schumpeterian Hypothesis*. Based on a study of 2,852 American companies which registered 4,553 patents, Bound *et al.* (1984) found that small firms (with less than $10 million in sales) accounted for 4.3 percent of sales but 5.7 percent of the patents. Such results are not limited to the United States. Schwalbach and Zimmerman (1991) found that the propensity to patent is less for the largest firms in West Germany than for small- and medium-sized enterprises.

It was the analysis of measures directly reflecting innovative activity that most strongly challenged the conventional wisdom embodied in the *Schumpeterian Hypothesis*. One of the earliest data bases directly measuring innovation activity was compiled at the Science Policy Research Unit (SPRU) at the University of Sussex in the United Kingdom. The SPRU data consist of a survey of 4,378 innovations that were identified over a period of fifteen years.[8] The SPRU data base identified that, in fact, the number of innovations per employee decreased as firm size increased (Rothwell, 1989; Pavitt *et al.*, 1987).

The most recent and most ambitious major data base providing a direct measure of innovative activity is the United States Innovation Data Base, compiled by the United States Small Business Administration (Audretsch, 1995). Over 8,000 innovations commercially introduced in the United States in 1982 were recorded. In their 1988 and 1990 studies, Acs and Audretsch used this data base and found that small firms (with fewer than 500 employees) contribute 2.38 more innovations per employee than do their larger counterparts.[9] Perhaps most importantly was the evidence suggesting that there are distinct industry characteristics related to either a large-firm innovative advantage or, alternatively, a small-firm innovative advantage. The differences between innovation rates of large and small firms can generally be explained by (1) the degree of capital intensity, (2) the extent to which an industry is concentrated, (3) the total amount of innovative activity in the industry, and (4) the extent to which an industry is comprised of small firms. In particular, the relative innovative advantage of large firms tends to be promoted in industries that are capital intensive, advertising intensive, concentrated and highly unionized. By contrast, in industries that are highly innovative and comprised predominately of large firms, the relative innovative advantage is held by smaller enterprises.

Along with the empirical evidence challenging the validity of the *Schumpeterian Hypothesis* has emerged new theories about the role that small firms ply in the innovation process. Rothwell (1989) suggests that the factors bestowing small firms with the innovative advantage generally emanate from the difference in management structures between large and small enterprises. This is consistent with Scherer (1991), who argues that the bureaucratic organization of large firms is not conducive to undertaking risky R&D. The decision to innovate must survive layers of bureaucratic resistance, where an inertia regarding risk results in a bias against undertaking new projects (Audretsch, 1995). However, in the small firm the decision to innovate is made by relatively few people.

Similarly, innovative activity may flourish the most in environments free of bureaucratic constraints (Link and Bozeman, 1991). That is, a number of small-firm ventures have benefited from the exodus of researchers who felt thwarted by the managerial restraints in a larger firm. Finally, it has been argued that while the larger firms reward the best researchers by promoting them out of research to management positions, the smaller firms place innovative activity at the center of their competitive strategy (Scherer, 1991).

III. The knowledge production function

Perhaps one of the strongest arguments suggesting that small firms are burdened with an inherent innovative disadvantage is implicit in what has become known as the knowledge production function. As introduced by Zvi Griliches (1979), the *knowledge production function* links inputs in the innovation process to innovative outputs. As Cohen and Klepper (1991, 1992) conclude, the most decisive innovative input is new economic knowledge, and the greatest source generating new economic knowledge is generally considered to be R&D. But, as pointed out in the previous section, the bulk of industrial R&D is undertaken in the largest corporations, while small enterprises account only for a minor share of R&D inputs. Thus, the knowledge production function seemingly implies that, as the *Schumpeterian Hypothesis* predicts, innovative activity favors those with access to knowledge production inputs – the large corporations (Audretsch, 1995).

