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Abstract

Using the uniquely rich database of the Italian Innovation Survey (CNR-ISTAT database), this paper examines the determinants of product and process innovation at the sectoral level. In comparison with the existing literature, this paper has separated innovations not only into products and processes, but has further disaggregated the latter into processes related to the introduction of new products, and those which only aim to increase efficiency in the production of existing goods. The average number of product innovation and cost-cutting processes introduced at sectoral level are well explained by the characteristics of different innovative patterns: i) Disembodied technology, in the form of R&D expenditure and user-producer linkages, is more important to explain the introduction of new goods. ii) Large scale production and concentrated market structure are associated mainly with process innovation. iii) In capital intensive sectors the introduction of new lines of business requires entirely new processes, and therefore a greater input of embodied technology.

1. Introduction*

Several studies have shown that there are substantial differences in the composition of innovative activities, including those aimed at product and process innovation. This has been shown at both the industry (Link, 1982; Pavitt, 1984; Levin, Cohen, and Mowery, 1985; Lunn, 1986; Levin, Klevorick, Nelson and Winter, 1987) and at the firm levels (Lunn, 1987; Kraft, 1990; Cohen and Klepper, 1992).

These studies have also highlighted the role that sectoral-specific characteristics play in the nature of the innovative output. Among these, the average size of the firm, the relevance of economies of scale, the rate of growth and the maturity of the industries, and the level of technological appropriability have been identified as the most important determinants of sectoral differences in the propensity towards product and process innovation.

Although product and process innovation are associated with different sectoral characteristics, however, this does not deny that they are closely inter-related. Studies using simultaneous equations models have reached the conclusion that product and process innovation foster each other. In particular, new process technology is often necessary in order to beget product innovation (Lunn, 1987; Kraft, 1990).

Using the unique rich database of the Italian Innovation Survey, this paper examines the determinants of product and process innovation at the sectoral level. In comparison with the already existing literature, this paper has separated innovations not only into products and processes but has further disaggregated the latter into processes related to the introduction of new products, and those which only aim to increase efficiency in the production of existing goods (cost-cutting process innovation). In this way it is possible to check whether the association between product and process innovation, found in other studies which did not adopt this distinction, is mainly a result of the strong complementarity between new products and new processes, or is related to other factors.

The next section will present the CNR-ISTAT survey. Section 3 will examine the theoretical basis regarding the determinants of product and process innovation, introducing the variables that will be employed in the empirical analysis carried out in section 4. Some conclusions will conclude the paper.

2. The CNR-ISTAT survey on innovation in the Italian manufacturing industry

The empirical evidence presented in this paper is based on the results of a broad survey on innovation in the Italian manufacturing industry carried out jointly by the Italian National Research Council and the National Statistical Office. The sample examined is composed of 6,839 firms that introduced innovations in Italy in the 1981-1985 period. Selection was not carried out at random but was itself based on a preliminary postal survey involving over 24,000 firms. This initial phase made it possible to eliminate roughly 65% of the firms as 'non-innovating' or 'less-innovating' and to concentrate on the remaining 8,220 firms, which constitute the core of Italian innovative firms. The follow-up involved an interview during which a further questionnaire was completed. The data obtained for each firm were then matched with those of an Istat survey on Gross Product. The combining of the two surveys led to the exclusion of over 1,000 more firms, leaving a sample of 6,839; these firms account for over 50% of the sample involved in the survey on gross product in terms of employees and sales. For these firms economic data were obtained for items such as sales, value added, employment and investment, as well as specific data on innovative activities made available by the CNR-ISTAT survey (ISTAT, 1989).[1]

Unique features of the CNR-ISTAT survey are:

> *1. Innovations introduced by each firm are split in three types: "products", "new processes related to old products", and "new processes related to new products".*
>
> *2. The total cost incurred by a firm for the introduction of the innovations has been classified under four headings: R&D, engineering and design, marketing, innovative investment.*

The analysis carried out in this paper is based on data on 95 industries at 3-digit disaggregation (ISTAT-NACE classification). Industries composed by less then 7 firms have been excluded from the analysis. The electronics industry could have been included if considered at 2-digit aggregation. We preferred, however, to not include this sector since it was a clear outlier due to its exceptionally high number of innovations.

