UNIVERSITAT DE VALÈNCIA
FACULTAD DE CIENCIAS ECONÓMICAS Y EMPRESARIALES
DEPARTAMENTO DE ECONOMÍA APLICADA II

TESIS DOCTORAL:

PRODUCT DIFFERENTIATION AND PROCESS R&D: THE TRADE-OFF BETWEEN QUALITY AND PRODUCTIVITY IN THE SPANISH FIRM

Rafael Llorca Vivero

DIRECTOR:
Dr. D. José Antonio Martínez Serrano

Valencia, 1999

JOSÉ ANTONIO MARTÍNEZ SERRANO, DOCTOR EN CIENCIAS ECONÓMICAS Y EMPRESARIALES POR LA UNIVERSITAT DE VALÈNCIA

<u>CERTIFICA</u>:

Que la presente Tesis, titulada "PRODUCT DIFFERENTIATION AND PROCESS R&D: THE TRADE-OFF BETWEEN QUALITY AND PRODUCTIVITY IN THE SPANISH FIRM" ha sido realizada por D. Rafael Llorca Vivero bajo mi dirección y conforme a mi criterio reune méritos suficientes para que su autor pueda obtener con ella el Grado de Doctor en Ciencias Economómicas y Empresariales.

Y para que conste, firmo el presente certificado en Valencia, a veintiocho de Abril de mil novecientos noventa y nueve.

Fdo. José Antonio Martínez Serrano.

A Alicia y a mis padres

AGRADECIMIENTOS

La labor de investigación que hay detrás de esta Tesis Doctoral es deudora del apoyo de un conjunto de personas que han hecho posible la realización de la misma. En primer lugar, debo expresar mi agradecimiento al "Professor" David Ulph quien supervisó el modelo teórico que se presenta en el capítulo tercero tanto en mi etapa de estudiante del Master en Economía en University College London durante el curso académico 1994-95, momento en el que se empezó a gestar este trabajo, como posteriormente durante los meses de septiembre a diciembre de 1996 en mi condición de "Affiliate Research Student". Agradezco, asimismo, la financiación que tanto la Fundación Ramón Areces como la Universidad de Valencia me proporcionaron para mi primera y segunda estancia respectivamente.

La elaboración de la parte empírica de este trabajo no hubiera sido posible sin la colaboración del Ministerio de Economía y Hacienda institución que, amablemente, me facilitó la fuente de datos. De igual modo, expreso mi gratitud al profesor José García Montalvo por haberme proporcionado el código Gauss de su estimador y que ha sido de gran valía para las estimaciones que se presentan en el capítulo IV.

A lo largo de la elaboración de esta investigación, la profesora Joaquina Paricio ha ido revisando y realizando comentarios muy interesantes a la misma, por lo que le agradezco sobremanera la dedicación que ello ha supuesto.

Debido a que la redacción de esta tesis se ha realizado en inglés he precisado de la revisión gramatical de Julie McGuinness, quien puso gran empeño en dicha labor.

Es de justicia agradecer al conjunto de compañeros y amigos que constituyen el Departamento de Estructura Económica de la Universidad de Valencia no sólo los comentarios hechos a esta investigación durante los seminarios internos en los que se presentaron partes de la misma sino también el crear el ambiente propicio para que este esfuerzo se haya acometido con ilusión. Asimismo, agradezco las sugerencias de los participantes en el XXII Simposio de Análisis Económico (Barcelona), 3rd Spring Meeting *of Young Economist (Berlín), I Encuentro de Economía Aplicada (Barcelona) y 25th EARIE meeting (Copenague).*

Mención aparte merece el director de esta tesis, el Doctor D. José Antonio Martínez Serrano, cuyo aliento, prestado desde hace ya unos cuantos años y ante cualquier tipo de circunstancia, no sólo ha sido decisivo para la consecución de esta empresa sino que ha permitido desarrollar una vocación. No basta el agradecimiento a la persona que ha hecho posible dirigir tu esfuerzo a aquello que te gusta, sino que es preciso demostrarlo en el quehacer diario.

INDEX

CHAPTER I: GENERAL INTRODUCTION 6

CHAPTER II: THE TRADITIONAL DETERMINANTS OF THE INNOVATIVE ACTIVITY

II.1.- INTRODUCTION 18

II.2.- FIRM SIZE AND INNOVATION 20

II.3.- INDUSTRY CONCENTRATION AND INNOVATION 28

II.4.- THE PULL OF DEMAND 34

II.5.- TECHNOLOGICAL OPPORTUNITIES 39

II.6.- UNCERTAINTY AND APPROPRIABILITY 44

II.7.- CONCLUSIONS 51

CHAPTER III: PRODUCT DIFFERENTIATION AND PROCESS R&D

III.1- THE THEORETICAL MODELS ON INNOVATION

III.1.1.- INTRODUCTION 54

III.1.2.- THE IMPORTANCE OF THE ASSUMPTIONS 57

III.2.- PRODUCT DIFFERENTIATION AND PROCESS R&D: THE MODEL

III.2.1.- INTRODUCTION 74

III.2.2.- THE MODEL 77

III.2.3.- COMPARATIVE STATIC

III.2.3.1.- Intra-industry analysis 89

III.2.3.2.- Inter-industry analysis 91

III.2.3.3.- Extensions 93

III.2.3.4.- Simulation Results 98

III.2.3.5.- Appendix 105

III.3.- PRACTICAL IMPLICATIONS OF THE MODEL 111

III.4.- CONCLUSIONS 113

CHAPTER IV: TESTING THE MODEL WITH SPANISH FIRM DATA

IV.1.- INTRODUCTION 117

IV.2.- THE SURVEY OF FIRM STRATEGIES 119

IV.3.- THE ECONOMETRIC MODEL 121

IV.4.- THE EMPIRICAL MODEL. 129

IV.5.- RESULTS 141

IV.6.- CONCLUSIONS 149

IV.7.- APPENDIX 151

CHAPTER V: THE IMPACT OF PROCESS INNOVATIONS ON FIRM'S PRODUCTIVITY GROWTH

V.1.- INTRODUCTION 153

V.2.- THEORETICAL BACKGROUND 155

V.3.- DATA AND THE MEASUREMENT OF VARIABLES 159

V.4.- RESULTS 163

V.5.- CONCLUSIONS 178

CHAPTER VI: CONCLUSIONS 181

REFERENCES 189

RESUMEN 198

CHAPTER I: GENERAL INTRODUCTION

CHAPTER I: GENERAL INTRODUCTION

Traditionally, Economic Theory did not take into account the technological innovation issue. The reason it would seem is that, until recently, the so-called "Solow residual" was thought to be exogenous and, as such, it was not deemed worthy of deeper study. As a result, the research conducted in the microeconomics field was essentially directed towards problems related to the efficient allocation of resources.

Nowadays, however, it is generally accepted that technological progress is an essential factor for both economic growth, caused through improvements in productivity as a consequence of the utilisation of resource saving productive processes, as well as for the increment in welfare, caused through the introduction of new or better quality products into the market. This makes the study of the mechanisms that encourage and condition this process of great interest and importance.

The last two decades have witnessed a growing interest by economists in the study of the determinants that influence a company's spending on research and development of new processes and products (R&D), that leads to the achievement of an innovation. This is not strange given the impressive technological revolution that has taken place in the second half of the century and which economics could not ignore.

The theoretical complexity that the inclusion of this new variable raises in the models has caused progress in this field to be slow. Nevertheless, the last few years have seen a certain acceleration in the achievement of relevant results at the same time as the amount of research in this topic has increased. In any case, it would be fair to say that the research is just beginning and the theoretical path that remains is long and problematic due to the special features of the variable under analysis.

For empirical studies the problems are in the collection of data and its interpretation. There are serious problems, for instance, when looking for a reliable indicator of the technological activity of a firm or industry (the number of innovations, patents or the expenses on R&D) because all of them present some kind of bias. A large part of the innovations achieved by firms are not patented because other better procedures sometimes exist to protect them (for instance, secrecy). Similarly, the innovative activity of a firm cannot be measured statistically if it does not have a specific department devoted to this, that is, if it operates this task in an "informal" manner. In this case, the expenses on R&D do not reflect with accuracy the firm's innovation performance. Moreover, the indicator of the number of innovations does not provide us with information about its real relevance.

The above comments are a consequence of the peculiarities that the technological innovation process presents and which makes analysis and applied implementation very difficult.

Thus, when a firm decides to invest a given amount of resources in R&D it faces an uncertain environment because the results that it will obtain and the time spent on reaching them are unknown. Moreover, it is generally accepted that innovation contains the public good characteristic in a high number of cases which reduces the amount of profits obtained and encourages protection through, for instance, patents. This, on the other hand, can present positive effects if, as established by Jaffe (1986), the cost of innovating is reduced by the externality that is generated by the R&D done by the firms located in a close "technological area". We then face the so-called "appropriability problem".

In a similar manner, innovating firms are located in non-competitive markets. This is because the effect of an innovation is to increase product differentiation or to reduce the cost of production. As is generally agreed, both have positive effects not only on profits but also on market share. In this respect, Schumpeter (1950), as the main reference author in this topic, established "market power" as one of the relevant incentives of the innovative activity for financial and appropriability reasons. This proposal, as we will see, has been empirically tested in a lot of studies. However, it seems that the relationship that exists between innovation and concentration acts in both directions making them, therefore, endogenously determined.