The recent wave of studies revealing small enterprises to be the engine of innovative activity in certain industries despite an obvious lack of formal R&D activities raises the question, "Where do small firms get the innovation producing inputs?" One possible answer is that, while the model of the production function may be valid, the assumed unit of observation – at the level of the *firm* – may be less valid. Paul Krugman (1991) argues that the relevant unit of observation may actually not be a single firm but rather a constellation of complementary firms with a *geographic unit*, so that knowledge can *spill over* from one firm within the region to another.[10] An important finding of Jaffe (1986, 1989) was that investment in R&D made by private corporations and universities spills over for economic exploitation by third party firms. Jaffe modified the *knowledge production function* where the patent activity within a geographical unit – a state – was related to the private corporate expenditures on R&D within that state as well as the research expenditures undertaken at universities. Jaffe's (1989) statistical results provided evidence that corporate patent activity responds positively to commercial spillovers from university research. Not only does patent activity increase in the presence of high private corporate expenditures on R&D, but also as a result of research expenditures undertaken by universities within the states. Acs *et al.* (1992) later confirmed that Jaffe's findings held when a direct measure of innovative output was substituted for the measure of patented inventions. However, while Jaffe (1989), Audretsch and Feldman (1996) and Acs *et al.* (1992) identified the extent to which corporate and university research spills over onto the generation of innovative activity by other firms, they shed little light on which type of firm is the recipient of such spillovers.

On possible answer, suggested by Link and Rees (1990) is that large corporations tend to benefit more from the R&D activities of their industrial counterparts, while small firms tend to benefit more from spillovers from research undertaken in university laboratories. Link and Rees (1990) survey 209 innovating firms and found that large firms tend to be more active in university-based research. However, small- and medium-sized enterprises are apparently better able to exploit their university-based associations to generate innovations. Link and Rees (1990, p. 25) conclude that there are diseconomies of scale in the production of innovations, due to the "inherent bureaucratization process which inhibits both innovative activity and the speed with which new innovations move through the corporate system towards the market".

In order to explicitly identify the recipients of R&D spillovers, Acs *et al.* (1994) modify the knowledge production function for adaptation to a model specified to incorporate spillover effects within spatial units of observation:

$$I = \alpha FRD^{\beta_1} * UR^{\beta_2} * (UR * GC)^{\beta_3} * \varepsilon, \qquad (1)$$

where I is innovative output, FRD is the private corporate expenditures on R&D, UR is the research expenditures undertaken at universities, GC measures the geographic coincidence of university and corporate research,[11] and ε represents stochastic disturbance. By estimating Equation (1) for the innovative activity contributed by all firms separately from the innovative activity contributed by small firms, and directly comparing the magnitude of the coefficients of FRD and UR, Acs *et al.* (1994) were able to identify the relative importance of R&D spillovers from universities and corporate laboratories for large and small firms. In particular, their empirical results suggested that the innovative output of all firms rises along with an increase in the amount of R&D input, both in private corporations as well as in university laboratories. However, R&D expenditures made by private companies play a particularly important role in providing inputs to the innovative activity of large firms, while expenditures on research undertaken at universities serve as an especially key input for generating innovative activity in small enterprises. These results suggested that large firms are apparently more adept at exploiting knowledge created in their own laboratories, while their smaller counterparts have a comparative advantage at exploiting spillovers from university laboratories.

IV. Measurement

A modified version of the *knowledge production function* represented in Equation (1)[12] is tested using a new longitudinal data base comprised of all twenty Italian regions spanning the period 1978–1986, resulting in a total sample size of 180 observations. Each observation spans all economic activity within the relevant region and is divided by resident population to control for the relative size of different Italian regions.

We follow Jaffe (1989) in measuring the dependent variable as the number of patents within the region in the relevant year. The data source is the SPRU data base at Sussex University and is based on the United States OTAF patent office. Regressions are alternatively estimated for all firms, large firms (measured as enterprises with more than 1,000 employees), medium-sized firms (measured as enterprises with between 100 and 1,000 employees), and small firms (measured as enterprises with fewer than 100 employees).

