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From Which Source Do Small Firms Derive Their Innovative Inputs? Some Evidence from Italian Industry *

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Abstract. This paper relies upon the hypothesis that the "knowledge production function" – defined in the geographical sense – is characterized by coefficient estimates which vary with firm size. In particular, large firms depend for their innovative output on direct and indirect R&D inputs, whereas small firms more extensively exploit the spillovers from research activities carried out by universities and by other firms. This hypothesis is tested against two different sets of data: the first based on patent statistics and dealing with 20 Italian regions over the period 1978–86; the second consisting of a selected number of product innovations identified by a literature-based counting procedure and dealing with 46 Italian provinces in year 1989. The results of regression analysis support the hypothesis that firms belonging to different size classes resort to different sources for the knowledge relevant to their innovative output. In particular, industry R&D prove to play a relatively more important function than do spillovers from university research in generating innovative output in large firms, whereas the opposite is true in the case of small firms.

Key words: R&D spillovers, product innovation, firm size.

JEL Classification: L11, O31.

I. Introduction

It is conventional wisdom in industrial organization that large firms are the most powerful engine of technological change, while small firms account for a scant portion of total innovative activities. This view can be traced back to the so called

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"second Schumpeterian hypothesis" (Schumpeter, 1942), which holds that the innovative capability increases with firm size, and to Galbraith's (1956) emphasis on the overwhelming importance of large firms in innovation.

However, since the early 1960s theoretical studies of the relationship between market structure and innovation (Arrow, 1962, 1983; Demsetz, 1969; Kamien-Schwartz, 1982) have viewed small firms as important contributors to the overall process of technological change, at least in certain industries and geographical units in which competition among a significant number of (small) firms provides an incentive to undertake innovative activities. Nevertheless, it was only during the 1980s that a wave of empirical studies showed that even small firms with a low committment to *formal* R&D activities provide a significant contribution in terms of innovative output, although in most cases they introduce incremental rather than radical innovations.[1] Besides, such studies (in particular Kleinknecht, 1987; Santarelli and Sterlacchini, 1990) stated that official data undercount the innovative capability of small firms, which turned out to be more active in (at least informal and non-systematic) research activities than is usually believed to be the case.[2]

In this paper we focus on the sources of the knowledge employed in Italy by small firms – which according to official surveys are uninvolved or little involved in formal R&D activities – to develop their innovative output. In particular, we shall seek to answer the following question: since the most important source of knowledge for the development of innovations is R&D expenditures and since these are to a large extent made by large firms (cf. Baldwin-Scott, 1987; Scherer, 1991; Cohen-Klepper, 1991, 1992), from which source do small firms derive their innovative inputs? One might answer this question by simply pointing out the effect of spillovers from universities and large firms on the informal innovative activities carried out by small firms. However, the ability to pick-up spillovers in the environment has been shown to be connected to the complementarity of a firm's R&D activity with research undertaken by other firms and/or universities located in the neighbourhood (cf. Cohen and Levinthal, 1989). This implies that under certain circumstances firms invest in R&D to improve their absorptive capacity, i.e. to assimilate and exploit externally developed technological knowledge.

Since official data do not allow for Italy a thorough investigation of a firm's ability to employ internal R&D for assimilating knowledge from the environment,[3] we limit our analysis to the (different) impact exerted *via spillovers* by R&D respectively carried out in universities and large firms on the innovative output of small firms. Our study is therefore aimed at identifying the degree to which university and corporate R&D spills over to small firms at the regional level.

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[1] Cfr. Bound et al. (1984); Acs and Audretsch (1987, 1988, 1990); Pavitt et al. (1987); Rothwell and Zegveld (1982); Rothwell (1989); Kleinknecht (1987, 1989); Santarelli and Sterlacchini (1990); Kleinknecht et al. (1991).

[2] Of course, there is no evidence that official R&D data are less accurate in the case of small firms. The undercounting problem is therefore connected to the fact that the innovative activities carried out by small firms are usually less systematic than those of their larger counterparts.