Although all the considerations made have always to be taken into account in the innovation process, the research in this field has actually been focused in determining the main incentives that a firm has to conduct R&D. Starting with the Schumpeter writers, an important part of the literature has directed its attention to the problem of the effects of the aforementioned "market power" on the variable of interest, as well as to "firm size", as an element in connection with the former, whose foreseeable effect is based on the supposed existence of scale economies in R&D and on its fixed cost nature for the firm. This is one of the main worries that remains today (e.g. Cohen and

Klepper, 1996a,b). The true incidence of the mentioned determinants is not solved and it seems that innovation is influenced by other variables with a more clear economic justification.

So, there are two factors which are believed to have a major impact on the decision to allocate resources to innovation: the market demand conditions the firm faces and the technological environment in which it develops its task. The first factor is called "the pull of demand" and the second "the push of technology". Both provide a more satisfactory explanation of the incentives that lead the firm in its technological evolution.

The basis of these determinants are the following. On the one hand, as Schmookler (1966) points out, the profits the firm obtains from its spending on R&D are directly related to the number of product units that encompass the new technology. The higher the potential market the firm faces the higher will be the incentive to conduct R&D, assuming that scientific knowledge is propagated enough so as all the industries are able to have access to it at the same cost. Similarly, the spending on R&D by firms has a fixed cost feature. Therefore, the higher the amount of sales in the respective line of business the lower the cost of the innovation per unit produced, which in turn will encourage the allocation of resources to research. On the other hand, more productive technological environments imply that the difficulty of obtaining an innovation is lower and, therefore, higher the effort directed by a firm to spending in this area (Rosenberg, 1974). In the literature, it is quite often considered that "technological opportunities" are typical of the industry where the firm is located.

Naturally, there are defenders of both hypothesis but, because an important number of empirical studies have revealed the significance of both factors, the debate has been focused only in its relative importance, as we will see in more detail in Chapter II.

Until now, expenses on R&D have been defined in a generic manner. However, when a firm innovates it can do this in two different ways, although, as we will see, these are not always clearly differentiated. The first one has the objective of reducing the unitary cost of production through the improvement of the productive process, this is called "process innovation". The second one tries to improve the quality of the existing products or to introduce a new product into the market, this is called "product innovation". In any case, this last type of innovation normally has the effect of obtaining a greater product differentiation in the market, and therefore it shifts the downward sloping demand curve the firm faces rightward (recall that we are in a non-competitive market), allowing the firm to obtain a higher price-cost margin.

The theoretical models have analysed only one of the two types of innovations or have treated the expenses on R&D as a whole unit, independently of the different effects that each one has on the profits of the firms. Given the fact that firms obtain patents in both types of innovations[1] (or, in any case, devote resources to both) it seems that taking into account only one aspect sheds light on part of the problem. Moreover, it is often the case that a product innovation requires a process innovation (Levin and Reiss, 1988),

[1] The distinction between product and process innovation is relative. It is common to observe that the product innovation for an industry becomes, in fact, a process innovation for the industry that acquires these goods and uses them as inputs in its productive process. Some authors argue that increments in productivity are in an important part due to the innovation acquired or used in a given sector (see

making the analysis much more complex. This is the reason why, recently, some simple theoretical models have started to appear in the literature trying to provide some explanation of the existing relationship between the expenses on R&D destined to product innovations and those devoted to process innovations within the firm (see, for instance, Bonanno and Haworth, 1998 or Yin and Zuscovitch, 1998). At the same time, in the empirical field there exits some research about the determinants that influence each type of innovation (Lunn, 1986, Levin and Reiss, 1988, Berstcheck, 1995, Cohen and Klepper, 1996a or Klepper, 1996).

We must take into account that, in the final analysis, the objective of an innovation (product or process) is to obtain a better position of the firm in the face of real or potential rivals and this should be the origin of the economic justification of the technological activity. For this reason, it is essential to consider the differential effect that these two distinct types of innovation have over the strategic features of the respective product (quality and cost), because it is quite obvious that these will be the main factors on which to base the competition position.

In this regard, it is logical to think that the variables "firm size" and "market power" are essentially the result of the relative position that a firm has in its price-quality relationship with respect to its competitors, taking as given consumer tastes. If we consider that both variables are affected in a great manner by the resources the firm devotes to innovation, then the endogeneity connection that the literature establishes between concentration and R&D should not be surprising nor the confusion existing in

---

Sterlacchini, 1989 or Geroski, 1991).

the role firm size has to play in its technological activity.

This, therefore, is going to be our point of departure. We will consider that the market share of the firm is essentially determined by the price-quality relationship that its product has compared to that of the rival firms and that these variables are basically affected by the expenses on R&D. So, in Chapter III, starting with the demand structure that comes from the product innovation model of Ulph (1991)[2], we will analyse the decision about the spending on cost-reducing R&D with the objective of investigating the influence of the different parameters of the model (quality gaps of the analysed and the rival innovative firm in relation to non-innovative ones, market dimension and technological opportunities) on this variable. In this analysis, we are mainly interested in the effect that own vertical product differentiation has on the incentive the firm has in reducing its unitary cost of production (productivity) as well as the impact of the rest of the parameters on this relationship.

Due to the fact that we consider Bertrand competition in the product market (the price of the product depends directly on the unitary cost of production as well as on quality gap) and given the existing strategic interdependence among firms already mentioned, we have had to resort to numerical simulations in order to check the relative importance of the incentives that vertical differentiation provides to the R&D spending on process innovation. We have detected a quadratic relationship between these two variables. However, the effect of own quality gap on process R&D intensity (the cost-

[2] This model was originally designed to study the existing relationship between the industrial structure of an economy and its growth rate. Once extended, it is used to study some aspects of the behaviour of innovative firms (product innovation) that present strategic interdependence in their decisions (Ulph and Owen, 1994).

reducing R&D in relation to total sales) will be positive or negative depending on the assumption that the quality of the product enters or not the cost function.

The motivation for this research is derived from the following argument. Until now, the research conducted in the technological innovation field has taken the "size" and "market power" variables as determinants of the technological activity of the firm. In our case, the variable "vertical product differentiation" (in relation to price) substitutes these. It is therefore interesting to check under what circumstances this substitution is correct. If the assumption is true, the debate about the convenience of a given market structure as a factor that impels the innovative activity would have less sense, making the product features and the possibilities that the product gives to the strategic competition among firms more relevant factors[3]. Moreover, our main aim is to check that what has been predicted by the theoretical model developed in this research is, in fact, accomplished with the data available. That is, our intention is to investigate the influence that own vertical product differentiation has on productivity gains of a firm and if there is a point at which there exists a trade-off between quality and productivity, giving up the improvements in cost reduction in favour of welfare increments. In the final analysis, the problem in hand is to investigate if the achievement of a great product differentiation implies lower economic growth.

The empirical section is presented in Chapter IV using as a data source the "Encuesta de Estrategias Empresariales" (Survey of Firm Strategies) conducted by the

[3] In general terms, the literature has not taken into account the effect that product differentiation has on technological innovation. Some approach in this topic, especially in relation to the influence that differentiation has on the relationship concentration-spending on R&D can be found in Comanor (1967) and Shrieves (1978).

Fundación Empresa Pública and which encapsulates for each firm in the survey information about a wide range of variables that are very useful for this study. In the empirical specification of the model we have had to resort to some simplifications to do the estimation, trying always to keep as close as we can to the essence of the theoretical model. By means of the utilisation of a panel data in which the dependent variable is discrete (the number of process innovations) and the independent ones are considered as weakly exogenous, we are able to observe how the estimations confirm the main proposition of the theoretical model, that is, the existence of a point beyond which we find a trade-off between the vertical product differentiation of a firm and its process innovation performance. In addition, the propositions derived about other variables (rivalry, market dimension, ...) are also, although only partially, confirmed.

Thus, when the sample is restricted exclusively to those firms revealing a certain degree of product differentiation, the "firm size" variable has a positive and significant effect that is able to severely reduce the impact of "rivalry" and "the pull of demand". This result contradicts, to a certain extent, the theoretical model (although own quality gap always behaves as predicted). The explanation we have given for this is that once some kind of "brand loyalty" is acquired, the negative impact that "rivalry" exercises in the attraction of new consumers as a consequence of the corresponding price reduction is significantly reduced and the argument of *cost-spreading*[4] of Cohen and Klepper (1996a,b) becomes of greater importance.

When we refer to process R&D intensity (R&D expenses in relation to total

[4] That is, at the same time the firm grows in size the cost of the innovation per unit produced decreases.

sales) the estimation, apart from revealing important sectorial differences, suggests that the quality of the product does not enters, at least in a relevant manner, the cost function that, to our understanding, implies that the product innovations reported by the firm are essentially of an incremental nature. In any case, the small sample at our disposal in this specific study (only 134 firms for 1990) means that we should accept the aforementioned results with caution.