3. The determinants of product and process innovation at the industry level

3.1. The representative firm

The aim of this study is to analyse the differences in the determinants of product and process innovation across different industries. Each industry is represented in our analysis by one fictitious firm for which the variables used assume the average values for the industry. Thus, we implicitly assume that all the firms in one industry are the same. Although the neglected intra-industry variability that is bound to exist can create some noise in the results (Levin, Klevorick, Nelson and Winter, 1987; Lunn, 1987; Kraft, 1990; Cohen and Klepper, 1992), this approach is justified by our attempt to capture the influence on the number of product and process innovations of some variables that act at the industry level.

A large number of studies have adopted the distinction between product and process innovation for different purposes. As we have shown elsewhere, the concepts of product and process innovation used in the literature are not always the same, and it is therefore necessary to explain the definitions adopted in this study clearly (Archibugi, Evangelista and Simonetti, 1992). The definitions used here, which are reported in the appendix, follow what we have called the "interview approach at the firm level", i.e. the firms themselves have classified each innovation as either a 'new product', or a 'new process related to existing goods', or a 'new process requested by the introduction of new goods'.[2]

3.2. Theoretical background

Two different factors contribute to determine the number of product and process innovations introduced by the "representative firm" of each industry, namely its the overall level of innovative activity, and its propensity to innovate in products with respect to processes[3].

A number of studies have shown the marked inter-sectoral differences in the intensity of innovative activity, which have been explained in terms of the differences in the levels of concentration, technological opportunities and appropriability of the results of innovative activities (Freeman, 1982; Scherer, 1982, 1983; Pavitt, 1984; Levin, Cohen, and Mowery, 1985).

In some industries the technology frontier is moving fast, allowing firms to introduce innovations more easily than in other industries. The activity of research and development in these sectors is more rewarding and firms devote to such activities a high share of their sales. The R&D intensity of the industry (RDINT) will be used therefore as a proxy for technological opportunities.

The exploitation of radical new technologies through R&D activities can allow the firm to grow very fast, especially when new markets are created. Usually R&D activities tend to focus more on the introduction of new products in order to capture the potentially greater rewards of product innovation (Cohen and Klepper, 1992). The variable RDINT is therefore expected to be associated with a higher share of product innovation.

Patenting and licensing are common means of appropriation of the benefits of innovation, especially in industries characterised by high technological opportunity (Levin, Klevorick, Nelson and Winter, 1987). The ratio of the number of patents to the number of innovations (pat) has been used as a proxy for the level of appropriability in an industry and it is expected to be associated mainly with product innovation.

In order to fully exploit the introduction of a new product, a firm has to promote it adequately. The share of the total cost of the innovation devoted to marketing (MKT), therefore, is expected to be higher in sectors with a large number and share of product innovations (Freeman, 1982). This should be truer in sectors where a large share of innovations are destined for the final consumers (FINDEM).

The importance of the linkages between producers and users of technology in the genesis of innovation has been highlighted in a number of studies (Von Hippel, 1982; Lundvall, 1988). The inputs to innovation coming from the first users (users) are expected to be very important for the introduction of new products, whilst the improvement of process technology usually stems from in-house activities.

In more mature and concentrated industries, on the contrary, where radical innovations are rarer and cost-cutting oligopolistic competition is more important in order to gain market share, large firms that exploit economies of scale and scope mainly seek improvements in the efficiency of their production facilities through process innovation (Abernaty and Utterback, 1975). The outcome of R&D activities in these industries is appropriated rather through secrecy, advantages in the learning curves and market power than through patenting and licensing (Levin, Klevorick, Nelson and Winter, 1987). The presence of large firms (size), a high degree of concentration, a proxy for market power (CONC), and high capital intensity, a proxy for mechanization (KAPIN), are expected to be associated with a high number and share of process innovation.