A particular difference between Italy and the United States is that public firms account for a significantly greater share of economic activity in Italy. Thus, firm generated R&D is measured as R&D expenditures by both private and public firms in real terms, using the implicit deflator for the Gross National Product (GNP).[13]

Unlike for firm R&D expenditures, research expenditures by Italian universities are not available at the disaggregated level of regions, but only at the national level. In order to allocate regional expenditures to the different units of observations, the appropriate weighting scheme had to be identified. For this purpose, the gross number of academic personnel might be a misleading weight because it does not take into account the distinction between scientific and humanistic university departments, thus resulting in a misleading measure which tends to be proportional to the resident population within a region. To avoid such measurement bias, the relative number of engineering graduates has instead been adapted as a weight with which the national university expenditures have been allocated according to the individual regions.[14]

It should be noted that the resulting proxy for university research is in some sense a composite measure which incorporates both the presence of large scientific universities and the quality of human capital within a given geographical area. In fact, the vast majority of innovative spillovers come from the engineering departments.[15] Other studies have used the gross number of scientists and engineers as a proxy measure of research activity (Scherer, 1967). As for the measure of firm R&D, university research expenditures are deflated by the implicit GNP price deflator.

V. Results

The simple linear correlation coefficients for the variables introduced in the previous section are reported in Table I. It should be noted that the high correlation between the patent activity of all firms and small firms (0.74) indicates the presence of spillovers from large to small firms. In fact, the patent activity of small firms is highly correlated with firm R&D expenditures (0.59), which are obviously undertaken mainly by large firms. Nevertheless, as the correlation coefficient of 0.51 indicates, the patent activity of small firms seems to rely also on university research.

In order to test the hypothesis that research undertaken at universities plays a more important role for the innovative activity of small firms, while firm R&D plays a more important role for large firms, separate regressions are estimated alternatively for all firms, large firms, medium-sized firms, and small firms. Using panel data, the covariance test for overall regression-coefficients homogeneity over time has been applied to the model specified here (see Hsiao, 1986). The statistical non-significance of F-values in all four cases (all firms, large firms, medium-sized firms and small firms) enables us to use the *pooled ordinary least squares estimator* (POLS). In addition, the estimated regressions suffer from

TABLE I
Correlation matrix

	Patents (all firms)	Patents (small firms)	Firm R&D expenditures	University research
Patents (all firms)	1.00	–	–	–
Patents (small firms)	0.74	1.00	–	–
Firm R&D expenditures	0.82	0.61	1.00	–
University research	0.51	0.51	0.57	1.00

heteroskedasticity; thus, a heteroskedasticity-consistent covariance matrix has been used for estimation. The coefficient estimates,[16] related T-statistics, and overall indexes of regression fitness and test results are reported in Tables II–IV.

Based on the inclusion of a sole knowledge input – firm R&D – Table II shows that the knowledge production function holds for firms of all sizes, in that an increase in the knowledge input of firm R&D leads to an increase in innovative output. However, the evidence suggests that firm R&D plays a more important role in generating innovative output for large firms than for small- and medium-sized firms. In Table III the other major source of new economic knowledge – university research – is included as a sole repressor. Again, the basic model of the knowledge production function is confirmed. The most striking result here is that the relationship between university research and patents is quite similar between the small and large firms, while it is somewhat weaker for the medium-sized enterprises.

Both sources of new economic knowledge are included as explanatory variables in Table IV. As the positive and statistically significant coefficients for the measure of firm R&D expenditures suggest, patent activity for all firms, large firms, medium-sized firms and small firms tends to be greater in regions exhibiting a higher level of firm R&D expenditures. This result is certainly consistent with the model of the *knowledge production function*. Yet, both the value of the coefficients as well as their levels of significance are less for small firms than for the large firms and the medium-sized firms.

On the other hand, expenditures on university research do not seem to significantly influence overall patent activity, or the patent activity of large and medium-sized firms. However, university research clearly plays a significant and key role in generating innovative activity in small firms. Thus, the knowledge production function for small firms tends to be well-balanced between the two sources of knowledge inputs, while the overall innovative activity, as well as for medium-sized and large enterprises is mainly based on firm-generated R&D expenditures.

