DETERMINANTS OF THE INNOVATION PROCESS

An Empirical Test for the Portuguese Manufacturing Industry

CARLA SUSANA MARQUES AND JOSÉ MONTEIRO-BARATA

ABSTRACT: The aim of this paper is to analyze the determinants of the main phases of the innovation process in Portuguese manufacturing firms. The analysis will adopt as its main frame of reference an interactive model of the innovation process, on which empirical tests will be carried out, making use of tobit and probit models and simultaneous equation systems. It is broadly concluded that the relationships shown between the main variables that are typical of the innovation process in the context of Portuguese manufacturing firms are tenuous and unsystematic.

RESUMEN: El objetivo de este artículo es analizar los determinantes de las fases principales del proceso de la innovación en empresas manufactureras portuguesas. El análisis adoptará como referencia principal un modelo interactivo del proceso de la innovación, en el cual los ensayos empíricos serán realizados, haciendo uso de los modelos tobit y probit y sistemas de ecuaciones simultáneas. Se concluye genéricamente que las relaciones demostradas entre las variables principales que son típicas del proceso de la innovación, en el contexto de empresas industriales portuguesas, son tenues y poco sistemáticas.

The central core of this paper is related to the notion of "innovation as a process"—a notion that is clearly recognized in the literature relating to the innovation field and acts as a benchmark for innovation management practices at firms (see, among others, Crépon, Duguet, & Mairesse, 1998; Kline & Rosenberg, 1986; Rothwell, 1992). Recently, Adams, Bessant, and Phelps (2006) affirmed that the measurement of the process of innovation is critical for both practitioners and academics.

The main aim of this paper is to analyze the determinants of the main phases of the innovation process—inputs of innovation and outputs of innovation—and the possible interactions between the phases of the innovation process in the context of Portuguese manufacturing firms.

The analysis will adopt as its main frame of reference a generic interactive model of the innovation process, on which empirical tests will be carried out, making use of tobit and probit models and simultaneous equation systems.

The data to be used will be related, in an integrated manner, to the innovation dynamics and the economic and financial performance of a panel of Portuguese manufacturing firms (573 firms). The data on innovation are drawn from the *Community Innovation Survey II* (*CIS II;* Portugal, 1995–97), and the economic and financial data are drawn from the database of the Bank of Portugal.

The specific contribution of this paper is therefore to model and specify the phases of the innovation process in econometric terms, estimate the respective parameters, and establish a critical assessment of the results.

INNOVATION AS A "PROCESS"

As the fundamental dynamic of the new paradigm for the competitiveness of firms and nations, innovation must be considered as a "process," thus counteracting the view of innovation as a static or epiphenomenal event. The analysis of

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innovation has made great progress with this type of increasingly dynamic and global approach. It is considered important "not to treat primarily innovations as single events [but, on the contrary] using terms such as 'the process of innovation' or 'innovative activities'" (Lundval, 1988: 350).

The general aim of this chapter is to present some concepts and models of innovation that make it possible to consider the increasingly closer link between innovation strategies and the competitiveness of firms. To this end, some fundamental concepts of innovation and technological development are presented, followed by a selection of two models for considering the phenomenon of innovation as a "process."

Innovation and Technological Development: Fundamental Concepts

In the field of "innovation and technological development," an area in which there is a great proliferation of concepts, it is important to clarify the meaning of some fundamental concepts—namely, those relating to R&D (input) and innovation (output). In this paper, we follow, in particular, the definitions of international organizations, most notably the guidelines of the *Frascati Manual* (OECD, 1981) and the *Oslo Manual* (OECD, 1992) (see Monteiro-Barata, 1992).

R&D, which includes basic research, applied research, and experimental development, is designed to increase or correct the stock of knowledge of humankind.

The definition of what "innovation" is immediately results in a series of important questions that can have different answers depending on the available indicators and the proposed aims. Most definitions associate the concept with the technological aspects of the introduction of new (or better) products or processes. However, other more general interpretations have commonly been developed, including, for example, any organizational and managerial changes that may have taken place, thus going far beyond the more limited analysis normally made at the level of equipment, systems, and devices.

The greater or lesser effect of innovations on the economic structure depends on the intensity with which they are disseminated among potential users—"innovation diffusion." It is this long-term cumulative process that, in conjunction with economic, social, political, institutional, and cultural changes—allows for the development of concepts such as "technological systems" and "techno-economic paradigms."

Two major areas of innovation (output) will be considered in this paper—innovation in "products" and innovation in "processes."

A product is regarded as technologically innovative when it displays a substantial difference in materials or components used in relation to similar products manufactured beforehand, or is designed for new uses. Innovation may refer to a new product, which is an entirely new product (radical innovation), or improvements to a product (incremental innovation)—that is, intervention in parts or components that modify their functioning or performance. Products that are considered innovative may be so at a world level, at a national level, at a branch level, or merely at the firm level and, as a rule, provide access to new markets.

A process is regarded as technologically innovative when it is used either for the production of new or improved products that could not be produced through conventional means or for the manufacture of products that were previously made by the firm but now use new techniques or the same techniques performed in a more effective manner. Here, one should also make a distinction between "new" and "improved" processes.

All these different specifications of innovation, its dynamic, economic, and social impact (radical versus incremental innovation), and the difficulties of the empirical approach point to the complexity of the phenomenon in question. Thus, the conceptual and methodological difficulties that arise would seem evident when one endeavors to carry out empirical studies on innovation, calling for sources of information that reflect this diversity.

With the purpose of simplifying these studies, the OECD drew up the *Oslo Manual* (OECD, 1992), which, similar to the *Frascati Manual,* specified for R&D activities, standardizes and systematizes the gathering of information on the different aspects of the innovation process in different countries.