[3] Which can be studied only by recurring to business unit level data on firms' R&D expenditures.

Section II explores the geographical dimension of R&D spillovers and discusses the findings of some empirical studies dealing with the US and Italy; Section III presents the results of a regression analysis, conducted at the regional level, in which the dependent variable is patented innovations; Section IV introduces a second database, reporting innovations identified by a literature-based procedure, and presents the results of analysis carried out at the provincial level; finally, Section V sets out some concluding remarks and suggestions for innovation policy.

II. Small Firms and the Innovative Environment

In one of the most widely used models of technological change, that of the knowledge production function, Griliches (1979) links inputs to the innovation process with innovative outputs: under this approach the crucial innovative input is new technological knowledge generated by R&D, whereas the innovative output is patented innovations.

However, from this input-output perspective, empirical tests of the knowledge production function approach give rise to contradictory conclusions. In effect, the bulk of industrial R&D is undertaken by the largest firms, whereas small ones account for only a minor share of total R&D inputs; nevertheless recent studies have shown that small firms make an important contribution in terms of innovative output in certain industries and geographical units. Therefore, if one follows the knowledge production function approach one can argue that, paradoxically, the prediction that innovative activity favors those with access to knowledge producing inputs does not apply (in all cases) to small firms. One solution to this problem would be to integrate the knowledge production function approach with the “externalities approach” (Antonelli, 1994). Accordingly, in study of the overall innovative process the unit of observation should be somewhat broader than an individual firm, and it should also comprise the spatial dimension represented by the “innovative system” of which each firm is part.

Various considerations argue in favour of the change of perspective suggested above. Firstly, as regards inputs, the whole nature of the knowledge relevant to the undertaking of innovative activities suggests that a constellation of complementary firms within a geographic unit is likely to benefit from significant network externalities. This is because knowledge can be transmitted through informal channels of communication from one firm within the unit to another (Becattini, 1987; Krugman, 1991a). In a similar context, the creation of innovative networks of small firms may (a) reduce the uncertainty associated with the innovative process (Freeman, 1991); (b) favour the circulation of human capital among different firms and thus the dissemination of tacit knowledge (Nelson and Winter, 1982); (c) reinforce learning processes (included those induced by the producer-user interaction) with the most significant increasing returns (Arthur, 1988; Von Hippel, 1988; David and Rosenbloom, 1990). Secondly, the innovative process is typified by spillovers and other types of externality. In particular, even in the absence of other externalities, the spillovers linking the innovative output of a particular firm to the innovative inputs of rival firms in the same or in related industries have been shown to play an important role (Scherer, 1982; Bernstein, 1989; Goto-Suzuki, 1989). Thirdly, on the basis of the above two arguments, one may conclude that the spatial dimension of the innovative process merits special attention; and this is also confirmed by the recent emergence of a new line of inquiry usually referred to as *geography of innovation* (Porter, 1990; Krugman, 1991a, b; Feldman, 1994a, b). In effect, if the unit of observation is a given geographical area and not an individual firm, it becomes easier to capture adequately the function of innovation networks, the effects of externalities and spillovers, and the amount of knowledge originating from outside the industrial system (specifically from universities) that firms in the relevant area are likely to exploit.

It may be assumed – and this is the hypothesis tested empirically in the present paper – that small firms benefit more than larger ones from the above mentioned network externalities, R&D spillovers and, in general, knowledge produced by other firms and institutions. In particular, the channels through which small firms benefit from these external sources of knowledge are various: explicit and tacit knowledge embodied in the human capital which moves from one firm in the geographical unit to another; different kinds of cooperation agreements, contracting, and subcontracting with larger firms; reverse engineering and analogous procedures; hiring of graduate personnel.[4]