The research would not be complete if we did not proceed to confirm one of our main premises which consists in assuming that the variable we have taken as a dependent one, that is, our measure of the process innovation performance of a firm, has a relevant impact on the firm's productivity evolution. This is done in Chapter V. Starting from the classical Cobb-Douglas production function extended with the inclusion of a measure of the knowledge capital, we test our hypothesis by establishing two assumptions not usually considered in this type of study. First, process innovation only is the technological variable responsible for the advances in productivity, leaving apart product innovation whose role is exclusive to the improvement of product quality. Second, in spite of considering the amount spent by a firm on R&D as the main component of its knowledge capital we assume that the process of learning is by doing successfully and, therefore, we focus on effective innovations. Our estimations reveal that the technological variable chosen has a significant impact on the productivity evolution of a firm and this result is robust under alternative specifications.

The present work has tried to shed some light on the study of innovation differentiating clearly the distinct impact that the increment in product quality and the reduction in production cost have on firm profits, as well as the existent interrelation between both types of improvements. I hope this to be an additional “research” capital in this field.

CHAPTER II: THE TRADITIONAL DETERMINANTS OF THE INNOVATIVE ACTIVITY

CHAPTER II: THE TRADITIONAL DETERMINANTS OF THE INNOVATIVE ACTIVITY

II.1.- Introduction.

The purpose of this second chapter is to establish the point in which economic science is situated about the determinants of innovation. Since Schmookler (1962) suggested that innovation could be explained following economic criteria, forgetting the past held beliefs of taking technological advances as given, the amount of studies in this field has increased continuously.

These studies have been first focused in testing the known Schumpeterian hypothesis about the advantages that the "monopolistic firm" would have when it comes to obtain innovations, leading implicitly to the emergence of serious doubts about the theoretical proposition of the perversity of non-competitive markets. In fact, the important thing is to test if the variables "market power" and "firm size" have the positive effects on innovation postulated by Schumpeter. Despite the effort devoted to this research, the results obtained are far from conclusive, although in the academic spheres the opinion is that the particular characteristics of the industry, the market and the firms that go to make it up are the real determinants of the existing relationship between size and innovation and that, in any case, concentration and innovation are both endogenously determined.

It seems that both the expected growth in demand and the technological opportunities of the industry are the variables with a higher relevance for generating incentives for firms with the intention of directing resources to technological advance. In any case, there is a wide consensus about the validity of these two factors guaranteed by empirical studies, although the debate is focused in the relative importance of each one.

Finally, the public good feature that usually is given to technology has been also a theme of discussion because although, on the one hand, it is true that sometimes it acts as a negative incentive, on the other hand, it can induce firms to invest in R&D in order to profit from the available knowledge (Cohen and Levinthal, 1989) or, additionally, to increase the productivity of R&D when the technological environment is improved (Jaffe, 1986). The diverse studies do not provide clear results because to empirically measure these effects is extremely difficult.

Our aim in this chapter is not to make an exhaustive analysis of what the different authors have considered to be the relevant variables that influence firm behaviour in order to direct resources to innovation[1] because we consider that this purpose has not sense. Our intention is to concentrate on the basis that supports each factor and the difficulties that its measure and interpretation presents. This will serve us as the starting point for the theoretical and empirical models .

[1]A detailed analysis about this topic can be found in Cohen (1995).

II.2.- Firm size and innovation

Since Schumpeter established the generic idea that firm size (or line of business size) as well as its market power could influence in an important manner in its innovation focus[2], establishing a dichotomy between static and dynamic efficiency, a high number of theoretical and applied studies have tried to test this hypothesis. In fact, investigating the level of certainty of this proposition has occupied the major part of the economic literature on R&D. The reasons for that lies, on the one hand, in the different interpretation that the distinct authors have given to the vague thoughts of Schumpeter[3] and, on the other hand, in the difficulties that present to empirically demonstrate its propositions as, for instance, those related with the measurement of the level of innovation.

The firm of a bigger size, that is, with a higher sales volume, can have some advantages when investing on innovation. For instance, the profitability obtained from cost-reducing R&D is directly related to the amount of product affected by the innovation, because the fixed cost that the innovation process implies is shared among a higher number of units (*cost-spreading argument*). Moreover, it is well known that in order to obtain an innovation it is necessary to put into effect projects with a high degree of uncertainty. For this reason, in a context of an imperfect capital market, the availability of liquidity by the firm and the stability of these funds may be of great relevance in its decision to direct resources to R&D. Therefore, it is assumed that a big

[2] The hypothesis of Schumpeter (1950) and Galbraith (1956) is that the bigger firms generate a disproportionate amount of the technological advances of the economy.

[3] The term "monopolistic firm" makes reference to both "size" and "market power" aspects.

firm has more possibilities to generate the necessary volume of resources (cash-flow), avoiding the problems related to liquidity constraints. Moreover, there are also arguments in favour of the existence of scale economies in the technology of R&D[4] and in the financial market (because of a great negotiation power) and that are more directly related with Schumpeter's reasoning. Finally, it is assumed that the expenses on R&D are more productive for big firms than for small ones because of the scope economies obtained as a consequence of the existence of complementary projects and the co-operation between the R&D department and others (e.g. marketing).

In an attempt to test the Schumpeterian hypothesis, in a classical study, Comanor (1967) works out for 21 industrial sectors the elasticity of the level of research (measured by the average of the professional employees between 1955 and 1960) in relation to firm size (measured by the average of the total number of employees in these years). The result obtained by Comanor is that in only 6 of the 21 sectors there seems to exist scale economies in R&D, finding in these an estimated elasticity with a value higher than 1. This leads to conclude that, in a great part of the industrial sector, the smaller firms conduct a greater proportion of research levels than the bigger ones, contradicting the thoughts of Schumpeter.

This approach, that is, to investigate the existing relationship between the scale of production and the inputs used for R&D, is widely criticised by Fisher and Temin (1973). These authors consider inappropriate the Comanor methodology in order to test

[4] There are two reasons. First, because of a greater division of labour, the higher is the number of people devoted to R&D the higher will be their efficiency, and second, given an amount of human resources devoted to this task, their productivity will be higher in a big firm due to the larger diversification of activities generated within it.

the existence of increasing returns (scale economies) in R&D at the line of business and firm level. They demonstrate that the elasticity of the R&D output (increment in profit that occurs because the firm dedicates to R&D activities) with respect to firm size (total employment) is equal to the elasticity of the input of R&D in relation to size plus the elasticity of the average labour productivity of R&D (additional production per worker obtained as a consequence of the task done by the employees dedicated to R&D) also in relation to size. Moreover, these authors note that the argument of scale economies does not necessarily imply that the elasticity of the R&D input in relation to size is higher than one which, at the same time, does not imply the accomplishment of the hypothesis attributed to Schumpeter.

Thus, Fisher and Temin argue that the existence of technological and financial scale economies cannot be tested directly disaffirming the studies that try to test a supposed consequence of it, that is, the more than proportional increment of the inputs of the R&D activities with firm size.

The reply comes from Kohn and Scott (1982). In their article, these authors adduce a logical mistake in the argument of Fisher and Temin because the latter do not consider the optimisation restrictions of the firm. In this sense, Kohn and Scott demonstrate that the elasticity of the R&D input and output with respect to size are in direct connection with another three elasticities. These are the following: that which reflects the potential returns of the industry in relation to R&D, that which defines the degree in which an industry is Schumpeterian in the "cost sense" (an industry will be more Schumpeterian from this point of view the greater the elasticity of the marginal cost of R&D in relation to the output of R&D) and that which encompasses the degree in which an industry is Schumpeterian in the productivity sense (an industry is more Schumpeterian from this perspective the greater the elasticity of the marginal value added of the R&D output in relation to the scale of production).

These authors demonstrate that if the elasticity of the R&D input in relation to firm size is higher than 1 or, alternatively, if the elasticity of the marginal value added of R&D in relation to firm size is higher than 1, it is possible to affirm that bigger firms obtain a proportionally greater R&D output. This is accomplished provided the existence of increasing returns in the R&D production as well as that the value added of the output of R&D (given the number of workers not dedicated to R&D) is increasing with the mentioned variable but at a decreasing rate. Therefore, the authors establish the possibility to relate firm size with employment, output and the value added of R&D. Moreover, they note that if an industry is excessively Schumpeterian, that is, if it is always profitable to invest an additional amount in R&D, a stable joint distribution between firm size and R&D activity will not exist in the market which probably would lead to an increasingly concentrated industry.

Once established the theoretical aspects of this topic, apart from the Comanor (1967) research, there are other relevant empirical studies that have tried to test the aforementioned hypothesis. Cumberston (1985) note that, within an industry, there exists a direct relationship between three variables given that all of them are related by an identity: firm size, market size and the relative position of the firm in the market. In this respect, although the tendency is to make a distinction between the absolute size of the firm and its relative size (concentration) a wider and more consistent focus of the problem is to consider the connection between both through a third variable, that is, market dimension. So, this author factorizes the changes on the expected R&D of the industry in the face of a transformation in its market structure in three effects, with the aim to expose with clarity the existent interactions among the different variables:

1.- The "number effect". This is the reduction in the number of firms due to an increment in its size and "market power". This effect implies that even accomplishing the Schumpeterian-Galbraith hypothesis, R&D could be reduced with market concentration, making the impact of this effect stronger the greater the technological opportunities of the industry.