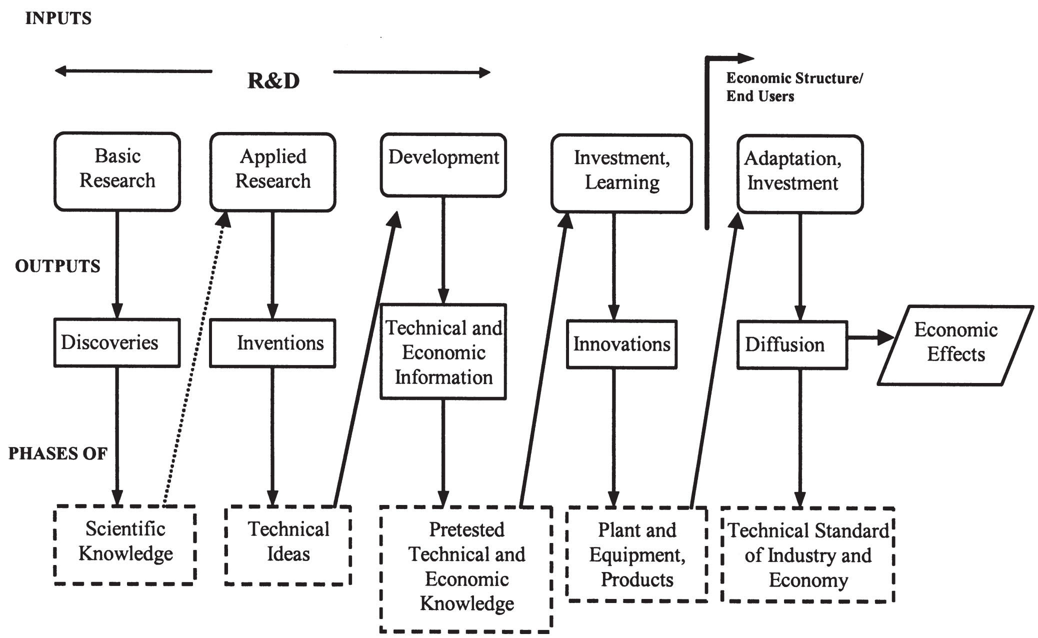
Moreover, through its Eurostat and General Directorate XIIII (DGXIII) services, the European Commission has played an important role, complementary to that of the OECD, in the development of the new type of statistics in the context of the European Innovation Monitoring System (EIMS). The launch of the Community Innovation Surveys (CIS) fits into the framework of this same effort.

One should also add that innovation—seen as a process—consists of a series of steps of a scientific, technical, commercial, and financial nature. Therefore, "R&D is just one of these steps" (OECD, 1981: 132–133), and it is R&D activities and non-R&D activities that together form innovative activities. Non-R&D activities consist of design, engineering, tests, financing, marketing, the acquisition of nonincorporated technology (patents, technological know-how, etc.), and the acquisition of incorporated technology (machinery, equipment, etc.). Therefore, these are central aspects within the study of the process of innovation.

The Innovation Process: Two Different Perspectives

With the aim of linking together the concepts presented above and, in particular, seeking to explain the transformation of "ideas" into new products and production processes, there now follows a brief look at some models for explaining innova-

FIGURE 1
Stage Model of Technological Change



Source: Adapted from Rosegger (1986: 9).

tion, in which innovation is viewed as a process. The first model analyzes the process of technological change as a process occurring in distinct phases—the "linear model of innovation" (Rosegger, 1986: 9) (Figure 1) .

This model—offering the classical view of technological change—presupposes a series of activities—among which the most important is R&D—that produce certain results (outputs). In turn, through the information that they produce, these results will affect the subsequent phases or stages in a sequential and linear fashion. Each specific combination of activity (input)–result (output) defines a "phase" or "stage." Overall, the process in question is characterized by the attempt to reduce the uncertainty about the technical and commercial characteristics of ideas through technical and market research undertaken by the different agents involved. Although it is elucidative and pedagogical, the model in question has several important limitations (Rosegger, 1986: 10):

1. Its division into phases is somewhat arbitrary, given that the process is evolutionary and continuous.
2. The model is unidirectional and does not take into account the numerous and complicated loopings, feedbacks, and various overlaps that exist.
3. The model seems to provide a fairly good description of the evolution of "radical innovations," but a less adequate one of "incremental innovations." However, it is these later innovations that sustain the daily life of firms.

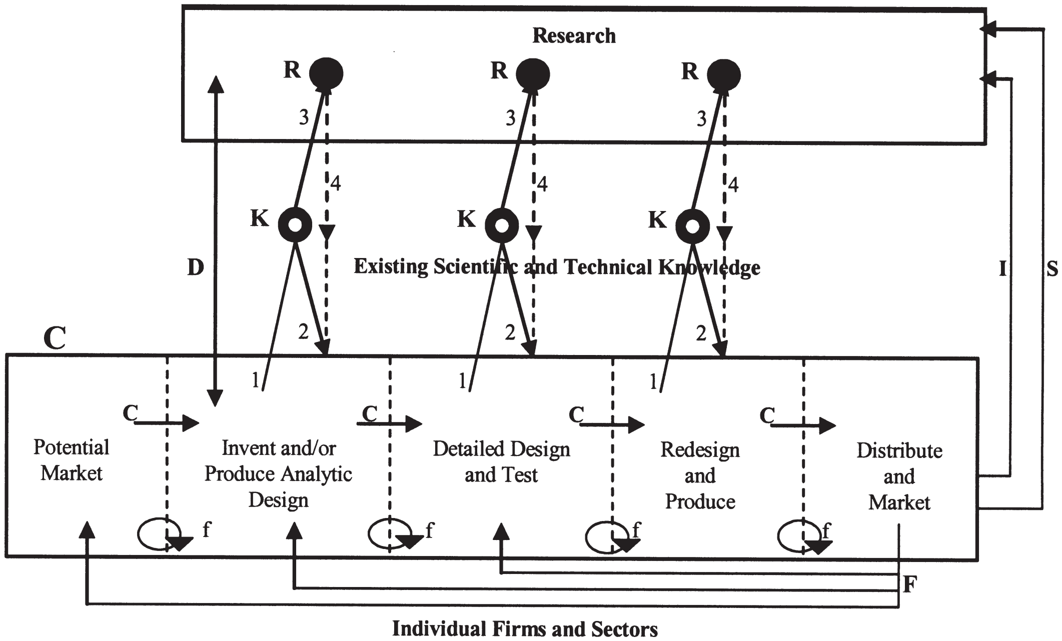
Currently, the phenomenon of innovation is seen, above all, as a nonsequential "process" that involves countless continuous interactions and feedbacks. A different representation from the previous one, which highlights the interactive nature of the innovation process, is shown in Figure 2. This is the "chain-linked model" of innovation developed by Kline and Rosenberg (1986; see also OECD, 1990).