This "geographical" approach to the knowledge production function was originally developed by Jaffe (1986 and 1989), who tested – for 29 U.S. states over the period 1972–77 and for 1979 and 1981, with a total sample size of 232 observations – the hypothesis that patent activity within a given portion of territory is related to the private corporate expenditures on R&D in that territory, as well as to the research expenditures undertaken in universities. Jaffe's statistical results provided evidence that corporate patent activity responds positively to spillovers from both private corporate expenditures on R&D and to research expenditures undertaken by universities within the state, although the former (elasticity >0.7) were shown to have a stronger impact than the latter (elasticity <0.1).[5]

The main drawback to Jaffe's study is that it does not take into account the size distribution of innovative firms. This aspect is instead considered in four recent contributions by Acs, Audretsch and Feldman (1992, 1994) and Feldman (1994a, b). Acs, Audretsch and Feldman (1992, 1994) employ a model analogous to

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[4] In the case of Italy, innovative spillovers are usually found within industrial districts specialized in the production of traditional consumer goods, which benefit from what has been called "diffused innovative capability" (Bellandi, 1989; Brusco, 1986; Becattini, 1987; Pyke et al., 1990).

[5] Jaffe (1989) takes the number of patents as a proxy for innovative output and argues that the proximity of university research to corporate laboratories should increase the potential for spillovers from the universities. However, the geographic coincidence index introduced in his article to capture this phenomenon is only marginally statistically significant.

that of Jaffe[6] with two important modifications: the use of the number of significant innovations (reported in the U.S. Small Business Administration Database) as the dependent variable; the use of three different dependent variables: the significant innovations of all firms, large firms (with more than 500 employees), and small firms (with fewer than 500 employees). The equation estimating the innovative output of all firms yields results similar with those obtained by Jaffe,[7] whereas the relative importance of industry R&D and university research as inputs in generating innovative output turns out to vary significantly between large and small firms. In particular, for large firms the elasticity of innovative output with respect to industry R&D is more than twice that of university research, whereas the opposite result is obtained for small firms, with the elasticity to university research being one fifth greater than elasticity to industry R&D. These results suggest that the knowledge production function for small firms is different from that for large firms and, in particular, that industry R&D plays a relatively more important function than do spillovers from university research in generating innovative output in large firms, whereas the opposite is true in the case of small firms.[8]

With respect to Italy, an interesting empirical study of the knowledge production function at the geographical level has been carried out by Antonelli (1986).[9] Antonelli breaks down the number of patents granted by EPO (European Patent Office) to Italian firms by province of the innovating firm. Whereas the estimates confirm a positive and significant link between innovative output and industry R&D, the coefficient of the “university research” variable (measured in terms of the number of graduates from scientific faculties), although positive as expected, is not significant. Unfortunately, Antonelli (1986) does not consider the distribution of patents across large and small firms, and therefore cannot answer the question of which type of firm is the recipient of such spillovers. The further examination of the Italian case conducted in the next two sections of the present paper seeks to answer this question. In particular, it originates from the belief that in Italy, too, small firms have a significant comparative advantage over their larger counterparts in exploiting spillovers from universities, while large firms are more adept at exploiting knowledge created in their own laboratories.

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[6] Both Jaffe (1989) and Acs et al. (1992, 1994) control specifically for industry characteristics by estimating the knowledge production function for four disaggregated technological areas.

[7] These authors also found evidence linking the proximity of university research to corporate laboratories with innovative spillovers.

[8] These findings are confirmed by those by Maryann Feldman (1994a, b) in a study of 3241 commercially significant innovations introduced in 13 U.S. manufacturing sectors in 1982.

[9] Other studies regarding Italy have been conducted by Audretsch and Vivarelli (1994), using an abridged version of the database described in Section III of the present paper, and Santarelli and Piergiovanni (1996), using a disaggregation by region of the data described in Section IV.A of the present paper.

III. A Test of the Knowledge Production Function for Italy Using Patent Data

The knowledge production function for firms of different size is tested in this section using a new longitudinal database developed by Franco Malerba at Bocconi University of Milan, comprising the twenty Italian regions over the period 1978–1986, and resulting in a total sample size of 180 observations.