Taking these results together, the hypothesis that small firms rely more on university research as a source of knowledge to generate innovative activity has been confirmed by the statistical

TABLE II
Regression results with firm R&D as sole regressor (POLS)

Dependent variable	Coefficient[a]	T-statistic[b]	White's test	Covariance test	R^2	$\bar{R}^2$
Patents (all firms)	17.30	9.97**	$\chi^2(2) = 52.7$**	F(16, 162) = 1.66	0.68	0.68
Patents (small firms)	1.20	5.36**	$\chi^2(2) = 45.5$**	F(16, 162) = 0.72	0.38	0.37
Patents (medium-sized firms)	7.60	9.23**	$\chi^2(2) = 60.3$**	F(16, 162) = 1.75*	0.59	0.59
Patents (large firms)	8.00	10.2**	$\chi^2(2) = 52.7$**	F(16, 162) = 1.82*	0.67	0.67

[a] All regression coefficients have been multiplied by 100,000 for presentation purposes.
[b] Statistically significant at the 95 percent level of confidence is indicated by *.
Statistically significant at the 99 percent level of confidence is indicated by **.

TABLE III
Regression results with university research as the sole regressor (POLS)

Dependent variable	Coefficient[a]	T-statistic[b]	White's test	Covariance test	R^2	$\bar{R}^2$
Patents (all firms)	52.30	6.92**	$\chi^2(2) = 19.8$**	F(16, 162) = 0.23	0.26	0.25
Patents (small firms)	4.900	5.73**	$\chi^2(2) = 28.2$**	F(16, 162) = 0.63	0.26	0.25
Patents (medium-sized firms)	21.10	5.44**	$\chi^2(2) = 18.8$**	F(16, 162) = 0.22	0.19	0.18
Patents (large firms)	25.00	7.88**	$\chi^2(2) = 19.1$**	F(16, 162) = 0.26	0.27	0.27

[a] All regression coefficients have been multiplied by 100,000 for presentation purposes.
[b] Statistically significant at the 95 percent level of confidence is indicated by *.
Statistically significant at the 99 percent level of confidence is indicated by **.

TABLE IV
Regression results of Italian patent activity

	All firms	Large firms	Medium-sized firms	Small firms
Firm R&D	16.70** (8.51)	7.54** (8.35)	7.67** (8.18)	0.95** (4.11)
University research	5.37 (0.79)	3.76 (1.21)	–0.49 (–0.14)	2.26** (3.20)
Constant	0.001 (0.23)	–0.011 (–0.59)	0.026 (1.07)	–0.005 (–0.90)
White's test	χ^2 (3) = 58.0**	χ^2 (3) = 47.2**	χ^2 (3) = 66.6**	χ^2 (3) = 52.2**
Covariance test	F(24, 153) = 1.3	F(24, 153) = 1.4	F(24, 153) = 1.2	F(24, 153) = 0.8
$\underline{R}^2$	0.69	0.68	0.59	0.41
R^2	0.68	0.67	0.59	0.41
F	190.0**	184.6**	127.5**	62.6**
Sample size	180	180	180	180

[a] All regression coefficients have been multiplied by 100,000 for presentation purposes.
[b] Statistically significant at the 95 percent level of confidence is indicated by *.
Statistically significant at the 99 percent level of confidence is indicated by **.

analysis. In comparison with large and medium-sized enterprises, small firms rely less on firm R&D expenditures and more on university research.

An important qualification of our results is connected with the manner that university research has been measured. As discussed in the previous section, this variable actually represents a combination of influences emanating from scientific university departments and the human capital characterizing a given region. So these results can be interpreted as a further confirmation that small firms rely heavily on knowledge inputs generated by the surrounding environment.[17]

A comparison between the results identifying the recipients of R&D spillovers between Italy and the United States, found by Acs *et al.* (1994) is presented in Table V. The coefficient values and t-values show a high degree of consistency between the estimates for Italy and the United States. In both studies the coefficient of firm R&D expenditures and its statistical significance is less for small firms than for all firms, while the university research coefficients and its statistical significant is greater for small firms than for their larger counterparts.[18] Thus, there is clear evidence in Italy, as well as in the United States, that university research plays an especially important role in providing knowledge inputs for small firms.