Beginning with the links between market opportunities, the existing scientific and technical knowledge, and the capacities of firms, the model combines two different types of interaction: the first has to do with the processes that are internal to the firm (or to firms organized in a network)—the "value chain"; the second has to do with the relationship that is established between the firm and the global system of science and technology.

Relations inside the firm are represented by the horizontal flows in the lower block—"central chain of innovation" (C). The process begins with the perception of a market opportunity or the emergence of new scientific or technological data, followed by the analytical conception of new products and processes, development, production, distribution, and marketing. Two types of feedback are envisaged—continuous and systemic links between the various phases and those immediately before them (short feedback loops) and links between the market and the phases upstream (long feedback loops). According to Kline and Rosenberg (1986), the emphasis laid on the conception and engineering of products and processes has a historical justification, corresponding to the basically incremental and cumulative nature of the innovation process.

The second type of interaction is established between the block relating to the innovation process at the firm and, on

FIGURE 2
Chain-Linked Model of Innovation



Source: Adapted from Kline and Rosenberg (quoted in OECD, 1990: 12).
Notes: C: central chain of innovation; f: feedback loops; F: particularly important feedback. Vertical links: K–R: links through knowledge to research and return paths. If problem is solved at node K, link 3 to R is not activated. Return from research (link 4) is problematic, therefore, the dashed line. D: direct link to and from research from problems in invention and design. I: contribution from manufacturing sector (instruments, machine tools). S: financial support of research by firms.

one hand, the existing "scientific and technological knowledge base" (K) and, on the other hand, research (R) (see Figure 2). Two levels can therefore be distinguished: the level of "existing/available knowledge" (K) and the level of activities that increase or correct the existing stock of knowledge (R). When confronted with certain technical problems in the course of the innovation process, engineers and technologists resort first to the existing stock of knowledge (intramural or outside the firm). It is only when these attempts show themselves to be fruitless for obtaining the desired information that the decision is taken to fund new research (intramural or outside the firm). This explains why, in the forms of already existing knowledge (K) or new research (R), science and technology are placed at the service of the innovative activities of firms, being called upon whenever necessary and at any time. In particular, this conception sees research as an activity that accompanies the innovation process and not as a precondition thereof. These relations established with research throughout the "central chain of innovation" are illustrated by the links "D" and "K–R" (see Figure 2). This model therefore proposes a very distinct perspective from the one that underlies the "linear model," in which activities are organized in a predetermined sequential form in order to provide "innovation."

Innovation Process: A Synthesis

Over the past few decades, our thinking about science, technology, and innovation has been accompanied by the linear conception of the research–development–production–market–type (Rothwell, 1992). Until the mid-1960s, the dominant perception of the innovation process consisted of a pure form of linear technology–push innovation, with it being assumed that there was a continuous progression from scientific discovery to the appearance of new products and processes on the market (first generation). In the second half of the 1960s, as a result of greater research, more importance began to be attached to the role of the market in the innovation process. This fact led to the emergence of a linear demand–pull (second generation) conception of innovation (Freeman, 1982).

During the 1970s, the most systematic study of the phenomenon—namely, about the success factors of innovation—showed that the earlier conceptions of innovation, when taken individually, were only extreme simplifications and particular cases of a more general process of confluence/coupling between science, technology, and market (third generation). In this conception of innovation, there remains essentially a sequential understanding of the innovation process.

Only in the course of the 1980s—namely, with the greater study of the development process of new products by Japanese firms—were the first truly integrated models produced. The "chain-linked" innovation model is just one example of this. The integrated models of the innovation process (fourth generation) (Rothwell, 1992) are characterized not only by their interfunctional integration but also by their ever greater integration with the scientific and technological system and by their vertical and horizontal integration with other firms (suppliers, clients, competitors). The idealized development of this fourth-generation integrated model—the "fifth-generation" model for the 1990s and for the beginning of the present century—will be characterized by the existence of systems integration and networking (SIN) (Rothwell, 1992). This presupposes a fully integrated parallel development: links with clients, strategic integration with suppliers, strategies based on time and an emphasis on flexibility, quality, and other extra-price factors. The strategies of access to complementary assets (Teece, 1987) and the implementation of interorganizational information systems will be valuable supports for this new conception of the innovation process. This last vision provided an agenda for a larger "opening" up of the innovation process. Various perspectives of opening up the innovation process include globalization of innovation, early supplier integration, user innovation, external commercialization, and application of technology. Globalization favors open innovation models (Gassmann, 2006).

In keeping with the evolution of innovation models, three general characteristics of successful innovation processes have gradually begun to assume greater importance—the multifaceted nature of success, the universalization of success factors, and the fundamental role played by people in this process.

DETERMINANTS OF THE INNOVATION PROCESS: MODEL OF ANALYSIS, HYPOTHESES, AND VARIABLES

With a view to the development of empirical tests, an explicit description will now be provided of the model of innovation adopted and working hypotheses, databases, and variables. With such an aim in mind, a research model is proposed that will make it possible to (1) identify the determinants of the main phases of the overall innovation process (innovation inputs and innovation outputs) and (2) analyze the relationship between the different phases in this process.