2.- The effect of "firm size". This effect establishes that the relationship between firm size and R&D is positive and strictly convex (hypothesis of Schumpeter-Galbraith). Thus, the increment in the size of the bigger firms at the expense of the smaller ones will lead to an increment in the expected R&D of the industry.

3.- Market power effect. This does not have a clear direction even assuming that the Schumpeter-Galbraith hypothesis is accomplished as a result of the existence of complex interrelations between the variables reflecting market power (e.g. market share and concentration ratio).

After their econometric analysis the conclusion of Culbertson is that the expected R&D of the industry may fall with greater market power and firm size. This could be accomplished even if the expected R&D of the firm is increasing with market power and at a higher proportion with firm size.

Cohen, Levin and Mowery (1987) note that it is necessary to consider an adequate unit of analysis in order to appropriately fix the effect of size on innovation. Then, the "cost-spreading" argument is better delimited when we consider the different lines of business within the firm (size of the line of business), firm size as a whole being more appropriate in order to measure the effects of imperfections in capital markets. In relation to those explanations based in the scale and scope economies, the most appropriate unit of analysis is a function of its nature. Moreover, these authors introduce in its regressions variables that try to reflect the different technological opportunities and market determinants (appropriability, market structure and demand conditions, market growth, price elasticity and income elasticity) that the distinct industries may present because taking them into consideration is important in order to extract valid conclusions for the relationship to be analysed. The data reveal that, once the fixed effects of the industry are taken into account, R&D intensity (not innovation intensity) at the level of line of business is not significantly affected by firm size. The size of the line of business has no effect on R&D intensity at this level although positively affects the probability to conduct R&D.

However, the authors find that firm size is significant (though with a very small impact) in industries with low technological opportunities. This seems to indicate that inter-industry differences in this variable (and probably also in appropriability conditions) influence the degree in which size gives advantages.

In the same line of research Pavitt, Robson and Townsend (1987) study the inter-industry distribution of the size of the innovating firms in the UK for the period 1945-

83. As before, these authors establish the same two determinant factors of the inter-sectorial variation of the innovating firms distribution: technological opportunities and appropriability conditions. They find how the relationship between firm size and innovative activity could be statistically described as U shaped[5].

Recently, the "cost-spreading" argument has served Cohen and Klepper (1996b) as a basis for explaining the empirical regularities that are observed in the literature in the existent relationship between firm size and R&D[6]. From the authors' point of view, there are two necessary conditions in order for the firm "ex-ante" output to influence in an important manner the expenses it conducts to R&D. On the one hand, the firm has to obtain the profits of the innovation essentially through its own output, that implies the assumption of the difficulty of licensing. On the other hand, the expected growth consequence of innovation must be low, being the main source of profits the growth in the price-cost margin of the firm and not the greater volume of sales. The main conclusion of these authors is that, contrary to previous arguments, firm size is quite determinant when spending on R&D at the intra-industrial level, and this is specially true in cost-reducing innovation.

---

[5] These authors stress the fact that the innovations distribution by firm size differs substantially from that based on R&D expenses. In particular, the number of innovations by employee is above the average in firms with less than 100 employees and in those with more than 1000 employees.

[6] These regularities are:

1) The probability to conduct R&D increases with size.

2) Within the industry, R&D expenses and firm size are positively and directly related.

3) In a great part of industries, R&D expenses growth proportionally with firm size.

4) The productivity of R&D decreases with firm size because it undertakes, at the margin, less profitable projects.

The study of the role that scope economies have in the relationship between firm size and innovation has been scarce. The only research with a certain interest is that of Henderson and Cockburn (1996), in which it is analysed the relationship existing between firm size and research productivity in the pharmaceutical industry.

As already mentioned, the expenses on R&D can be more productive in bigger firms not only for reasons of scale economies but also for the existence of scope economies. These are derived from a larger diversification of projects that occurs in firms with a higher dimension which allows externalities within and outside the firm to be captured. There are two ways in which to obtain increasing returns from the technological effort of the firm. On the one hand, the accumulated knowledge of a given project can be used, at low cost or without cost, as productive input in other related projects. That is to say, the different activities can share inputs without additional cost. On the other hand, externalities of knowledge among programmes can exist that increase the productivity of each one, making the research output affected irrespective of the expense incurred. It seems that both effects are presented in the pharmaceutical industry because the authors find a certain advantage on innovation for bigger firms and these also have more efficient research programmes.

As we have seen, we cannot establish a clear conclusion about the effect firm size has in its innovation effort. In any case, it seems that if we take into account technological opportunities and appropriability conditions of the industry as well as the particular features of the market (size, price elasticity, etc) the impact of firm size is, in general, very small making the aforementioned characteristics of greater relevance.

Although it seems that at the intra-industrial level there are some authors for whom this is an essential variable.

The relevance of the innovations obtained by firms with different sizes is a point which has not been empirically solved. Rosen (1991) presents a theoretical model in which the author demonstrates that in order for the Schumpeterian hypothesis of action-reaction to be accomplished, the bigger firms have to invest more in R&D but in safer projects than the smaller ones, which implies that the latter obtain a greater percentage of the relevant innovations. The reason for the aforementioned empirical shortcoming is the non-availability of adequate data about the importance of the innovations and the level of risk which a firm incurs when it spends resources on R&D.

II.3.- Industry concentration and innovation

The influence that the degree of industry concentration has on innovation activity is another of the hypothesis established by Schumpeter that has had the attention of researchers as much as that of firm size. In any case, as we have seen, both determinants are closely connected (Culbertson, 1985).

Diverse are the reasonings that have tried to explain the fact frequently observed in the data that innovative activity grows with the degree of concentration until a given point beyond which it decreases.

The argument of Schumpeter lies in the consideration that greater industry concentration implies, through higher market power of the firms that go to make it up, a reduction in market uncertainty and provides, therefore, the internal funds necessary to undertake a costly and risky activity to an efficient scale as is the investment in R&D[7]. Other arguments make reference to the more favourable conditions of appropriability of the profits derived from innovation that the firms that operate in more concentrated markets have.

In this sense, Scherer (1983) in an study in which connects the degree of industry concentration with the amount and the type of expenses on R&D the firm incurs (process or product) and, from here, with productivity growth, finds that probably the appropriability conditions and, to a lesser extend, the technological opportunities of the industry are the most important factors to explain the positive relationship that the estimations reflect between concentration and R&D intensity[8]. The intuition of Scherer is the following: the higher the industry concentration the higher will be the market share of its main firms and also the portion of cost-saving the firm can appropriate through its process innovation (assuming high transaction cost for licensing). In this respect, the firm will have higher incentive to invest in R&D, and as a consequence, it will have larger productivity growth.

[7] Comanor (1967) highlights the fact that the Schumpeterian hypothesis could be considered as concentration having two separate effects on the research level. On the one hand, an effect of firm size as a function of the relative size of the main firms in the industry. On the other hand, we have the aforementioned market power effect. Moreover, this author puts the connection between the possibility of differentiate the product in the market and the impact that concentration may have on R&D expenses. The greater the possibility of differentiate the product (barriers to entry) the lower this impact because the competition in R&D is important.

[8] When we speak about R&D intensity we refer to the current spending on R&D as a ratio to total sales.

As Geroski (1990) noted, for an adequate testing of the Schumpeterian hypothesis it is necessary to distinguish between the expected market power that is presumably obtained as a result of an innovation and the market power the firm has now.

The expected monopoly power is directly connected with the innovator ability to appropriate for all the profits of the innovation avoiding being imitated. If, from this point of view, it is considered that the Schumpeterian hypothesis implies that innovation takes place only when it is expected to reach a degree of market power that allows the firm to cover at least its cost, it seems that the consensus is easy to obtain.

By contrast, if this hypothesis is formulated in terms of the actual market power, serious doubts emerge about its validity because there exist forces that act in inverse senses. A indirect positive effect of having at present a certain degree of monopoly power is derived, for instance, from the capacity the firm has to raise barriers to entry in the future because it benefits from them today. This affects the size of post-innovation reward. The direct effects are defined for a given level of post-innovation reward. In the positive side, a firm with certain monopoly power can have more qualified employees and an important amount of cash-flow that leads to a better adaptation to any event, not having to resort to costly external funds. Moreover, it is usually affirmed that resorting to external financial funds is not adequate for this type of spending in order to avoid that valuable information reaches rival firms. In the negative side, we also find distinct arguments. Firstly, the absence of competitive forces can reduce the ability of a firm to adapt to external shocks. Secondly, it is well known that the higher the number of firms the higher is the probability of innovating in any given moment of time. Finally, the leader firm in a given period has reached this position because of past innovations, having lower net profits from innovation than potential entrants because part of the innovations obtained are displaced.

Taking into account the above considerations, the estimations of Geroski (1990) suggest that the existence of higher degree of rivalry among firms in the market does not lead to a reduction in the innovation rate. Moreover, the data indicates that a positive effect of the actual degree of monopoly on innovation does not exist but on the monopoly which is expected in the future. In any case, this author highlights the fact that the factor that has the greatest importance on innovation is that which reflects the technological opportunities of the industry. If we do not take them into account the results are biased as they overestimate the concentration effect.