The database is constructed by breaking down for each year of the relevant period the Italian patents extended to the U.S. by region of the innovating firm (either private or public[10]). The source of patent information is the database of the Science Policy Research Unit at Sussex University, which is in turn based on data provided by the Office of Technology Assessment and Forecasting of the U.S. Patent Office. Therefore, we follow Jaffe (1989) in measuring the dependent variable as the number of patents within the region in the relevant year, while the first independent variable is measured as R&D expenditures by both private and public firms in real terms using the implicit deflator for GNP.[11] Both variables have been divided by resident population to control for the different sizes of Italian regions. Since, unlike industry R&D expenditures, figures on research expenditures by Italian universities are available only at the national level,[12] a suitable weight had to be identified in order to allocate regional figures to the different units of observation. Thus – following, among others, Scherer (1967) – the relative number of engineering graduates has been used as a weight with which the national university expenditures have been allocated according to the individual region.[13] The index is constructed by dividing the national university research expenditures by the total number of engineering graduates (source: ISTAT, "Laureati per facoltà e sede nel 1978 . . . 1986," Rome) and then multiplying the resulting value for the ratio of engineering graduates to resident population in each region. This undoubtedly rough procedure has the merit of focusing only on the portion of university research which is likely to be more significant for the development of new industrial products and processes, i.e. that undertaken in the engineering departments. In any case, one cannot help but note that it is in some sense a composite measure which incorporates both the presence of large scientific universities in certain regions and the quality of the "human capital" within any given region. Besides, with this proxy one implicitly assumes that the engineering graduates within a given region will be employed by firms located in the same region, which is not always the case in Italy, where the

[10] A particular difference between Italy and the U.S. is the greater share of economic activity accounted for by public firms in Italy. Thus, both the innovative output and the R&D input of public firms have been considered in our analysis, whereas they were excluded from previous studies carried out for the U.S.

[11] *Source:* ISTAT (National Statistical Institute of Italy), "Spesa effettuata dal settore delle imprese per circoscrizione geografica, tipo d'impresa e tipo di ricerca."

[12] Recent estimates from the Commissione Tecnica per la Spesa Pubblica allow disaggregation of total university research expenditures by individual university only for 1989.

[13] *Source:* ISTAT, "Laureati per facoltá e sede nel 1978 . . . 1986." Also this variable has been deflated using the implicit deflator for GNP.

demand for this kind of personnel is much higher in the North-western regions than elsewhere.[14] Nonetheless, this specification is in our view consistent with the hypothesis that university research may be particularly helpful in disseminating the technical knowledge relevant to industrial activities, in particular through the formation of specialized technical personnel.

In order to test the hypothesis that the innovative output of large firms is mainly based on firm R&D expenditures, while that of smaller ones depends more on university research, four groups of regressions are estimated alternatively for (a) all firms; (b) small firms with fewer than 100 employees;[15] (c) medium firms with between 100 and 1000 employees; (d) large firms with more than 1000 employees. Using panel data, the covariance test for overall regression-coefficients homogeneity over time has been applied to our specifications (see Hsiao, 1986). The non-significance of F-values in all four cases confirmed the lack of significant time series variation and enabled us to use pooled ordinary least squares estimators (POLS). On the other hand, application of the White test reveals that all specifications suffer from heteroscedasticity; thus an heteroscedasticity-consistent covariance matrix has been used for estimation. Finally, the robustness of the estimates was controlled for fixed geographical effects. These were proxied following the traditional scheme of the "Three Italies,"[16] which takes into account the different industrial and structural features of Italian regions over the relevant period (1978–86). Accordingly, inserted in the equation are three dummy variables which are, respectively, equal to one for each of the North-Western (NW) industrialized regions, for each of the North-Eastern and Central (NEC) regions characterized by widely diffused entrepreneurial capabilities, for each the later developed regions of the South (S), and zero otherwise.[17] The knowledge production function model modified to incorporate spillovers within spatial units of observation will be thus