This paper distinguishes three main blocks of variables—the variables of innovation input, throughput (the specific process of transforming inputs into outputs), and innovation output.

The literature—for example, the model of Kline and Rosenberg (1986), which was analyzed earlier—establishes innovation processes consisting of at least four phases:

- First phase: Deciding upon the act of innovating, with several aspects influencing this decision.
- Second phase: Establishing the level of inputs. With the decision to innovate, the level of innovation input (the innovation effort) is influenced.
- Third phase: Obtaining the direct innovation outputs. In this phase, the innovation output (products and processes) is analyzed, with this frequently being determined by the innovation input.

  Between the second phase and the third phase, the innovation inputs are "transformed" into outputs, or, in other words, the *throughput process* takes place (Kemp, Folkeringa, Jong, & Wubben, 2003; Klomp & van Leeuwen, 1999; Lööf, Heshmati, Asplund, & Naas, 2001).
- Fourth phase: Finally, the firm's economic and financial performance is analyzed, representing an immediate result of the innovation output.

The typical variables of the throughput process are those that, broadly speaking, relate to "innovation management"—namely, the definition of an innovation strategy, the linking together of the technological strategy and the business strategy, the creation of an internal climate that is favorable to innovation, technological cooperation with entities outside the firm, marketing, funding, and so on. They are, in sum, typically "variables of context."

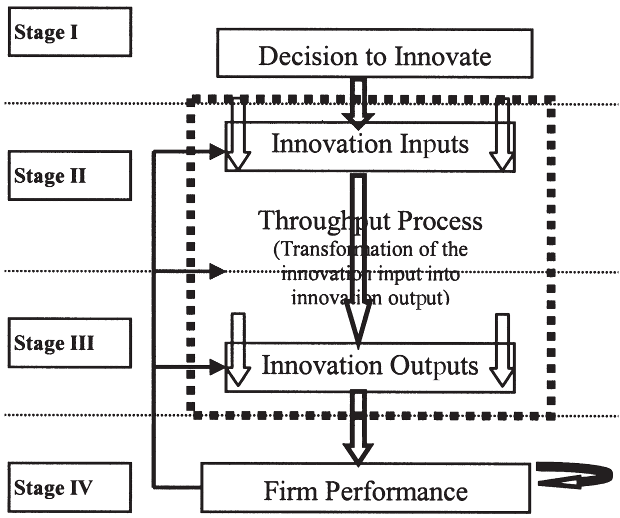
The proposed research model can be seen in Figure 3. Stage I will not be examined in this paper. Positive correlations are expected between all of the model's components.

The innovation process includes various feedbacks. Innovation output may affect the level of investment in innovation (R&D, for example). The firm's economic and financial performance can influence all the earlier phases of the innovation process. As a result of this interconnection, the innovation process must be tested globally and simultaneously through the application of appropriate econometric methods, such as simultaneous equation regression. The philosophy underlying the construction of the CIS—which provides the panel database on innovation that is to be used—is based on this research model (see Kemp et al., 2003).

This model will be used to identify the variables influencing each of the phases of the process and, succinctly, to check if there is a feedback relationship between the different phases. The research will be centered upon the Portuguese manufacturing industry (sectors of Classificação das Activadades Económicas [CAE; Portuguese Industrial Classification] Rev. 2, 15–37; see the Appendix) using the data from CIS II. In this context, the two main hypotheses to be tested are:

Hypothesis 1: The input phase is influenced by the determinants of the throughput process, the determinants of output, and the firm's economic and financial performance.

FIGURE 3
Overall Research Model



Hypothesis 2: The output phase is influenced by the determinants of input, the determinants of the throughput process, and the firm's economic and financial performance.

The prior identification of the variables related to each phase of the innovation process (innovation input, innovation output, throughput, and the firm's economic and financial performance) made use of factor analysis. The method used for extracting the factors followed the eigenvalue greater than 1 rule, and all the variables with a factor weight of less than 0.5, in absolute values, were removed from the analysis. Table 1 presents the four blocks of identified variables.

Two variables were selected for measuring the innovation (input) effort: *percentage of R&D in relation to sales* and *total investment in innovation*. The variable relating to human resources (*HR_RD*) was removed from the analysis because of the lack of a sufficient number of observations for later statistical treatment.

The following variables were retained for measuring the throughput process: *innovation strategy*, *use of subsidies*, *market studies,* and *assessment of client satisfaction.* Also included were the variables of cooperation, distinguishing between cooperation with other companies, technological institutes, and educational institutions/universities.

The main variable used for measuring innovation output was *percentage of sales resulting from new products.* Based on CIS II, a distinction can be drawn between those firms that undertook product innovation and those that undertook process innovation. It was decided that these two variables should also be used as variables for measuring innovation output.

Sales, *evolution of sales*, *profits*, *evolution of profits*, and *evolution of exports,* as well as the *operating profit ratio (OPR)* and the *return on investment (ROI)* are variables that will be used to measure the firm's performance.

The variable most commonly used for measuring the innovation effort (input) is *investment in R&D in relation to sales (%)* (Klomp & van Leeuwen, 1999; Lev & Sougiannis, 1996; Lööf et al., 2001; Rogers, 1998). Other studies conclude that the variable that best represents the innovation effort is *total investment in innovation* (Kemp et al., 2003; Kleinknecht, 2000; Lööf et al., 2001; Vossen & Nooteboom, 1996). These two variables will therefore be the dependent variables that will be used in the empirical tests concerning the determinants of innovation inputs.

The variable *percentage of new products in total sales* is one of the variables most commonly used for measuring output (see, among others, Grinstein & Goldman, 2006; Kemp et al., 2003; Vossen & Nooteboom, 1996). Variables relating to the undertaking of product and process innovation will also be tested.