In this line of research we also find the work of Levin, Cohen and Mowery (1985) with a very similar approach to that analysed in the previous epigraph. These authors use likewise the line of business as a unit of analysis and include the systematic inter-industrial differences existing as a result of distinct points of departure in that referred to technological and appropriability conditions. They conclude that the degree of concentration of the industry has a very small impact on innovation effort and, in some cases, it is non-significant depending on the estimation procedure. Scott (1984) argues that the explanation of this fact may be that the degree of concentration of the industry is the reflection of a collection of specificities that it presents and that can be encompassed by the state of technology and the imitation possibilities. Following the guidelines established by the rest of the studies mentioned, the author observes how the particular effects of the firm and the industry explain a high percentage of the spending on R&D per unit of product.

In any case, we have to always take into account that the relationship between concentration and innovation is in both ways and that both variables are endogenously determined (Dasgupta and Stiglitz, 1980). Thus, the achievement of an innovation by a firm gives it a transitory monopoly power that can be gradually reduced when the rival firms obtain innovations or imitate the existing ones. Following this reasoning, Levin and Reiss (1984) starting from a theoretical model in which innovation and concentration are simultaneously and endogenously determined, show that R&D intensity has a strongly positive effect on industry concentration. In contrast, the degree of concentration influences negatively this variable except for those industries with a greater orientation to product innovation.[9] For these authors, the simultaneous determination of R&D and industry concentration is a function of three main factors: the demand structure, the richness of the technological opportunities and the technological and institutional conditions that establish the degree of appropriability.

Angelmar (1985) carries out an interesting research that, in some sense, qualifies the above affirmation. The study of Angelmar is focused on industries with very rich technological environments in which it is assumed, a priori, that greater industry concentration will have a negligible effect (or even negative) on R&D expenses because of the lesser importance that in this case the introduction of better products into

[9] However, Lunn (1986) finds a positive relationship between concentration and the patents that reflect process innovation but not with those reflecting product innovation.

the market would have. This author notes that at least two additional factors must be taken into account: the cost and uncertainty of R&D (different among industries because of minimum budget needs or the time necessary to introduce the innovation into the market) and the imitation capacity of the rival firms. The estimations of Angelmar lead to the conclusion that when the cost and uncertainty of R&D as well as the imitation speed by rival firms are high[10], concentration has positive effects on R&D. In contrast, if the cost and the uncertainty of R&D are low and there exists important imitation barriers the net effect is negative.

A recent study related to this point is that of Blundell et al. (1993). This work is based on the same sample used by Pavitt et al. (1987). The results of this research highlight the fact that, being true that firms with greater market shares have higher probability of innovating because of their higher incentives[11], more competitive industries tend to induce higher levels of innovation. This reasoning is in line with the work of Geroski (1990). Therefore, it is necessary to add information at the firm and industry level to establish rigorously the impact of market structure on innovation.

As we have seen the number of studies is very high and, therefore, the results obtained allows for the possibility of diverse interpretations. The clearest conclusion we can extract from this overview is that both the degree of industry concentration and the expenses on R&D are endogenously determined and that the technological environment

---

[10] Following Levin et al (1987) the speed of imitation by rival firms is negatively related to the capacity of patenting, secrecy and the possibility to induce brand loyalty and positively related to the frequency with which consumers buy the product.

[11] Following the model of Gilbert and Newbey (1982), the monopolist has greater incentives to the achievement of a process innovation than the entrants because the profits of the industry decrease when the market is shared with a higher number of firms. This effect is taken into account by the monopolist but not by the entrants. This is the reason why the former innovates more.

in which the industry is located and the demand structure as well as the existing barriers to imitation condition in a great manner the relationship between both variables. These, therefore, are ultimately the factors that determine innovative activity.

II.4.- The pull of demand

The idea that market dimension or, more generally, the demand conditions of an industry is the factor with higher relevance in the direction and magnitude of the innovation effort was first established by Schmookler (1966)[12]. This author observed a linear relationship and high correlation between the innovations (patents) achieved in the industries producing capital goods and the demand directed to these firms (measured by capital investment)[13].

The argument of Schmookler (1966) relies mainly in considering that the private profit from research varies in direct proportion to the amount of product that encapsulates the new knowledge. An additional explanation of this positive incentive also being the aforementioned argument of "cost-spreading". In order to sustain this affirmation, this author assumes, on the one hand, that the ability for invention responds very rapidly to profit opportunities and, on the other hand, that the greater the dimension of the actual and potential market the higher the innovative activity directed to it, because profits increase with market dimension. Additionally, the greater the productive activity directed to satisfy a given demand the higher the possibilities of finding a

[12] This author was also the first one in postulating that innovative activity could be explained through economic incentives.

[13] This result depends critically on the fact that capital goods innovations were classified by the industry of use and not by the industry of origin.

solution to the set out problem (Scherer, 1982). All of this implies that scientific knowledge is sufficiently developed and disseminated as the supply of new knowledge is very elastic, at the same cost level, for all industries and firms. That is to say, the cost of the invention is the same for all the industries.

However, Schmookler (1966) itself qualifies this restrictive assumption, recognising that firms in industries with more richer technological environments have certain advantages in the achievement of innovations. At the same time, the author argues that the application of technology is very adaptable and it will be directed towards one sector or another depending on the potential profit to be obtained and that, in the final analysis, it would be determined by its demand.

The arguments of Schmookler have not been void of critics. Rosenberg (1974) presents, with an abundance of examples, the evidence that the cost of invention differs among industries, a fact that is demonstrated by the diverse evolution in the progress of the distinct branches of science. Moreover, it is argued that it is not completely true that the progress of the invention or innovation is the reflection of a given existing demand because an important part of individual needs or wishes have remained unsatisfied or badly supplied during prolonged periods of time despite the existence of a solid demand. A clear example is that of medicine, where accelerated progress has not been possible until the existence of scientific knowledge that could allow it (i.e. the development of bacteriology). Through successive historical examples, Rosenberg demonstrates how the supply side, that is, the increasing stock of knowledge, has been determinant in explaining the progressive satisfaction of human needs through innovation. So, the state of the different sources of scientific knowledge have lead to some innovations being less costly than others. As a conclusion, this author highlights the fact that the allocation of resources of the innovative activity in an economy is not only the result of forces operating on the demand side (that determine the profitability of the innovation) but also the result of the advance occurring in the supply side (knowledge) which determines the probability of success of the innovation and is also an indicator of the cost of obtaining it.

A more rigorous attempt to test the Schmookler hypothesis is done by Scherer (1982). This author uses a wider survey than Schmookler[14] and less biased towards traditional sectors. In this case, the patents sample is classified in a manner that does not imply any difference in doing this by industries of origin and industries of use as was the case of Schmookler[15].

In his estimations, Scherer finds that the relationship between the demand index and patents flow is positive and significant although, and this is one of the important differences, the relationship is not linear revealing the existence of decreasing returns. Moreover, in the sample a distinction is made between capital goods and industrial materials innovations considering that the relationship with the respective demand measures is stronger for the first case, arguing that Schmookler started from the most

[14] The Schmookler analysis included only between 6% and 8% of the total number of patents registered in the USA between the end of the forties and the beginning of the fifties.

[15] Schmookler estimated also classifying patents according to the industry of origin. The relationship found was also linear but with much lower correlation, a fact that the author explains for the existence of differences in technological opportunities among industries (a greater number of innovations per unit of product for the industries with richer opportunities). When the differences in technological opportunities are aggregated, classifying the innovations by industries of use the high correlations indicate, following the author's point of view, the greater relevance of the demand forces.

favourable case in order to demonstrate his own proposition. But perhaps, the most important contribution of Scherer is to consider the technological opportunities of the industries (classified according to the richness of its knowledge basis) through the use of dummy variables in his regressions in order to investigate the role of this variable on innovation. The results obtained show that factors on the supply side explain a very high fraction of the variance of the innovative activity (around 60%) and at all times a higher that those obtained in the Schmookler estimations.

Pakes and Schankerman (1984) carry out a similar study but in this case the measure of the innovative activity is R&D intensity. In this case, the Schmookler hypothesis has to be modified because it is based on levels of innovative activity and absolute market size. Given that there is a normalisation by the current level of output, the differences that might be produced in the expected market size will be determined by the expected demand growth rate.

These authors argue that the optimal level of R&D activity depends, in a wide sense, on two main factors: the supply of new scientific and technological knowledge and the existence of effective demand for this knowledge that depends on the ability to extract profits of a given unit of the produced knowledge (appropriability) and on the output level and expected demand growth of the good that encapsulates the new knowledge. The estimations carried out by the authors differ when considering the intra-industry and inter-industry context.

At the intra-industry level, the mechanism of demand induction has a very small effect making the "appropriability" factor and the intra-industrial differences in technological opportunities more importance. These results do not necessarily contradict the Schmookler hypothesis because, as already mentioned, they refer to innovation level.

At the inter-industrial level the growth rate of demand explains a high percentage of the variance (65%) that, at first sight, is surprising and contradicts the intra-industrial results. The explanation may be that growth rates of the different industries are highly correlated with those factors at the intra-industry level that encourage the research activity of firms.

Finally, Jaffe (1988) carries out, basing his study on a cross-section of data, a very rigorous analysis in which, apart from introducing variables on the demand side, considers the incidence of the different technological opportunities of the industries as well as the possible externalities of innovation that could exist. In this study, the author analyses for the USA manufacturing industries the effect that both demand and supply factors could have over R&D intensity and productivity growth.