TABLE V
Comparison of R&D spillovers between Italy and the United States

	United States (Tobit regressions)			Italy (POLS regressions)		
	Innovations			Patents		
	All firms	Large firms	Small firms	All firms	Large firms	Small firms
Firm R&D expenditures	0.615** (5.437)	0.95** (7.133)	0.550** (4.184)	17.70** (0.23)	7.54** (8.35)	0.95** (4.11)
University research	0.550** (5.635)	0.446** (4.569)	0.661** (5.848)	5.37 (0.79)	3.76 (1.21)	2.26** (3.20)
Sample size	145	145	145	180	180	180

[a] T-Statistics are listed in parentheses.
* Statistically significant at the 95 percent level of confidence.
** Statistically significant at the 99 percent level of confidence.

VI. Conclusions

The empirical evidence presented in this study helps to resolve the seeming paradox posed by the recent wave of literature suggesting that small firms might be at least as innovative as their larger counterparts in certain industries. While the *knowledge production function* links knowledge creating inputs to innovative outputs, the results of our paper suggest that the relevant unit of observation may be significantly broader than at the level of the individual firm, both in terms of the product and geographic market. Thus, our findings suggest that small firms are able to innovate by exploiting knowledge created outside of the firm. In particular, research associated with universities apparently provides a fertile environment for small-firm innovative activity.

While a link between R&D spillovers from universities to small firms has already been identified in the United States, it was not known whether such research externalities also existed in Europe. The results of this paper suggest that not only do such R&D spillovers exist but that they are much stronger for small firms than for their larger counterparts.

While we have been able to shed at least some light on the recipients of R&D spillovers, the actual mechanisms facilitating R&D spillovers remain relatively unexplored. That is, do R&D spillovers occur more through formal programs facilitating technology transfer or through informal channels, such as the transmission of knowledge via the mobility of humans? Because there are relatively few formal technology programs between Italian universities and firms,[19] our guess is that the latter factor plays the decisive role in generating R&D spillovers, at least in Italy. That is, it is the creation of an environment with relatively high endowments of knowledge workers and skilled engineers that provides the mechanisms for transmitting knowledge.

Acknowledgements

We would like to thank the referees along with participants at the *International Conference on Small Business Economics*, Rotterdam, August 26–27, 1995, for their helpful comments and suggestions. Any errors or omissions remain our responsibility.

Notes

[1] For documentation of the shift away from large scale enterprises and towards small firms, see Acs and Audretsch (1993), Loveman and Sengenberger (1991), and Sylos-Labini (1986).

[2] For the United States see Acs and Audretsch (1988, 1990) and Scherer (1991), and for Great Britain see Pavitt *et al.* (1987) and Rothwell (1989).

[3] This view dates back at least to Karl Marx (1912, p. 836), who predicted that the efficiencies inherent in the corporate structure of organization, along with the exploitation of scale economies in a competitive market, would result in "a constantly diminishing number of the magnates of capital, who usurp and monopolise all advantages of this process of transformation".

[4] For a more detailed explanation of the *Schumpeterian Hypothesis*, see Scherer (1992).

[5] For a review of these studies see Baldwin and Scott (1987), Cohen and Levin (1989) and Scherer (1991).

[6] For a review of the studies relating R&D to firm size see Acs and Audretsch (1990, Ch. 3), Baldwin and Scott (1987), and Cohen and Klepper (1991, 1992).

[7] For a thorough description of patent measures see Scherer (1984).

[8] The SPRU survey was compiled by writing to experts in each industry and requesting them to identify "significant technical innovations that had been successfully commercialized in the United Kingdom since 1945, and to name the firm responsible" (Pavitt *et al.*, 1987, p. 299).

[9] Similar evidence for Italy has been found by Santarelli and Sterlacchini (1990) and for the Netherlands by Kleinknecht (1989) and Kleinknecht *et al.* (1991).

[10] This argument can be traced back to Marshall (1920) and was expressed more recently by Becattini (1987), Audretsch and Feldman (1996), Audretsch and Stephan (1996), and Feldman (1994a and 1994b).