Various studies (Kemp et al., 2003; Kleinknecht & Mohnen, 2002; Klomp & van Leeuwen, 1999) show that firms that innovate have higher growth rates in terms of sales and profits. It was therefore considered that the variable *growth of sales* is the one that best reflects the performance of firms.

It is this model, together with the variables, hypotheses, and respective tests, that will form the basis for the empirical analysis of this paper.

DETERMINANTS OF INNOVATION INPUTS AND OUTPUTS: AN EMPIRICAL TEST FOR THE PORTUGUESE MANUFACTURING FIRMS

First, the empirical analysis to be undertaken will define the main determinants of both innovation inputs (the innovation effort) and innovation outputs (the results of innovation dynamics). Second, an analysis will be undertaken of the integrated and interactive relationship between inputs, outputs, and economic and financial performance. The presentation and discussion of the econometric tests carried out will go along with the empirical analysis undertaken.

General Characterization of the Firms Making Up the Panel

CIS II records 820 observations for the Portuguese manufacturing industry (CAE sectors 15–37). Of these, 247 firms were not included in the panel under study due to the impossibility of establishing an unequivocal match between the respective data on innovation, provided by *CIS II,* and the corresponding accounting data, provided by the Bank of Portugal (a data match problem). The final panel under study consists of 573 firms, or, in other words, 70 percent of the

TABLE 1
Variables of the Innovation Process and Their Characteristics

Variables	Description	Scale	Operationalization
Input			
INVT_INNOV	Total investment in innovation	Interval	
RD_SALES	Percent of R&D in relation to sales	Interval	
HR_RD	Percent of personnel involved in R&D	Interval	
Throughput			
INNOV_STRAT	Innovation strategy	Dichotomous	0 = no 1 = yes
MARKETING	Market studies	Dichotomous	0 = no 1 = yes
SATISF	Assessment of client satisfaction	Dichotomous	0 = no 1 = yes
COOPINSTEC	Cooperation with technological institutes	Dichotomous	0 = no 1 = yes
COOPUNIV	Cooperation with educational institutions/universities	Dichotomous	0 = no 1 = yes
COOPFIRM	Cooperation with other firms	Dichotomous	0 = no 1 = yes
SUBD	Use of subsidies	Dichotomous	0 = without subsidy 1 = with subsidy
Output			
INNOV_PROC	Process innovation	Dichotomous	0 = no 1 = yes
INNOV_PROD	Product innovation	Dichotomous	0 = no 1 = yes
NEW_PROD	Percent of sales resulting from new products	Interval	
Performance			
PROFIT95_97	Evolution of profit rates 1995–97	Ordinal	–1 = decreased 0 = remained the same 1 = increased
PROFIT97	Profits in 1997	Dichotomous	0 = without profit 1 = with profit
ROI95_97	Evolution of the return on investment (ROI) 1995–97	Ordinal	–1 = decreased 0 = remained the same 1 = increased
OPR95_97	Evolution of the operating profit ratio (OPR) 1995–97	Ordinal	–1 = decreased 0 = remained the same 1 = increased
EXPORT95_97	Evolution of exports 1995–97	Interval	
SALES95_97	Evolution of sales 1995–97	Interval	
SALES97	Sales in 1997	Interval	
Size			
SIZE1	Dummy variable of size 1	Dichotomous	1 = the firm has 0–49 workers 0 = does not have
SIZE2	Dummy variable of size 2	Dichotomous	1 = the firm has 50–250 workers 0 = does not have
SIZE3	Dummy variable of size 3	Dichotomous	1 = the firm has +250 workers 0 = does not have

observations of CIS II. The research period included the years from 1995 to 1997.

We began by analyzing the observations of the panel under study, taking into account the dichotomous innovation variable of *innovative/noninnovative firms.* Of the firms in the study, 36.5 percent were found to be innovative.

As far as the distribution of firms by size is concerned, the data show that 28.6 percent of firms are small enterprises, 37.5 percent are medium-sized enterprises, and 33.9 percent are large companies, with the innovation rate increasing in accordance with the size of firms.

If we now analyze innovation from a sectorial point of view, it can be seen that the sectors that most contribute to innovation are rubber, with 76.9 percent of innovative firms; electrical and optical equipment, with 73.7 percent; chemicals, with 66.7 percent; and machinery and equipment with 60.9 percent. In contrast, one finds that the *traditional* sectors have the lowest percentages of innovative firms: leather and leather products (13.2 percent); wood, cork, and their products (26.3 percent); other manufacturing industries (27.6 percent); textiles and clothing (29.4 percent); and nonmetallic minerals (29.8 percent).

Determinants of Innovation Inputs

The first part of the empirical analysis is designed to identify the determinants of innovation inputs. This calls for an explanation of the innovation effort that is represented here by both *percentage of investment in R&D in relation to sales* and *total investment in innovation*. The variables of the throughput process, innovation outputs and performance—including the dummy variables of size—are used as explanatory variables in the innovation effort equation. The innovation input equations will be estimated with tobit models, given that some of the firms in the sample have an innovation input value of zero (Franses & Paap, 2001; Greene, 2000). In fact, estimating the model through a regression of the linear type by using the ordinary least squares (OLS) method would lead to biased estimates. For this reason, the tobit model was chosen as the preferable method for modeling such a dependent variable.

The results obtained with the estimation of the tobit models are presented in Table 2. All the estimations presented in this section were made with the use of the STATA econometric software. For each explanatory variable, its estimated coefficient is shown, together with the respective marginal effect of its variation on the observed dependent variable. The *t*-statistic is also presented.