The results of Jaffe indicate that both types of determinants are relevant. In particular, this author finds that the explained variance by factors representing the market conditions is a little higher than that explained by technological opportunities.

All in all, as we have explained the forces that act on the demand side and that mainly affect the profits that can be achieved from innovation or, at least, can serve as an indicator of it, must be taken into account. Perhaps, Schmookler was not accurate in highlighting that the factors that, in one sense or another, condition the market size of the product that encapsulates the new knowledge have a higher relevance, trying to reduce the importance of the restrictions that could come from the state of scientific and technological knowledge and the speed of its progress. To see in more detail if this omission is relevant, in the next section we will analyse the contribution in the literature to the analysis of the effect of these technological factors, although we have already given an idea of their significance.

II.5.- Technological opportunities

In previous sections, in which we described the effects of firm size, concentration and market dimension on innovative activity, we have occasionally outlined the relevance of considering a variable, specific to each industry, that apparently condition the relationship to be investigated[16]. This variable is called "technological opportunities". The concept that is encapsulated in the expression "technological opportunities" is too wide, diffuse and, on some occasions too ambiguous in providing a precise description.

[16] As Dosi (1988) points out, the scientific knowledge plays a crucial role in the emergence of new possibilities to greater technological progress. In any case, this author highlights the fact that, even taking into account technological opportunities, market dimension and its growth rate have some influence in the propensity to innovate.

As mentioned above, Rosenberg (1974), in his critique of Schmookler, outlines the importance that scientific progress has for achieving an innovation. Through the verification of some historical events, he describes how the different development in the distinct fields of science at each moment in time have implied that the emergence of inventions is not equally possible for all industries[17]. From this point of view, technological opportunities would be the expression of the cost of invention that differs among industries.

In a similar line of research, Pakes and Schankerman (1984) define the technological opportunities of an industry as the reflection of the difficulty with which scientific knowledge allows firms to transform the inputs used in research on innovations. Although this focus seems appropriate, it is defined in excessively general terms to be satisfactory.

Cohen, Levin and Mowery (1985, 1987) make a more concrete approximation to the significance of technological opportunities establishing three factors that characterise and determine these: the degree of proximity to science, the importance of the external sources to technical knowledge and the industry maturity. Based on a known survey among executives of the main USA firms carried out by Levin et al. (1987), the authors build on some variables that approximate the three factors mentioned above.

[17] It is very interesting, for instance, the description that this author makes about the difficulty that supposed the substitution of wood by coal in some industrial activities.

The proximity to science is measured by the importance of the different basic and applied sciences (among 11 branches) in the technology of each industry. In reference to the influence exercised by the different sources of technical knowledge that operates with the firm, the variables that determine it can be defined in four different ways: the equipment and raw material suppliers, the users of the industry products, the governmental agencies and research laboratories. The last mentioned factor is approximated by a variable that captures the relative maturity of the technology of an industry through the industrial property and the equipment installed in a recent period of time. Following the distinct estimations done, the aforementioned variables are significant in the explanation of the R&D intensity.

The analysis that, from our point of view, presents a higher degree of accuracy is that of Jaffe (1986, 1988 and 1989) in its different studies. The main premise of this author in relation to this innovation dimension is in accordance with that exposed before because, for him, technological opportunities reflect the exogenous variation in the cost and difficulty of innovation[18] in what he calls, and this is where he is original, the different "technological areas"[19].

The author postulates the distinction that should be made between industries and technologies, concepts which in previous works have lead to confusion. Within an industry firms can adapt different technological strategies. The example of Jaffe clarifies

[18] However, the author recognises that the technological position of a firm can have a certain degree of endogeneity, although only in relative long periods of time. Then, he finds evidence of the adjustment of the technological position of firms in response to technological opportunities.

[19] Jaffe argues that the factors affecting innovation in the supply side cover two aspects both enshrined in the concept of technological opportunities: the variation in the intrinsic difficulty of the innovation in the different technological areas and the state of scientific knowledge in each area.

this. A firm in the vehicle sector can, for instance, carry out research in three different areas: engines, aerodynamics and the structural properties of some materials. For this reason, the use of dummy variables for each industry with the objective to incorporate technological opportunities in the empirical model (e.g. Scherer, 1982) does not seem adequate and, even more, when we pretend to distinguish between the effect of technology and that of market size.

The procedure of Jaffe is the following. First, the author classifies the patents achieved by a firm in a given period of time according to the corresponding technological epigraph working out, for each one, the proportion that those carried out in each technological field represents as part of its total number of patents. Consequently a vector of the participation that each firm has in each technological space is obtained. The relative technological proximity of each firm with respect to the rest of the firms is determined as a function of this vector. Thus, for each pair of firms, it is possible to obtain this data working out the angular separation of its vectors. Once Jaffe has these values, he identify clusters with a similar technological position, that is to say, combinations of technologies with a high scientific relationship.

Following this procedure, the author finds a very relevant effect of the dummy variables build on the technological groups mentioned above in four economic indicators: patents, revenues, profits and the market value of the firm. In any case, it is necessary to say that the distinction between industries and technological areas, although convenient, does not seem to imply important classification differences. When dummy variables for industries and technological areas are introduced into the regressions we observe that both factors are significant. When we consider each one independently the effects of the industry dummies are non-significant in the equation in which the dependent variable is patents.

Geroski (1990) also highlight the relevance that technological opportunities have over innovations. His estimations establish that variations in technological opportunities explain approximately 60% of variations in innovations. In this case, the dependent variable is the number of innovations and technological opportunities are encapsulated in the individual effects because this author considers that they cannot be measured by observables but have the property that, although differing by industries, are relatively constant in the short and medium run for each one.

More recently, we find the work of Thompson (1996). The author estimates for 13 industries the elasticity of the production function of R&D, which is interpreted as a measure of technological opportunities[20]. Some results of this research have to be outlined. There is a certain evidence of decreasing returns in R&D, that is, the number of additional innovations achieved decreases with the effort devoted to R&D. Moreover, the variations in technological opportunities over time are not correlated among industries, reinforcing the fact that they encapsulate very specific factors of each one. Therefore, the behaviour that technological opportunities of each industry present does not depend on what matters in other industries. However, the expected rate of growth of technological change in the different industries are clearly correlated with the expected growth at the aggregate level.

[20] What the author is really estimating is the marginal productivity of R&D for a given level of spending on R&D.

All in all, technological opportunities refer to the productivity that the firm located in a given industry (or, alternatively, technological area) obtains from its expenses on R&D, that is to say, reflects the importance of the innovation that can be reached given the R&D expense. This parameter is specific to each industry (or technological area) and its evolution seems independent of the evolution experimented in other industries and, without exception, it is very significant in the explanation of the allocation of resources to R&D.

II.6.- Uncertainty and appropriability

Perhaps, these are the two most characteristic aspects of the spending the firm directs to R&D of new products and process. At the same time, they are the least known and studied because of the difficulty of their analysis, although for the externalities case there have been in recent years a significant advance with the emergence of an increase in the literature.

The uncertainty aspect has been treated explicitly in theoretical models and, for this reason, it will be analysed in more detail in Chapter III of this thesis. In any case, it would be convenient to provide, at least, its concept. It seems quite evident that, when a firm devotes resources in order to maintain a given infrastructure on R&D (employees, plant and equipment) it does not know, a priori, what is going to be the result of this spending and when it will occur. That is to say, the firm faces a high degree of uncertainty about the productivity of the employed resources and in which period of time the results will be achieved. The theoretical modelling takes into account this fact through the so-called "hazard functions". It is established that the probability that a firm obtains an innovation in a given moment of time, conditioned on not having obtained it until this moment, depends directly on the amount of resources directed to R&D. That is to say, it is assumed that the greater the amount of resources directed to research the higher the probability to obtain an innovation in a shorter period. Although this type of modelling is interesting and, as we will see, outlines some relevant points, it has no empirical implementation and this is the reason why it losses a part of its interest.

The topic of externalities, usually reflected in the literature as the study of the impact that appropriability conditions of an industry have on the incentives a firm has to invest in innovation, has been treated in a relevant number of studies with the achievement of contradictory results. Although, the externalities of R&D are generally considered as the problem the appropriability of the profits an innovation leads to, it also presents another different aspect.

In this respect, Cohen and Levinthal (1989) highlight the role that the expenses on R&D can play as a way to acquiring the knowledge generated outside the firm and that can be profitable for it. These authors argue that the fact that the knowledge is in the public domain does not imply that it has to be considered as a public good because costs of assimilation of the technological knowledge exist. In other words, the firm has to acquire enough training (through expenses on R&D) for interpreting in its own benefit the knowledge that is at its disposal. From this point of view, the expenses on R&D not only serve to generate innovations but also to improve the ability of the firm in order to assimilate and extract the existing information from different sources. Thus, the spending on R&D has an aspect called "absorptive capacity".