The production of new technology is one of the major determinants of competitiveness on international markets (Franko, 1989; Hughes, 1986). Firms in sectors with a high level of internationalisation (export) are then expected to have a stronger incentive to innovate due to a higher degree of competitive pressure 4. Since the pressure of foreign competition influences market power, however, this can adversely affect the stimulus to introduce new innovations reducing the possibility of appropriate the returns of innovation through market power (Kraft, 1990).

Besides technical uncertainty, which is common to all types of innovative activity, product innovation also involves risk arising from the commercialisation of the new goods, therefore a higher level of self-financing through retained profits (CASH) is expected to be associated with a higher share of product innovation (Freeman, 1982; Lunn, 1986, 1987).

Figure 1 reports the exact definitions of all the variables used in the analysis.

Figure 1: Variable definitions

Variable definitions	Mean	Std Dev
Endogenous variables:		
PROD: average number of 'product innovations' introduced by the firms in the industry	5.183	3.811
PROCOLD: average number of 'process innovations related to existing goods' introduced by the firms in the industry	1.638	1.862
PROCNEW: average number of 'process innovations related to new goods' introduced by the firms in the industry.	3.771	2.991
PRODSH: share of product innovations on the total number of innovations.	0.463	0.149
PROCPROD*: average number of 'process innovations related to new goods' divided by the sum of the 'average number of process innovations related to new goods' plus the 'average number of product innovations'.	0.455	0.167
Exogenous variables:		
RDINT: R&D expenditure divided by sales (industry averages).	0.003	0.005
users: Importance of customers' requests in the introduction of innovation (industry average).	2.228	0.619
SIZE: Average sales of the firms in the industry (billions of lire).	289.03	1001.2
CONC: Herfindahl index divided by average sales.	0.001	0.001

KAPIN: Investment in machinery and building divided by the number of employees (industry averages).	0.272	0.163
MKT: Percentage of expenditure for marketing on total innovation cost (industry average, weighted by total innovation cost).	4.525	3.318
FINDEM: Percentage of innovations produced in the industry and used by the household sector on total innovations produced in the industry.	0.330	0.357
PAT: Number of patents granted to firms in the industry divided by number of innovations introduced by the firms in the industry (industry averages).	0.251	0.468
CASH: Value added minus wages minus value of capital replaced, all divided by value added (industry averages).	0.299	0.109
EMBODIED: Percentage of expenditure for innovative investment on total innovation cost (industry average, weighted by total innovation cost) divided by the percentage of expenditure for R&D on total innovation cost (industry average, weighted by total innovation cost)	22.421	44.024

Figure 2: Equation specifications

Regression 1:

$$PROD = \alpha_0 + \alpha_1 \cdot USERS + \alpha_2 \cdot RDINT + \alpha_3 \cdot CONC + \alpha_4 \cdot SIZE + \alpha_5 \cdot KAPIN + \alpha_6 \cdot MKT + \alpha_7 \cdot FINDEM + \alpha_8 \cdot EXPORT + \alpha_9 \cdot CASH + \alpha_{10} \cdot PAT.$$

Regression 2:

$$PROCOLD = \beta_0 + \beta_1 \cdot RDINT + \beta_2 \cdot CONC + \beta_3 \cdot SIZE + \beta_4 \cdot KAPIN + \beta_5 \cdot MKT + \beta_6 \cdot FINDEM + \beta_7 \cdot EXPORT + \beta_8 \cdot CASH + \beta_9 \cdot PAT.$$

Regression 3:

$$PROCNEW = \gamma_0 + \gamma_1 \cdot USERS + \gamma_2 \cdot RDINT + \gamma_3 \cdot CONC + \gamma_4 \cdot SIZE + \gamma_5 \cdot KAPIN + \gamma_6 \cdot MKT + \gamma_7 \cdot FINDEM + \gamma_8 \cdot EXPORT + \gamma_9 \cdot CASH + \gamma_{10} \cdot PAT.$$