Three tobit models were estimated for each of the two input innovation variables: (1) a tobit model with all the explanatory variables mentioned earlier (equations 1 and 4); (2) a tobit model with all the explanatory variables, including qualitative (dummy) variables to control the effect of firm size (equations 2 and 5); and (3) a tobit model, in which only those firms presenting sales of new products are included (equations 3 and 6). Now that the variables under analysis have been explained, only the statistically significant results will be presented (Table 2).

In order to choose from among the alternative modelings the one that best describes the determinants of innovation input, Akaike's information criterion is used (Johnston & DiNardo, 2001: 81), and, in order to assess the quality of the adjustment, the likelihood ratio test is used, because it is not possible, in this case, to obtain the measurement of the quality of the adjustment R^2 (Greene, 2000: 831). Robust covariances were also used to control heteroskedasticity, due, in particular, to the cross-sectional nature of the data (Peña & Yohai, 1999; Yohai, 1997).

Through an analysis of Table 2, it can be seen that the variable *innovation strategy* is statistically significant (at a 1 percent level of significance) in four of the six estimated regressions and that their estimated coefficients have the expected sign, which makes it possible to state that the firms that include innovative activities in their business strategies effectively invest more in innovation. This innovation strategy has a significant and positive effect on innovation inputs. In contrast, undertaking market studies (*MARKETING*) or being closer to clients—analyzing perceived quality (*SATISF*)—did not appear to have any significant impact on the innovation effort. Cooperation with other firms (*COOPFIRM*) and technological institutes (*COOPINSTEC*) similarly did not have any positive effect on innovation inputs in any of the six regressions presented in Table 2.

The variable relating to *profits in 1997* (*PROFIT97*) is shown to be statistically significant at a 1 percent level of significance in two regressions relating to *percentage of investment in R&D in relation to sales* (*RD_SALES*), with its coefficient having the expected sign.

The variable of innovation output (*percentage of sales resulting from new products*; *NEW_PROD*) and that of performance (*growth of sales*; *SALES95_97*) are always seen to be statistically significant, and the signs of their coefficients are as expected, amounting to determinants of the innovation input. The variable *sales* (*SALES97*) has opposite signs from the ones that would normally be expected.

It should be noted that the variable *cooperation with educational institutions/universities* (*COOPUNIV*) is only statistically significant in model 3 (Table 2) and is in accordance with the expected sign.

It is interesting to note that the variable *use of subsidies* (*SUBD*) is significant in the three models relating to investment in R&D, but not significant in any of the three models relating to total investment in innovation. In fact, in Portugal, the subsidies given to innovative activities have tended to be awarded mainly in the form of support for R&D activities, for example, at the level of industrial development programs (*PEDIP*).

Based on the results of equations 2 and 5 of Table 2, it may be concluded that size does not influence the relationship between the various defined explanatory variables and innovation inputs. A similar result was obtained by Lööf et al. (2001) in their study for Sweden.

TABLE 2
Determinants of Innovation Input (Tobit Model)

Independent variables	Total investment in innovation (*INVT_INNOV*)			Investment in R&D/sales (percent) (*RD_SALES*)		
	Tobit (1)	Tobit[1] (2)	Tobit[2] (3)	Tobit (4)	Tobit[1] (5)	Tobit[2] (6)
INNOV_STRAT	0.13**	0.13**	—	0.07**	0.07**	—
(Strategy)	[0.10]	[0.10]		[0.05]	[0.05]	
	(4.14)	(4.06)		(2.93)	(2.93)	
COOPUNIV	—	—	0.03†	—	—	—
(Cooperation with educational			[0.01]			
institutions/universities)			(1.71)			
SUBD	—	—	—	0.02*	0.02*	0.02*
(Subsidies)				[0.01]	[0.01]	[0.01]
			(2.43)	(2.42)	(2.57)	
NEW_PROD	0.04*	0.04†	0.08**	0.03†	0.03†	0.04*
(percent of sales of new products)	[0.02]	[0.02]	[0.07]	[0.01]	[0.01]	[0.03]
	(2.00)	(1.93)	(2.94)	(1.89)	(1.91)	(2.03)
INNOV_PROD	0.03*	0.03*	0.09**	0.02*	0.02*	—
(New products)	[0.02]	[0.02]	[0.08]	[0.02]	[0.02]	
	(2.24)	(2.26)	(2.64)	(2.11)	(2.11)	
PROFIT97	—	—	—	0.03**	0.03**	—
(Profits 1997)				[0.02]	[0.02]	
			(2.96)	(2.99)		
SALES95_97	0.03**	0.03**	—	0.03**	0.03**	—
(Growth of sales)	[0.02]	[0.02]		[0.02]	[0.02]	
	(3.66)	(3.53)		(4.32)	(4.32)	
SALES97	–0.04†	–0.03**	–0.05**	–0.02**	–0.02*	–0.02**
(Sales)	[–0.03]	[–0.03]	[–0.04]	[–0.01]	[–0.01]	[–0.02]
	(–5.36)	(–3.63)	(–4.94)	(–3.17)	(2.63)	(–2.75)
Size						
SIZE1 Small firms		ns			ns	
SIZE2 Medium-sized firms	—	ns	—	—	ns	—
SIZE3 Large firms		ns			ns	
Constant	0.09†	—	—	—	—	—
	(1.96)					
χ^2	85.08	85.81	45.93	69.27	69.47	29.33
Significance	0.00	0.00	0.00	0.00	0.00	0.01
Log-likelihood	219.26	219.63	158.57	219.21	219.31	167.98
Akaike information criterion	–2.30	–2.31	–2.32	2.43	2.45	2.47

Notes: t-statistics are shown in parentheses, and the marginal effects are shown in brackets. [1] *Tobit* model, including dummy variables for size. [2] *Tobit* model, in which the dependent variable is limited to those firms that have sales of new products. ns = not significant. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$.

Bearing in mind the aim of this section—to establish the innovation effort equation—and after analyzing the models presented in Table 2 with the help of Akaike's information criterion, model 1 was chosen as being the most suitable.