Following these premises, Cohen and Levinthal (1989) develop a theoretical model reflecting the generation of the technological knowledge of a firm through three sources: the spending on R&D by the firm, the externalities generated by the R&D of the rival firms and the knowledge generated outside the industry. The last two factors influence the firm's knowledge to a greater or lesser extent depending on its ability to assimilate them. This ability will depend on its own expenses on R&D which are conditioned by the external knowledge features (for instance, the complexity that the knowledge to acquire incorporates or the degree to which this knowledge may cover the firm's needs reflecting the greater or lower difficulty of its learning). In fact, in their theoretical analysis, the authors demonstrate how at the same time that assimilation (or learning) depends on a higher extend on own R&D expenses, more important technological opportunities or externalities have a stronger impact in its R&D effort. Therefore, the inclusion into the model of the existence of an endogenous "absorptive capacity" may modify the qualitative impact of the determinants of the innovative activity mentioned above.

The empirical analysis tries to include both the negative aspect of the externalities (appropriability) and the positive one (absorptive capacity) over the R&D effort of firms. Although the latter cannot be done directly, it is feasible to see how the different level of difficulty of the knowledge assimilation that each industry presents[21]

[21] It is measured by the maximum score revealed in the aforementioned survey of Levin et al. (1987) that six different mechanisms have in the efficiency of protecting the profits generated from new process

influences the distinct impact that appropriability has in the variables of interest. The estimations reveals a negative net impact of externalities but they confirm that the "absorptive capacity" effect is significant. Moreover, the positive effect grows in relation to the negative one the greater the intrinsic ease of learning of each industry, the higher the price-elasticity of demand and the higher the number of firms in the industry[22] (these last two related with a more competitive environment).

We find in a similar line of reasoning the work of Jaffe (1986). From the author's point of view, there exists a positive aspect of the externalities that is not sufficiently taken into account in the literature. Following Jaffe, the scientific knowledge is by its nature a public good[23]. So, the existence in the firm environment of technologically related research efforts can allow the achievement of similar results devoting less amount of resources to R&D than would be necessary in a situation where this did not occur. Therefore, from a strictly technological point of view a positive externality exists, that is, the productivity of R&D is increased with the R&D of technological neighbours. However, the author also recognises that this type of externality cannot be identified in practise and distinguishes it from the negative effect that from an economic perspective is produced because of competitors′ rivalry.

---

and products: patents that protect duplication, patents that secure revenues through royalty rights, secrecy, being the first to obtain the innovation, faster movement through the learning curve and complementary efforts in services and sells.

[22] In a version of the theoretical model in which the authors introduce the process innovation aspect, they demonstrate that in more competitive environments is more likely that the equilibrium level of R&D grows with externalities. This is because greater competition implies that the private loss associated with the public aspect of the externalities of R&D decreases in relation to the private profits that represents "absorptive capacity".

[23] In this sense, Jaffe does not take into account the cost that supposes the knowledge acquisition outlined by Cohen and Levinthal (1989).

In order to study the impact of the externalities on the different indicators of the output of the innovative activity (patents, profits and market value of the firm) Jaffe build on a variable that serves as an indicator of the externalities that are potentially at the disposal of a firm coming from the firms located in its technological area. This index is composed of a weighted sum of the R&D of the firms located in the corresponding technological area, where the weight is defined by the "technological proximity" between two firms as explained in the previous epigraph. In any case, the author assumes that appropriability conditions are the same in all technological areas.

The corresponding estimations reflect a positive impact of the externalities on patents both directly and indirectly through the elasticity of R&D. However, this impact is negative if we consider the direct effect on profits and the market value of the firm. The indirect effect through the increment in the productivity of the own R&D is relevant in firms with a high effort on R&D, but for those below the average it can even be negative. The negative effect because of rivalry seems to play a greater role in those firms with lower effort on R&D. In posterior works (Jaffe, 1988 and 1989) the author confirms these results.

In the work of Cohen, Levin and Mowery (1985, 1987) already reviewed, there is also an approximation to the problem presented by externalities. Similarly to previous studies, these authors recognise a double aspect derived from them. On the one hand, they highlight the necessity of the existence of effective measures that favour the appropriability of the profits of the innovation in order to encourage the incentives of a firm to invest in R&D. Alternatively, the existence of externalities acts to increase the productivity of R&D reinforcing the basis of the scientific knowledge of the industry. Following the survey of Levin et al. (1987) they build on two types of variables. One reflects the appropriability aspect (whose impact will be likely positive in the effort on R&D). The other captures the time necessary to imitate a patent that incorporates a relevant product innovation (the greater the time of imitation, the greater the firm incentive to invests on R&D but, because of the reduction of the externalities, the lower the productivity of R&D). The estimations confirm the foreseeable effects of the different variables.

Levin and Reiss (1988) develop a theoretical model that incorporates product and process innovation and in which both are the result of the expenses on R&D carried out by the firm and of the amount of industry knowledge at its disposal. The latter is composed of its own expenses on R&D as well as those of rival firms which are included in the mentioned amount as imperfect substitutes (the degree of substitution is determined by the level of the existing externalities). This implies that greater competition in R&D by rival firms decreases the marginal productivity of own R&D. Moreover, the effect that R&D of the rival firms has on the reduction of the unitary cost of production of a given firm or over the improvement of the quality of its products will be a function of the extension of these externalities as well as of its productivity (i.e. the utility of the acquired R&D).

In this model, it is allowed that technological opportunities and the degree of appropriability could differ between the R&D devoted to product innovation and that devoted to process innovation. Thus, it is possible to examine the impact of the externalities both in the amount and composition of R&D. The estimations of this model reveal a relevant inter-industrial variability in the amount and productivity of externalities. In any case, and it is important to note it, both in the product and process innovation cases it is not possible to reject that the extension of the externalities be different from zero.

Finally, we will mention two aspects of the externalities not often studied in the literature: its international transmission and its impact on the geographic concentration of the innovative activity.

In the first case, Coe and Helpman (1995) try to study how the total factor productivity of a country depends, apart from its own R&D stock, on the R&D stock of its trade partners. Own R&D allows the firm to profit in better conditions from foreign technical advances which increases its productivity. Foreign R&D have direct and indirect effects. The direct effects imply the learning of new technologies, production processes, etc. The indirect effects are encapsulated in the goods and services imported. The estimations of these authors indicate that the beneficial effects of foreign R&D on a country's productivity are greater the more open its economy is.

Audrestsch and Fieldman (1996) highlight the importance of the externalities for the geographic location of the innovative activity. Their premise is the following. If the capacity to receive the externalities of knowledge is a function of the distance to the source of this knowledge, a certain geographic concentration should be observed and be stronger in those industries in which externalities of knowledge have, presumably, greater importance. Their estimations for the USA economy show that, even taking into account the geographic concentration of production, greater concentration of the innovative activity is identified in those industries in which externalities are more relevant (that is, where the industry R&D, the University research and the qualified labour are more important).

All in all, we have to realise that the externalities of innovation not only have to be seen in their aspect of a negative incentive for the expenses on R&D through imitation or rivalry but also as a positive incentive through the existent knowledge in the firm environment that may increases the productivity of its R&D.

II.7.- Conclusions

So far we have analysed separately what are thought to be the main determinants of the resource allocation to R&D of new process and products by firms or, in general terms, of their innovative activity.

It seems that firm size and industry concentration (following the Schumpeterian hypothesis) have no clear influence on innovation specially once we have taken into account other variables with more solid economic justification. In any case, is probably more convenient to establish the inverse causation order, that is, from innovation to concentration and firm size. As Culbertson (1985) outlines, these last two variables are connected through market dimension.

More importantly is the impact of demand conditions, degree of appropriability and technological opportunities presented by the different industries. The first two are more directly related to the profitability of the innovation and the latter to the productivity that can be achieved from the R&D expenses (difficulty of the innovation) that can also be affected by certain positive externalities. The diverse empirical studies analysed in this chapter confirm the significance of these variables although they differ, to a greater or lesser extent, in their relative importance. Apart from the mentioned variables, there exist other factors with lower relevance that have also been taken into account by the literature such as cash-flow, output diversification, management capacity, etc.

As we have observed, in the different sections we have made repeated mentions to different studies. This is due to the effort made to isolate each determinant of the innovative activity in order to make an individualised study with the aim to ease its understanding. It is quite clear that these factors act jointly in the explanation of the innovation process and that some interactions also exists among them. They have been outlined in the chapter as and when necessary.

CHAPTER III: PRODUCT DIFFERENTIATION AND PROCESS R&D

CHAPTER III: PRODUCT DIFFERENTIATION AND PROCESS R&D

III.1.-THE THEORETICAL MODELS ON INNOVATION

III.1.1.- Introduction

The theoretical literature accepts that a firm has mainly two reasons for investing in R&D. First, the achievement of a new (or better) product or a more efficient productive process in the development of its activity. Second, the acquisition of the knowledge and ability necessary to adapt itself to the dynamic evolution of the industry in which it enhances its activity and, at the same time, benefit from the valuable available information.

Usually, economic models have only paid attention to the first of these factors[1] establishing that a firm has two motivations for doing R&D: the pursuit of greater profits (profit incentive) and the maintenance of a given competitive position which is in danger because of the action of its rivals (competitive threat). The "profit incentive" will exists even if the firm would be alone in the market and encapsulates the desire of a firm to increases its profits. The "competitive threat" appears because a firm does not want to loss its current market position and it is looking for a strategic advantage.