$$I_{ir} = \alpha_1 + \alpha_2 \mathrm{IND}_{ir} + \alpha_3 \mathrm{UNIV}_{ir} + \alpha_4 D_{\mathrm{NO}} + \alpha_5 D_{\mathrm{NEC}} + \alpha_6 D_S + \varepsilon \qquad (1)$$

$$\text{with } i = 1978, \ldots, 1986, \qquad r = 1, \ldots, 20,$$

where the dependent variable I_{ir} is the number of patents extended to the U.S. per region; IND_{ir} stands for total industrial R&D expenditures by region; UNIV_{ir} denotes university research by region, D_{NO}, D_{NEC}, and D_S are the dummy variables for fixed geographical effects, and ϵ is an error term. The coefficient estimates, related t-statistics, and R^2 are given in Table I.

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[14] In any case, it must be noticed that the geographical mobility of labor in Italy is comparatively lower than in the other large industrialized countries.

[15] Given the particular structure of Italian industry – biased towards small and very small firms – a lower threshold for small firms has been chosen.

[16] On this see Bagnasco (1977); Brusco (1986).

[17] Since two regions, Valle d'Aosta and Molise, cannot be included in anyone of the macro-regions taken into account in the scheme of the "Three Italies," the three regional dummies have been included in the estimates along with an intercept term.

TABLE I. Regression results using patent data: 20 regions; 1978–1986

	All firms	Small firms	Medium firms	Large firms
Intercept	-0.119^{**}	-0.007^{*}	-0.048^{**}	-0.061^{**}
	(22.53)	(−2.05)	(−2.50)	(−2.53)
IND_{ir}	14.5^{**}	0.90^{**}	5.79^{**}	7.42^{**}
	(4.99)	(2.87)	(4.78)	(4.97)
UNIV_{ir}	3.13	2.25^{**}	−1.62	2.68
	(0.41)	(2.80)	(−0.41)	(0.75)
D_{NO}	0.461	0.007	0.342^{**}	0.084
	(1.45)	(0.28)	(2.36)	(0.55)
D_{NEC}	0.282^{**}	0.015^{*}	0.175^{**}	0.092^{**}
	(4.04)	(1.90)	(4.42)	(2.66)
D_S	0.070	−0.009	0.033	0.039
	(0.90)	(−1.01)	(0.87)	(1.06)
R^2	0.70	0.43	0.64	0.68
n	180	180	180	180

All the coefficients have been multiplied by 100,000.
t-statistics in parentheses.
* = significant at 95% level of confidence.
** = significant at 99% level of confidence.

The results of our estimates allow extension to Italy of the findings by Jaffe (1986, 1989), Acs et al. (1992, 1994) and Feldman (1994a, b). In the regression estimated for all firms, the input-output link between R&D expenditures and innovative output (total patents) is in effect positive and statistically significant, whereas the "university research" variable has a positive but not significant coefficient.[18] With respect to small firms the university research variable instead obtains a coefficient significant at the 99 per cent level of confidence and higher than that (equally significant) for industry R&D. Unlike medium and large firms, small firms are therefore shown to rely on both university research and industrial R&D as the source of knowledge relevant to their innovative activity, although the former serves as an especially crucial input for such activity. In this respect, it should be noted that the coefficient estimated for the "industry R&D" variable – although always significant – increases monotonically along with firm size (both in value and significance). As regards the dummy variables, the coefficient estimates confirm the expected result, namely that returns from the knowledge production function are on average higher in the NEC regions, which are characterized by an industrial structure which favours interdependence among firms and a much closer relationship between firms and the surrounding environment (for instance, industrial districts are particularly widespread in such area).

[18] This result confirms that obtained by Antonelli (1986).

IV. A Further Test with Literature-Based Innovation Output Indicators

1. The Database

In this section the empirical procedure introduced in Section III is applied to a unique set of data consisting of the product innovations introduced in the Italian market in 1989 and reported in a selected number of technical and trade journals. This further test of the modified knowledge production function model is made possible by the availability of two recently developed databases. On the one hand, the PRODIN89 database on product innovations introduced in Italy in 1989 which has been constructed by Santarelli and Piergiovanni (1996; see also Santarelli, 1993) following a literature-based counting procedure. On the other hand, the estimates of university research expenditures by individual university made by the Commissione Tecnica per la Spesa Pubblica for the same year (Catalano and Silvestri, 1992).