In short, H1 is confirmed. The results obtained show that the innovation effort (*total investment in innovation* and *percentage of investment in R&D in relation to sales*) results from typical variables of the throughput process (*innovation strategy, subsidies,* and *cooperation with educational institutions/universities*), innovation output (*percentage of sales resulting from new products* and *product innovation*), and the firm's performance (*profits* and *growth of sales*).

Of the determinants of the innovation input phase identified through model 1, only two of these were also identified in other international studies: continuous innovation as a strategy of the firm (Lööf et al., 2001) and the growth of sales (Klomp & van Leeuwen, 1999). The other determinants were not identified as being significant in any other similar study.

Determinants of Innovation Outputs

Percentage of sales of new or improved products in total sales (*NEW_PROD*) will be used as the innovation output variable (dependent variable). Given that a significant number of the firms in the sample have a value of zero for this variable, it was also decided to make an estimation through the use of a tobit model.

As far as the analysis of other innovation output variables is concerned—*product innovation* (*INNOV_PROD*) and *process innovation* (*INNOV_PROC*)—it was decided that the probit model should be used, given that the tobit method was seen to be unsatisfactory, bearing in mind the results of the application of the likelihood ratio test. This test has the same function as the "*F*-test" in the case of estimations made by the least square method (Greene, 2000: 826).

The coefficients obtained with the estimation of the tobit and probit models for the innovation output variables are those presented in Table 3. Again, in this table, only the statistically significant results are presented.

Beginning with an analysis of the tobit models relating to the dependent variable *percentage of sales resulting from new products* (regressions 1 and 2), it can be seen that this variable has as its only determinant the dynamics of continuous innovation as a fundamental strategy of the firm (*INNOV_STRAT*), with the sign that is expected in both models.

Observing the two probit models for the dependent variable *product innovation* (regressions 3 and 4), it can be seen that, as in the previous case, the introduction of the control variables (size) does not alter the results, and these variables are not statistically significant. *Product innovation* is, fundamentally, influenced positively by *market studies* (*MARKETING*), *sales* (*SALES97*), and *evolution exports* (*EXPORT95_97*).

The last dependent variable observed is *process innovation*. The two probit models presented for this variable show a slightly different behavior. The two models are positively influenced by the *evolution of exports* (*EXPORT95_97*)—as happened in the last case—and *profits* (*PROFIT97*); in the probit model in which the control variables of size were included (regression 6), besides the variable representing *medium-sized firms* (*SIZE2*) being significant, the variable *cooperation with educational institutions/universities* (*COOPUNIV*) also becomes significant and has the expected sign.

Using Akaike's information criterion, the first model was selected for the innovation output equation (model 1 of Table 3), so that innovation output will only be explained by the firm's innovation strategy (continuous innovation dynamics)—a variable of the throughput process. This variable was also considered as a determinant of innovation output in the study by Kemp et al. (2003). Other empirical studies on innovation in Portugal also show the importance of the variables related with the definition of the firm's strategy: possessing a written document on technological strategy, execution of R&D outside the firm, management of talents, and so on (Monteiro-Barata, 2000).

The Overall Relationship at the Level of the Innovation Process

After estimating the equations relating to innovation input (innovation effort) and innovation output, a check will finally be made, in a merely exploratory fashion, of the existence of feedbacks between the different phases of the innovation process. To this end, use will be made of the estimation of a model of simultaneous equations (see Figure 4), using the seemingly unrelated regression (SUR) method as the technique for estimating its parameters, devised by Zellner, 1962 (see also Johnston & DiNardo, 2001: 349). The statistically significant results of the estimation of this method are presented in Table 4.

In analyzing the three equations estimated by the Zellner method, it can be seen that (1) the input (innovation effort) equation is influenced by a variable of the throughput process (*innovation strategy*; *INNOV_STRAT*), an innovation output variable (*NEW_PROD*), and by the firm's performance (positively by the *growth of sales* and negatively by *sales*); (2) the innovation output equation is influenced by innovation input (*total investment in innovation*; *INVT_INNOV*) and by *innovation strategy*; and (3) the equation of the firm's performance (*growth of sales*; *SALES95_97*) is influenced negatively by *process innovation* and positively by *exports*.

It should be stressed that, as a whole, the three equations of the model of simultaneous equations estimated by the SUR method are according to all the determinant factors of each of the phases of the innovation process identified in the previous sections. It should be noted—as would be expected—that an input variable influences the defined output variable. Clearly unexpected is the absence of a positive relationship between the most typical variables of the innovation process (input and output) and performance.

SUMMARY AND CONCLUSIONS

According to the analysis that was undertaken, innovation output and the actual levels of the firm's performance are determinants of innovation input. This result confirms H1. In turn, in a systematic fashion, no direct dependence was detected between the innovation output variables and the innovation input variables (tobit and probit regressions)—which only partially confirms H2. It should, however, be noted that the most significant determinant of both innovation inputs and outputs is the definition and implementation of a strategy of the firm based on "continuous innovation dynamics" (innovation strategy). These results are consistent with the

TABLE 3
Determinants of the Innovation Outputs (Tobit and Probit Models)