Regression 4:

$$PRODSH = \delta_0 + \delta_1 \cdot USERS + \delta_2 \cdot RDINT + \delta_3 \cdot CONC + \delta_4 \cdot SIZE + \delta_5 \cdot KAPIN + \delta_6 \cdot MKT + \delta_7 \cdot FINDEM + \delta_8 \cdot EXPORT + \delta_9 \cdot CASH + \delta_{10} \cdot PAT.$$

Table 1: Regression results

4. Results of the empirical analysis

Dependent variables	PROD	PROCOLD	PROCNEW	PRODSH	PROCPROD
Regression number	(1)	(2)	(3)	(4)	(5)
R Square	0.51	0.74	0.16	0.50	0.42
F value	8.85	26.43	1.56	8.36	10.49
Sig. F	(0.000)	(0.000)	(0.133)	(0.000)	(0.000)
N	95	95	95	95	95
Intercept	-4.15621	-0.23955	0.339957	0.132685	0.81071
RDINT	290.2595 a	76.88901 a	45.07379	4.971113 c	
	(4.502)	(3.405)	(0.677)	(1.940)	
USERS	2.318149 a		1.036524 c	0.083661 a	-0.1224 a
	(3.863)		(1.672)	(3.508)	-(5.052)
SIZE	3.94E-07	1.47E-06 a	8.15E-07 b	-1.96E-08	-1.76E-11

	(1.007)	10.676)	(2.016)	-(1.263)	-(0.001)
CONC	-16433.9	354015.4 a	230233.8	-23916 b	
	-(0.057)	(3.475)	(0.779)	-(2.093)	
KAPIN	-0.0051	-9.01E-04	-0.00286	-2.81E-04	3.73E-04 b
				b	
	-(1.445)	-(0.716)	-(0.784)	-2.003)	(2.286)
EXPORT	3.856889 c	1.621852 b	-1.71031	0.2326177	
				a	
	(1.822)	(2.373)	-(0.783)	(2.808)	
MKT	0.239108 b	0.009994	0.223701 b	0.010224 a	-0.01098 b
	(2.450)	(0.289)	(2.220)	(2.637)	-(2.624)
FINDEM	2.14217 b	0.287315	1.202592	0.034235	
	(2.275)	(0.913)	(1.237)	(0.915)	
PAT	-1.33728	0.033423	-1.5481 c	-0.02242	
	-(1.512)	(0.106)	-(1.695)	-(0.638)	
CASH	3.798558	1.320241	0.232054	0.229297 b	-0.25954 b
	(1.393)	(1.360)	(0.082)	(2.115)	-(2.067)
EMBODIED					5.76E-04 c
					(1.711)

t-statistics in brackets. Significance levels are: a) 1%, b) 5%, c) 10%

4.1. The emergence of different technological regimes

Using OLS, in the first three equations the association between the variables illustrated above and the average number of new products (prod), new processes related to existing goods (PROCOLD), and new processes developed for the introduction of new products (PROCNEW) have been estimated.

Since the absolute number of product and process innovation measured by prod, PROCOLD and PROCNEW are influenced also by the sectoral average firm size, a further regression has been run in order to identify the determinants of the share of new products on the total number of innovations (PRODSH). The latter can be considered a more strict proxy of the propensity to innovate in products with respect to processes.

The results of the four regressions, shown in Table 1, confirm patterns emerged from other studies, in both the cases of new products and new processes related to existing goods. The most interesting result, however, is that the average number of new processes related to product innovations introduced in an industry (PROCNEW) is not significantly associated with any of the variables that explain either product or the other process innovations, as it is apparent from the poor measure of fit of regression 3. Process innovation introduced to allow product innovation, thus, seems to be something different from that aimed at the improvement of the production processes of existing goods.

Two different patterns emerge from the outcome of the regressions 1, 2 and 4. As expected, in mature concentrated industries, where economies of scale are important, firm R&D activities mainly aim to introduce new processes.