[11] Jaffe (1989) argued that the proximity of university research to corporate laboratories should raise the potency of spillovers from the universities. While Jaffe (1989) was unable to substantiate this theory, Acs, Audretsch and Feldman (1992) found evidence linking the proximity of university research to corporate research laboratories with innovative spillovers.

[12] In particular, the variable representing the geographic coincidence between university and corporate research has been omitted, since Italian regions are considerably smaller than U.S. states. In this context, the concept of *proximity* loses its significance. In addition, the econometric specification is expressed in terms of absolute value and not in logarithms.

[13] The data source is the National Statistical Institute (ISTAT).

[14] The data source for both the national university research expenditures and the number of engineers in each region is ISTAT.

[15] The other main linkage between universities and economic activity occurs through the medicine and pharmaceutical departments; however, these spillovers are especially oriented towards large chemical companies.

[16] Due to the presence of zero-values in both the dependent and the independent variables, log-transformations were not

appropriate; thus, estimated coefficients cannot be interpreted as elasticities, and they reflect the different measures and units of the specific variables. For the dependent variable we used the actual number of patents, while the values of the independent variables are in terms of millions of lire.

[17] For an elaboration of this argument, as well as empirical evidence, see Audretsch and Vivarelli (1995).

[18] It should be noted that cross-comparisons of the actual values of the coefficients cannot be made, because of the differences in specifications of the estimation model.

[19] For an international comparison of formal linkages between universities and firms, see Onida and Malerba (1989).

References

Acs, Zoltan J. and David B. Audretsch (eds.), 1993, *Small Firms and Entrepreneurship: An East-West Perspective*, Cambridge: Cambridge University Press.

Acs, Zoltan J. and David B. Audretsch, 1988, 'Innovation in Large and Small Firms: An Empirical Analysis', *American Economic Review* **78**, 678–690.

Acs, Zoltan J. and David B. Audretsch, 1990, *Innovation and Small Firms*, Cambridge, Mass.: MIT Press.

Acs, Zoltan J., David B. Audretsch and Maryann P. Feldman, 1992, 'Real Effects of Academic Research: Comment', *American Economic Review* **82**, 363–367.

Acs, Zoltan J., David B. Audretsch and Maryann P. Feldman, 1994, 'R&D Spillovers and Recipient Firm Size', *Review of Economics and Statistics* **77**, 336–340.

Audretsch, David B., 1995, *Innovation and Industry Evolution*, Cambridge, Mass.: MIT Press.

Audretsch, David B. and Maryann P. Feldman, 1996, 'R&D Spillovers and the Geography of Innovation and Production', *American Economic Review* **86**.

Audretsch, David B. and Paula Stephan, 1996, 'How Localized Are Networks in Biotechnology?' *American Economic Review* **86**.

Audretsch, David B. and Marco Vivarelli, 1995, 'New-Firm Formation in Italy: A First Report', *Economics Letters* **48**, 77–81.

Bagnasco, Arnaldo, 1977, *Tre Italie. La Problematica Territoriale dello Sviluppo Italiano*, Bologna: Il Mulino.

Baldwin, William L. and John T. Scott, 1987, *Market Structure and Technological Change*, London: Harwood Academic Publishers.

Becattini, Giacomo (ed.), 1987, *Mercato e Forze Locali: Il Distretto Industriale*, Bologna: Il Mulino.

Bound, John, Clint Cummins, Zvi Griliches, Bronwyn H. Hall and Adam Jaffe, 1984, 'Who Does R&D and Who Patents?' in Zvi Griliches (ed.), *R&D, Patents and Productivity*, Chicago: University of Chicago, pp. 21–54.

Cohen, Wesley M. and Richard C. Levin, 1989, 'Empirical Studies of Innovation and Market Structure', in Richard Schmalensee and Robert Willig (eds.), *Handbook of Industrial Organization*, Volume II, Amsterdam: North-Holland, pp. 1105–1107.

Cohen, Wesley M. and Steven Klepper, 1991, 'Firm Size versus Diversity in the Achievement of Technological Advance', in Zoltan J. Acs and David B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 182–203.