As regards innovation data, it is commonly accepted that none of the most widely used innovation output indicators is exempt from serious weaknesses and shortcomings. In general, the traditional patent-based indicators do not handle the problems raised by the implicit contrast between technological complexity and the economic value of innovations and by the not always straightforward distinction between *inventions* (not yet brought to the market) and *innovations* (already marketed).[19] More in detail, patent data – which have been used in Section III of the present paper – bring with them the following problems:

(a) not all innovations are patented;
(b) not all patents become commercial innovations;
(c) the propensity to patent varies greatly across firms of different sizes.[20]

Conversely, the literature-based indicator employed in this section avoids, at least in part, the above and other problems since: (1) it provides information about commercially introduced innovations; (2) the collection and use of data at the firm level is not hampered by secrecy problems; (3) data collection need not involve any direct contact with the innovating firm, and this reduces the amount of unexamined biases in the database; (4) the procedure is relatively cheap compared with others. The database PRODIN89 – developed by following this procedure – comprises all innovations reported in the complete 1989 volume of 25 Italian technical and trade journals containing information on 15 industrial sectors.[21] It employs a procedure

[19] Interesting surveys on the merits and shortcomings of different innovation output indicators are those by Cohen-Levin (1989); Griliches (1990); Archibugi (1992).

[20] In effect, when applying for patent, the patentee makes the technical features of his/her invention available to potential competitors, even before the actual commercialization of the novelty. Thus in some cases patents are considered to be an inefficient means to protect returns from inventions.

[21] The journals selected are the following: *Largo Consumo, Il Pesce, Industrie Alimentari, La Nuova Selezione Tessile, L'Informobili, LM-L'Industria del Legno e del Mobile, L'Italia Grafica, Il Poligrafico Italiano, Annunciatore Poligrafico, Rassegna Grafica, Cellulosa e Carta, Rassegna Chimica, Il Farmacista Moderno, Il Giornale del Farmacista, Industria della Gomma, Il Mondo della*

which was used for the first time by The Futures Group (1984) – under contract by the U.S. Small Business Administration and for the construction of the database used, among others, by Acs et al. (1992, 1994) and Feldman (1994a, b) in the studies discussed in Section II of the present paper. The same method has been adopted also for a series of recent studies regarding some European countries which are reported in Kleinknecht and Bain (1993).

The main difficulty of the literature-based procedure lies in the selection of the relevant journals and in the features of the new products section in each of them. It is likely that the number of innovations identified will be positively correlated with the number of journals selected or, in any case, with the total number of journals in each country reporting this kind of information and the length of the new product section in each of them. As regards Italy, Santarelli and Piergiovanni (1996) attempt to overcome this problem by selecting the relevant journals from a much larger number of similar publications according to the following criteria:

(1) the presence of a clearly distinct “new products” column or section;
(2) the provision of detailed technical information about each innovation presented;
(3) the specification of the name and address of the innovating firm;
(4) continuity of publication and the ready availability of the journal throughout the country upon payment of a subscription.

The Italian innovations identified and selected with this method should therefore represent a reliable proxy of the overall innovative output of domestic firms in 1989. In effect, although the total number of domestic innovations reported in PRODIN89 is not particularly high (530), their sectoral and geographical distribution is consistent with the results of previous field studies using different innovation indicators which have been conducted at both the sectoral and the geographical level (cf. among others, Balloni et al., 1992; Becattini, 1987; Brusco, 1982). In particular, the industries producing capital goods (especially specialized industrial machinery) and traditional consumer goods – as well as highly dynamic regions such as Lombardia, Emilia-Romagna, Veneto, and Tuscany – are confirmed to predominate in terms of innovative output.