Both R&D activity and inputs to the innovative process coming from final users external to the firm are strongly associated with the introduction of new goods. In industries in which product innovation is an important instrument of competition, the share of resources devoted to marketing in the overall innovative costs of the firms is higher. The final destination of the new products is usually the household sector, although FINDEM is not significant in regression 4.

Firms in sectors with a higher degree of internationalisation are more likely to respond to competitive pressure by introducing both product and process innovation. As regression 4 shows, moreover, foreign competition seems to stimulate product innovation to a much greater extent. Caution must be used, however, in the interpretation of this result, because OLS estimation neglects the existence of simultaneity between innovative activity and trade.

The percentage of innovations patented, pat, is not significant in any regression. Two considerations can explain this unexpected result. First, appropriability through patents tends to affect the outcome of innovative activity only indirectly, influencing the input devoted to innovation. In the Italian case, moreover, the variable pat is strongly associated with the average size of the firms, which is not significantly correlated with product innovation.

Although it always has the expected sign, the measure of cash flow adopted is never significant as a determinant of any type of innovation, although it is associated, as expected, with a higher share of product innovation (regression 4).

4.2. Embodied and disembodied technology as determinants of product and process innovation

Although a fairly good picture of sectoral characteristics associated with product and cost-cutting process innovation emerges from the outcome of regressions 1, 2 and 4, the introduction of new processes related to new products (PROCNEW) does not seem to be linked to the variables that influence the other types of innovation. How should we interpret this result?

In order to answer this question we must understand the nature of the new processes functionally linked to product innovation. By definition, PROCNEW is associated with product innovation. The poor results of regression 3, however, show that PROCNEW is not just a mere consequence of the introduction of new goods (otherwise it would be associated with the same sectoral characteristics as product innovation). This means that the innovative patterns associated with product innovation are not homogeneous across industries.

In some sectors new goods are mainly introduced by adapting existing production facilities, whilst in others it is necessary to set up completely new lines of production. In the latter case, therefore, a large amount of the overall innovative cost is bound to be devoted to investment in embodied technology, whilst in the former sectors the role of disembodied inputs to technical change, such as R&D activity and user-producer relationships, is prevalent. The composition of innovative inputs between embodied and disembodied technology could therefore be associated with different patterns of product innovation.

In order to verify this hypothesis a further equation has been estimated. A new dependent variable measuring the level of complementarity and interdependence between product and process innovations has been created. PROCPROD, constituted by the share of process innovation related to new products on the total number of innovations related to new products (products plus processes needed to introduce new goods) assumes high values in sectors where the introduction of product innovation is associated with a high value of PROCNEW.

Disembodied technology, represented by R&D and user-producer linkages, is assumed to be more important when existing facilities can be adapted in order to produce new goods. When entirely new production processes are needed, on the contrary, the importance of investment in new facilities (embodied technology) becomes more relevant than R&D. The importance of embodied technology is represented by the new variable embodied, a ratio whose numerator is the percentage of the innovative investment on the total innovation cost, and whose denominator is the percentage of R&D expenditure on the total innovation cost (as we saw above, the data collected by the CNR-ISTAT survey splits the total cost of innovation into four categories: R&D, marketing, innovative investment, and design and engineering).

In industries with a high level of capital intensity the introduction of new products is bound to involve a large amount of investment in embodied technology, therefore PROCPROD is expected to have a positive relationship with KAPIN. When the bulk of the innovation cost is represented by the investment in production facilities, in addition, the weight of the expenditure for marketing should also decrease. The variable cash has also been included in the equation to check whether a larger amount of investment needs to be financed by internal capital.

The fifth equation estimated is:

$$\text{PROCPROD} = \theta_0 + \theta_1 \cdot \text{USERS} + \theta_2 \cdot \text{EMBODIED} + \theta_3 \cdot \text{CASH} + \theta_4 \cdot \text{SIZE} + \theta_5 \cdot \text{MKT} + \theta_6 \cdot \text{KAPIN}\,.$$

The results support the view that the innovative patterns associated with the introduction of product innovation are not homogeneous. In particular it is possible to identify two additional innovative patterns related to the embodied or disembodied nature of innovative activities. The variables that discriminate between embodied and disembodied technological inputs to innovation (KAPIN, EMBODIED and USERS) are all significant with the expected signs. The negative signs of CASH and MKT suggest that product innovations that require a greater degree of disembodied technological input are more risky, and therefore need a greater amount of internal financing and marketing effort.