Cohen, Wesley M. and Steven Klepper, 1992, 'The Tradeoff between Firm Size and Diversity in the Pursuit of Technological Progress', *Small Business Economics* **4**, 1–14.

Feldman, Maryann P., 1994a, 'Knowledge Complementarity and Innovation', *Small Business Economics* **6**, 363–372.

Feldman, Maryann, P., 1994b, *The Geography of Innovation*, Boston: Kluwer Acadmic Publishers.

Galbraith, John K., 1956, *American Capitalism: The Concept of Counterveiling Power*, Revised Edition, Boston: Houghton Mifflin.

Griliches, Zvi, 1979, 'Issues in Assessing the Contribution of R&D to Productivity Growth', *Bell Journal of Economics* **10**, 92–116.

Hsiao, Cheng, 1986, *Analysis of Panel Data*, Cambridge: Cambridge University Press.

Jaffe, Adam B., 1986, 'Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value', *American Economic Review* **76**, 984–1001.

Jaffe, Adam B., 1989, 'Real Effects of Academic Research', *American Economic Review* **79**, 957–970.

Kleinknecht, Alfred, 1989, 'Firm Size and Innovation: Observations in Dutch Manufacturing Industry', *Small Business Economics* **1**, 215–222.

Kleinknecht, Alfred, Tom P. Poot and Jeroen O. N. Reijnen, 1991, 'Technical Performance and Firm Size: Survey Results from the Netherlands', in Zoltan J. Acs and David B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 84–108.

Krugman, Paul, 1991, *Geography and Trade*, Cambridge, Mass.: MIT Press.

Link, Albert N. and John Rees, 1990, 'Firm Size, University Based Research, and the Returns to R&D', *Small Business Economics* **2**, 25–32.

Link, Albert N. and John Rees, 1991, 'Innovative Behavior in Small-Sized Firms', *Small Business Economics* **3**, 179–184.

Loveman, Gary and Werner Sengenberger, 1991, 'The Re-emergence of Small-Scale Production: An International Perspective', *Small Business Economics* **3**, 1–38.

Marshall, Alfred, 1920, *Principles of Economics*, Eighth Edition, London: Macmillan.

Marx, Karl, 1912, *Capital*, translated by Ernest Untermann, Volume I, Chicago: Kerr.

Onida, Fabrizio and Franco Malerba, 1989, 'R&D Cooperation between Industry, Unviersities and Research Organizations in Europe', *Technovation* **9**, 131–195.

Pavitt, Keith, M. Robson and J. Townsend, 1987, 'The Size Distribution of Innovating Firms in the UK: 1945–1983', *The Journal of Industrial Economics* **55**, 291–316.

Rothwell, Roy, 1989, 'Small Firms, Innovation and Industrial Change', *Small Business Economics* **1**, 51–64.

Santarelli, Enrico and Alessandro Sterlacchini, 1990, 'Innovation, Formal versus Informal R&D, and Firm Size: Some Evidence from Italian Manufacturing Firms', *Small Business Economics* **2**, 223–228.

Scherer, F. M., 1967, 'Market Structure and the Employment of Scientists and Engineers', *American Economic Review* **57**, 524–530.

Scherer, F. M., 1982, 'Inter-Industry Technology Flows in the United States', *Research Policy* **11**, 227–245.

Scherer, F. M., 1984, *Innovation and Growth: Schumpeterian Perspectives*, Cambridge, Mass.: MIT Press.

Scherer, F. M., 1991, 'Changing Perspectives on the Firm Size Problem', in Zoltan J. Acs and David B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 24–38.

Scherer, F.M., 1992, 'Schumpeter and Plausible Capitalism', *Journal of Economic Literature* **30**, 1416–1433.

Schumpeter, Joseph Alois, 1942, *Capitalism, Socialism and Democracy*, New York: Harper and Row.

Schwalbach, Joachim and Klaus F. Zimmerman, 1991, 'A Poisson Model of Patenting and Firm Structure in Germany', in Zoltan J. Acs and David B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 109–120.

Sylos-Labini, Paolo, 1986, *Le classi sociali negli anni '80*, Roma: Laterza.