2. Model Specification and Empirical Results

To obtain an acceptable sample size, we broke down the PRODIN89 database by province instead of region of the innovating firm. It was thus possible to work with 46 observations, corresponding to all the provinces for which at least one innovation was identified. As a consequence, we use simple cross-section estimates to shed light on cross-province variation in terms of innovative output, therefore adopting

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Calzatura, L’Industria Meccanica, Management e Informatica, Bit, Rivista di Informatica, Tecniche dell’Automazione e Robotica, Automazione Oggi, Elettronica e Telecomunicazioni, L’Automobile.

the same perspective as Feldman's (1994a, b) studies on the U.S. The modified knowledge production function model to be estimated is then

$$I_p = \alpha_1 + \alpha_2 \mathrm{IND}_p + \alpha \mathrm{UNIV}_p + \epsilon \tag{2}$$

with $p = 1, \ldots, 46$,

where the dependent variable I_p is the number of commercially significant innovations in each province identified by means of the literature-based procedure; IND stands for total industrial R&D expenditures by province, and has been constructed by allocating the regional figures used for Equation (1) to the different provinces according to their share of industry employment in the regional total; UNIV_p denotes university (only scientific faculties) research expenditures by province, and has been taken directly from the already mentioned estimates by the Commissione Tecnica per la Spesa Pubblica (see Catalano – Silvestri, 1992); and ϵ is an error term. As was the case with Equation (1) above, four regressions are estimated alternatively for (a) all firms (530 innovations); (b) small firms with fewer than 50 employees (104 innovations); (c) medium firms with between 100 and 499 employees (120 innovations); (d) large firms with more than 500 employees (67 innovations). The disaggregation by size of the innovating firm differs from the one adopted in estimation of Equation (1), because it was necessary to maintain a reasonably large sample size and a significant level of variability within each employment class.[22]

For the dependent variable I_p and all the independent variables, employment in the industrial sector in the relevant geographical unit was used as a weight with which to correct for the different size and degree of industrialization of each province.[23] Application of the White test shows that only the specification for all firms suffers from heteroscedasticity. Consequently, in this case, an heteroscedasticity-consistent covariance matrix has been used for estimation of the relevant regression. The coefficient estimates, related t-statistics, and R^2 are given in Table II.

As a first comment, one notes that the coefficients significance and R^2 are in all cases lower than those obtained for Equation (1). However, besides that of footnote twenty above, at least three explanations for the worse performance of this second group of regressions may be advanced. First of all, in this case a simple cross-section estimate was made in relation to only one year, whereas in the case of Equation (1) we were able to pool nine years of data. Secondly, the necessity to take the province, instead of the region, as the relevant unit of observation reduced

[22] Only 291 firms (out of 530) could be precisely included in the three size classes, due to the firms' reluctance to disclose information concerning their total number of employees. Of course, this implies a serious loss of information, although evenly distributed among the three size classes.

[23] In practice, this procedure serves the same purposes of the three dummy variables in Equation (1) and is therefore a means to control for certain fixed geographical effects. Therefore, to avoid redundancy, the above dummy variables are not inserted in Equation (2).

TABLE II. Regression results using literature-based innovation output indicators: 46 provinces; 1989

	All firms	Small firms	Medium firms	Large firms
Intercept	37.75***	9.02	12.90**	0.54
	(2.67)	(1.11)	(2.08)	(0.17)
IND_p	21.41**	3.37	3.83	4.17**
	(1.82)	(0.69)	(1.03)	(2.17)
$UNIV_p$	669.17*	310.73***	72.51	37.60
	(1.58)	(2.50)	(0.77)	(0.77)
R^2	0.134	0.130	0.032	0.103
n	46	46	46	46

All the coefficients have been multiplied by 1,000.
t-statistics in parentheses.
* = significant at 90% level of confidence.
** = significant at 95% level of confidence.
*** = significant at 99% level of confidence.

the representativeness of data: in particular, the smaller the geographical unit of observation, the less spillovers from industry R&D and university research are likely to produce their effects only within the borders of the relevant area. This point is reinforced by the fact that in Italy each Regional Government provides incentives and introduces institutional arrangements which favour the internalization (within the region) of such spillovers, whereas similar policy interventions are not permitted at the provincial level. Thirdly, as already suggested by Acs et al. (1994), innovations identified by means of a literature-based procedure are the result of technical knowledge coupled with complementary knowledge of the market.