5. Conclusions

This paper offers a number of hints on the sectoral determinants of product and process innovation. The "innovation" introduced in this study is that, in order to investigate the links between the introduction of new products and new processes, innovation has been classified under three headings: "products", "new processes related to old products", and "new processes related to new products". Each type of innovation has been found to be associated with different determinants.

Three different patterns can be identified:
i) Disembodied technology, in the form of R&D expenditure and user-producer linkages, is more important to explain the introduction of new goods.

ii) Large scale production and concentrated market structure are mainly associated with cost-cutting process innovation.

iii) Product innovation, however, is not homogeneous. Whilst in some sectors R&D activity allows firms to introduce new lines of business by adapting existing production facilities, in capital intensive industries, where the systems of production are usually more complex, product innovation is associated with the introduction of completely new processes that require a significant investment in embodied technology.

This paper is the first step towards a more in-depth analysis of the dynamics of innovation. Further research is needed to investigate the following issues:

a) In our analysis, intra-industry variability has been neglected, and some studies have shown that it is considerable (Levin, Klevorick, Nelson and Winter, 1987). Some of the inter-industry variability existing at the industry level, thus, could be better explained by variables that act at the firm level (Cohen and Klepper, 1992).

b) Variables like appropriability and internal financing of innovation affect the number of innovations introduced only through their influence on the resources devoted to innovative activity (Levin, Cohen and Mowery, 1985; Von Hippel, 1987). The relationship between input and output of innovative activity, thus, must be analysed in more detail.

c) The existence of two way links between some of the dependent and explanatory variables, as, for instance, in the case of number of innovations and share of exports, should be controlled for using a simultaneous equations model (Hughes, 1986; Lunn, 1987; Kraft, 1990).

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University of Sussex. The authors wish to thank all SPRU's members for comments on the paper, and Aldo Del Santo of ISTAT for support regarding access to and elaboration of the data.

1 Data on the firms included in the survey are not consolidated and do not provide information concerning the national or foreign ownership of the firms.

2 The adoption of the distinction between product and process innovation at the firm level for an analysis at the industry level is justified by the fact that we aim to study how sectoral characteristics influence the type of innovation introduced by the firm.

3 Although we make this distinction for theoretical clarity, these two factors are not necessarily independent from each other. In fact, a number of empirical studies carried out in the majority industrialised countries (with the very significant exception of Japan) have shown that the share of product innovations is nearly twice as much as that of process innovations. The overall sectoral level of innovative activity, therefore, is bound to be associated with the propensity to innovate in products.

4 It must be considered, however, that the association between export share of an industry and its innovative output can also be explained by an inverse causal link, i.e. the high share of exports of firms in an industry can be explained by the higher level of innovative activity of the firms in that industry (Hughes, 1986).

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Throughout the 1990s, The Open University has been developing its research capacity in economics. Economists at the OU comprise a lively and expanding group with a wide set of interests ranging from development policy to decision theory, from Marxist theories of profit to libertarian foundations of environmental policy and from econometric analysis of large data sets through institutional economics to the use of case-studies in policy formation. Nearly a 1000 students from around the world register each year to study economics courses and their needs, together with the multi-disciplinary nature of social science at the university, shape out research. Through a variety of personal and group research projects, our work makes a strong contribution to areas like business, public policy and even philosophy where sharply focused analysis can inform decision-making as well as contribute to scientific progress.

In 1999, approximately £250,000 million worth of externally funded grants (3 from the ESRC) were held by discipline members, some of whom also act as consultants to national and international bodies. Approximately half a dozen students are currently reading for doctorates with members of the discipline and we are always interested in proposals from colleagues or potential students who would like to do research with us.

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