	Percent sales of new products (*NEW_PROD*)		Product innovation (*INNOV_PROD*)		Process innovation (*INNOV_PROC*)	
	Tobit (1)	Tobit[1] (2)	Probit (3)	Probit[2] (4)	Probit (5)	Probit[2] (6)
INNOV_STRAT (Strategy)	0.60** [0.35] (3.21)	0.61** [0.35] (3.20)	—	—	—	—
MARKETING (Market studies)	—	—	0.97** [0.30] (2.89)	0.99** [0.31] (2.94)	—	—
COOPUNIV (Cooperation with educational institutions/universities)	—	—	—	—	—	0.93* [0.11] (2.13)
PROFIT95_97 (Growth of profits)	—	—	–0.27* [–0.07] (–2.18)	–0.27* [–0.07] (–2.12)	—	—
PROFIT97 (Profits 1997)	—	—	—	—	0.60* [0.14] (2.09)	0.66* [0.14] (2.23)
EXPORT95_97 (Exports)	—	—	0.77* [0.19] (2.35)	0.75* [0.19] (2.22)	0.75* [0.14] (2.26)	0.73* [0.12] (2.25)
SALES95_97 (Growth of sales)	—	—	—	—	–0.39** [–0.07] (–2.72)	–0.41** [–0.07] (–2.71)
SALES (Sales)	—	—	0.45** [0.11] (2.74)	0.36† [0.09] (1.69)	—	—
Size						
SIZE1 Small firms		ns		ns		ns
SIZE2 Medium-sized firms		ns		ns		0.78* [0.12] (1.98)
SIZE3 Large firms		ns		ns		ns
Constant	—	—	—	–1.88† (–1.72)	—	—
χ^2	29.98	32.13	46.17	47.16	38.30	45.66
Significant χ^2	0.03	0.03	0.02	0.00	0.00	0.00
Log-likelihood	–101.40	–100.33	–90.47	–89.58	–73.82	–70.38
Akaike information criterion	0.21	0.22	1.04	1.05	0.87	0.86

Notes: *t*-statistics are shown in parentheses, and the marginal effects are shown in brackets. [1] Tobit model, including dummy variables for size. [2] Probit model, including dummy variables for size. ns = not significant. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$.

FIGURE 4
The Three Simultaneous Equations

1 — Innovation input (innovation effort)	=	F1	(throughput, output, performance)
2 — Innovation output	=	F2	(input, throughput, performance)
3 — Performance (growth of sales)	=	F3	(output, performance)

TABLE 4
Results of the Estimation of the Model of Simultaneous Equations

	Innovation input *INVT_INNOV*	Innovation output *NEW_PROD*	Performance *SALES95_97*
Innovation input			
INVT_INNOV	—	1.14**	—
		(3.69)	
Throughput			
INNOV_STRAT	0.05*	0.19†	—
	(2.16)	(1.87)	
Innovation output			
INNOV_PROC	—	—	–0.36**
			(–2.94)
NEW_PROD	0.06**	—	—
(Innovation output)	(3.68)		
Performance			
EXPORT95_97	—	—	0.29**
			(3.43)
SALES95_97	0.02**	—	—
	(3.22)		
SALES97	–0.03**	—	—
(Sales)	(–5.46)		
Constant	0.17**	—	0.08†
	(4.96)		(1.72)
χ^2	76.54	26.31	28.72
Significant χ^2	0.00	0.03	0.00
R^2 adjusted	0.74	0.55	0.62

Notes: t-statistics are shown in parentheses. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$.

results of the research work undertaken by Tidd, Bessant, and Pavitt (2001) on the superiority of those firms that innovate in a "persistent" manner. In this sense, an equally pertinent study would be that of the effect of "dynamic capabilities" (Teece, Pisano, & Shuen, 1997) on the performance of firms.

It may also be concluded that the size of firms does not generally influence the relationship between the various blocks of variables under study here. However, size does positively influence the innovation rates (of both product and process) in Portugal (see, for example, Monteiro-Barata, 1999).

Bearing in mind the results obtained by the simultaneous equation method, it can be stated that there are feedback relationships between the different phases of the innovation process. Or, in other words, the links established in the research model between the different phases of the innovation process are, broadly speaking, confirmed.

However, the main conclusion to be drawn is that the relationships noted between the typical main variables of the innovation process, in the context of Portuguese manufacturing firms and during the period in question, are tenuous and unsystematic. This represents another possible view of the already identified fragility of the innovation system in Portugal (see, for example, Conceição & Ávila, 2001), calling for a new and more highly developed culture of innovation, particularly among firms.

As far as innovation policies are concerned, the conditions must be created for firms and other private and public agents of the innovation system to recognize and implement continuous innovation strategies as the central source for gaining a competitive advantage. In this way, the effect of the "invisible hand" of managers will have a fundamental role to play (Miller & Blais, 1992).

In this sense, it would be appropriate to exploit the demonstration effects of innovative firms on the market, giving greater dynamism to the mechanisms of venture capital and industrial property and introducing specific supports for the creation or development of knowledge-intensive and strategic service activities for firms.

In short, the complex and interactive nature of the innovation process is confirmed, such as it is generally explained in the relevant literature (Berkhout, Hartmann, van der Duin, & Ortt, 2006). In order to be successful, this process requires reasonable performances at the internal level of the firm (organization/value chain) and in the relationships between the firm and the technical, scientific, and business environment in which it operates (interorganizational relations/value system). This situation serves to define the contours of a coherent and active national innovation system and presents new challenges to public innovation policies and the methodologies used for assessing science and technology.

Finally, it is considered that it would be desirable to undertake a more profound analysis of the determinants of the innovation process in some industrial subsectors of the Portuguese economy. Furthermore, considering that during the period under consideration, the Portuguese economy was enjoying a period of relative expansion, it would be important to undertake a longitudinal analysis, taking into consideration the different economic and innovation cycles.

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APPENDIX

Sectors Involved: CAE (15–37)

Food products, beverages, and tobacco (CAE 15-16)
Textiles and clothing (CAE 17-18)
Leather and leather products (CAE 19)
Wood, cork, and their products (CAE 20)
Paper, pulp, and cardboard, publishing and printing (CAE 21-22)
Manufacture of oil products and coke (CAE 23)
Chemical industry (CAE 24)
Rubber and plastic products (CAE 25)
Nonmetallic minerals (CAE 26)
Base metallurgy and metal products (CAE 27-28)
Machinery and equipment (CAE 29)
Electrical and optical equipment (CAE 30-33)
Transport equipment (CAE 34-35)
Other manufacturing industries (CAE 36-37)