Thus, while industry R&D and university research are perhaps the most important components of the *invention* process which results in the granting of a patent, these same resources are only one component, usually not the most important, of the more complex process of introducing commercially significant *innovations*. In any case, it is worth recalling that the aim of the present paper has not been to identify the determinants of innovation output at the geographical level, but more modestly to test empirically the hypothesis of heterogeneity in the external sources of knowledge inputs employed by small and large firms for their innovative activity. In this respect, we focus mostly on the hypothesis of coefficients heterogeneity between small firms and their larger counterparts. In particular, as was the case with Equation (1), also estimation of Equation (2) allows rejection of the hypothesis that the coefficients of industry R&D are equal for large and small firms. There is in fact substantial evidence that, whereas industry R&D expenditures play a more important role than do spillovers from university laboratories in generating innovative output in large firms, spillovers from universities play a more decisive function in the innovative output of small firms than do spillovers from industry R&D.

Besides, in this case too the coefficient of industry R&D expenditures increases monotonically as one moves from small, to medium and then to large firms (both in value and significance).

Of course, the findings of the empirical analyses carried out in the present and previous sections are based on the assumption that no differences exist between industry and university research in terms of appropriability. As regards Italy, it is instead highly likely that industrial R&D, undertaken mainly by large firms, is more appropriable than university research.[24] As a consequence, the higher and more significant coefficients of industry R&D in the estimates which take the innovative output of large firms as their dependent variable may be explained by the better ability of such firms to appropriate the results of *their own* research activity. Conversely, not only do the higher and more significant coefficients of university research in the estimates for small firms demonstrate that spillovers from universities play a more important function in the innovative output of such firms than do spillovers from industrial R&D, but they also suggest that the (relatively little) amount of resources devoted by small firms to R&D is partly aimed at enhancing their ability to assimilate technological knowledge which is created by universities. In effect, although most formal R&D partnerships and cooperation agreements between university and industry involve large firms, the coefficients of university research when the innovative output of small firms is the dependent variable signals that a significant amount of the university research which "spills over" for exploitation by third party firms affects mostly the innovative output of small firms. This is undoubtedly an indication that knowledge which originates outside the industry can be easier assimilated by small firms than knowledge which originates with their competitors' R&D spillovers.

V. Conclusions

The findings in this paper show that in the case of Italy, too, spillovers from university research are a relatively more important source of innovation in small firms, while spillovers from industrial research are more important in producing innovation in large ones. Comparing these results with the predictions of the theory and the findings of previous empirical studies, one may conclude that a fundamental reason why large firms are not always predominant in innovation is that small firms exploiting knowledge created by expenditures on research in universities (prevalently) and on R&D in large firms (less markedly) are in most cases able to generate innovative output. More specifically, in the knowledge production function for small firms those sources of knowledge which are external to the industrial system are more important than internal sources represented by industry

[24] Significantly different is instead the case of the U.S., where most innovative start-ups are created by former researchers in universities in order to exploit the results of their research activity. As regards Italy, some of the innovations included in PRODIN 89 were developed by newly created firms, but none of them was started by former researchers in universities.

R&D. Conversely, the knowledge production function for large firms indisputably links direct inputs (autonomous R&D) in the innovation process with innovative output.

In the light of this evidence, it is clear that small firms, usually weak in terms of technological competence and knowledge, benefit mostly from knowledge produced within the geographical area in which they are located but outside the industrial system. Accordingly, with respect to small firms the most effective science and technology seems to be one which facilitates the access of third parties to the results of university research and provides indirect support for privately funded innovative activities, mainly by promoting the creation and development of a local innovative system.

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