The attempt by the economists of explaining the R&D phenomenon has driven to the emergence of a high number of models. These models arrive at different

[1] One exception is the aforementioned model of Cohen and Levinthal (1989).

conclusions as a result of the different assumptions made. Therefore, it is necessary to define accurately the assumptions about the behaviour of economic agents and the parameters and functional forms employed in each model in order to have a good understanding of the implications of the resulting outcomes. By doing this, it will be possible to better evaluate the virtues and shortcomings of the model developed in the next section which will serve us as a basis for the empirical analysis.

There are two types of models: decision-theoretic approach (developed in the sixties) and game theoretic literature (since 1980). As it seems clear, with the course of the years models have become more sophisticated and realistic. Therefore, we will pay attention to the game theoretic approach as more adequate focus for our purpose: the explanation of how firms allocate resources to innovative activity and the market structure that is obtained as a result of this process.

The game-theoretic literature has four paradigms. Two of them assume a deterministic relationship between the amount of money spent in R&D and the innovative output that results: auction models and non-tournament models[2]. In the rest, there is a stochastic relationship between the amount of R&D and the expected date of innovation: tournament models and the probabilistic contest model.

However, the important distinction that appears in the literature is that which exists between tournament and non-tournament models. As we have said above, in tournament models it is assumed that firms, by investing resources in R&D, are able to

[2] The most known of these models is that of Dasgupta and Stiglitz (1980).

influence the date of the innovation[3]. This fact has the implication that firms are involving in something similar to a race to be first to make the discovery. As a consequence, these types of models are characterised by the existence of one successful innovator only. In contrast to tournament models, non-tournament models assume that the amount of R&D affects only the size of the innovation and, as a consequence, it is allowed the possibility that many firms obtain it. This is possible because of the existence of many different research path with equal result or, alternatively, the intrinsically unpatentable nature of the innovation.

As in tournament models, in auction models there can only be one successful bidder and this is the reason why in this kind of models the "strategic" incentive outlined above (competitive threat) has the central role. For his part, in the Probabilistic Contest Model it is assumed that the probability for a firm for being the successful innovator depends on the amount of resources invested by this specific firm as a ratio to the total amount spent in the industry in which the firm is located.

Apart from these considerations, there are also two important distinctions in the elaboration of models that have very important implications. The first one is between process and product innovation, each one with differentiated effects in firm's profits as already mentioned in other sections. In some situations, the consideration of one type of model or another could reverse the conclusions. The second distinction is between a single innovation and a sequence of innovations. In a single innovation model it is

[3] We are placed in a context of uncertainty if we assume in our model that the investment in R&D has only a limited probability of success at any time that depends directly on the amount of resources employed. Alternatively, we are in a model of certainty if the relationship between the resources devoted and the date of success is deterministic.

assumed that there is only one stage in the R&D competition game. Then, the prize obtained from become the innovator last forever. However, it is more realistic to consider that the game has more than one stage. Thus, if we consider that the R&D competition is repeated in various stages we are in a model of sequence of innovations. In this case, in each stage the winner can be the same as in the precedent stage or another and this fact can dramatically change the outcomes obtained when a single innovation is considered.

In the next epigraph, we will revise briefly the more relevant features of some tournament models with uncertainty and auction models. We will do this for two reasons. First, because these models are those with more academic influence, although they do not have empirical implementation. Second, because in the context of the former the uncertainty aspect of R&D is encapsulated and in the context of the latter the differences existing in the evolution of the market structure when we consider alternatively process innovation or product innovation are evidenced.

By doing this, we would have established the framework for a better understanding of the theoretical model developed in next section.

III.1.2.- The importance of the assumptions

The model of Loury (1979) is considered one of the pioneer in the context of tournament models with uncertainty. Loury develops his model with the objective to study the impact of market structure on R&D performance at firm and industry level and the corresponding welfare implications.

This model assumes the existence of "n" identical firms in the market which compete for the achievement of a "perpetual" flow of rewards "V" (single innovation), considering that one firm only introduces the innovation. Each firm invest in R&D under both technological and market uncertainty.

Technological uncertainty is present because there exists a stochastic relationship between a firm's R&D investment and the time at which it obtains the innovation. Then, Loury considers that a firm "i" by making a contractual commitment[4] to R&D, that implies a present value of cost of, say, "x_i" purchases a random variable $\tau(x_i)$ which is the representation of the uncertain date at which the successful innovation takes place. Or, in other words, the assumption is that the random variable $\tau(x_i)$ is purchased by paying "x_i" at $t = 0$. The technological relationship considered is that $\tau(x_i)$ is exponentially distributed, that is:

$$pr\left[\tau(x_i) \leq t\right] = 1 - e^{-h(x_i)t}$$

where:

t: time

[4] The literature makes an important distinction between contractual and non-contractual cost in R&D. We are in a model with contractual cost when R&D expenditures take the form of a lump-sum incurred at the outset. Non-contractual cost implies that each firm incurs in a flow cost until someone successfully innovates. Of course, in the real world the most likely situation is a mixture of both.

$h(x_i)$: is a constant function of x_i called "hazard rate" and represents the probability that a firm innovates in a small interval of time conditional on no one else has succeeded up till then. Loury assumes that this function has initially increasing returns to scale in order to ensure a finite number of firms in the industry.

The expected time at which the R&D project will be successfully completed is:

$$E\tau(x) = h(x)^{-1}$$

Market uncertainty results from assuming that firms are uncertain about the date at which any of its rivals' R&D effort will be successful. Let $\hat{\tau}_i$ the random variable that represents this unknown date. Assuming rational expectations the relationship between $\hat{\tau}_i$ and the behaviour of other firms is given by:

$$\hat{\tau}_i = \min_{1 \le j \ne i \le n} [\tau(x_i)]$$

Assuming no externalities in the R&D process the random variable can be taken as independent. Then:

$$pr(\hat{\tau}_i \le t) = 1 - \exp\left[-t\sum_{i \ne j} h(x_i)\right] = 1 - e^{-a_i t}$$

where:

$a_i = \sum_{i \neq j} h(x_j)$, is taken as given by the i-th firm.

Knowing that there is a reward flow of "V" and given the market structure, equilibrium occurs when each firm investment decision maximises its expected discounted profits, taken as given the R&D investment strategies of other firms (Cournot assumption).

Due to the existence of symmetry in the model (which implies the same investment strategy for all firms) Loury arrives to the following result:

$$x^* = x^*(n, r, V)$$

where

x^*: equilibrium level of firm's R&D given the market structure.

n: number of firms in the industry.

r: interest rate.

Loury was interested in studying the impact of greater rivalry (an increasing number of identical competing firms in the industry) on a firm's innovative activity, that is, the sign of $\frac{\partial x^*}{\partial n}$. The author finds that this expression is negative which implies that the increment on rivalry decreases the expenses on R&D done by each firm. It is important to note that this result does not implies that a more competitive market structure means a latter expected introduction date for the innovation. In fact, the contrary occurs because the increment in the number of firms compensates the reduction in the amount of R&D spent by each one.

Another important result of Loury is that in the long-run industry equilibrium (zero expected profits condition), when there is an initial range of increasing returns in the R&D technology, all firms invest below the efficient scale, that is, above the minimum average cost level (excess capacity proposition).

Concerning the welfare analysis, Loury refers to three factors that act against socially optimal resource allocation:

1.- A generic factor that results in the known failure in the market for inventions (appropriability).

2.- A short-run factor, that is, when we consider as given the number of firms in the industry. In this case, the symmetric Nash equilibrium implies that each firm has the same probability ($1/n$) of being the innovator. Thus, in the short-run equilibrium, firms have the tendency to invest in R&D more than is socially optimal because they do not take into account the parallel nature of their activities. The social loss is the result of the duplication of effort.

3.- A long-run factor, that appears when it is considered both socially optimal (maximisation of social profits) and industry equilibrium (zero expected industry profits condition) number of firms. Loury demonstrates that if there are initially increasing returns to scale in R&D, the industry equilibrium induces too many firms joint the innovation race if we compare it to what is socially optimal. This is clear because, with initial economies of scale in R&D, the social optimum implies a finite number of firms producing at efficient scale and earning positive expected profits but due to positive expected profits tend to incentive entry this is not the case in the market equilibrium.

Lee and Wilde (1980) note that some of the conclusions of Loury are sensitive to the specification of the cost of R&D. In particular, the result that an increase in rivalry implies a reduction in the equilibrium level of firm's investment and the existence of excess capacity.

These authors consider a model formally identical to that of Loury except in one aspect, that is, the assumption that the random variable specified above ($\tau(x_i)$) is now purchased by paying a fixed cost (F) and incurring in a flow cost "x" which is paid until someone in the market produces a new technology.

This modification implies that the expression of the function of the expected discounted profits is not the same in both models. In particular:

Loury's model

$$E\Pi = \frac{Vh}{a+r+h} - x$$

where

x : expected total cost (fixed cost).

Lee and Wilde model:

$$E\Pi = \frac{Vh - x}{a + r + h} - F$$

where

$\frac{x}{a+h+r}$: expected variable cost.

F: fixed cost

With this new formulation Lee and Wilde obtain, contrary to Loury's model, that as the number of firms increases, the equilibrium investment rate in R&D per firm increases as well and that in the symmetric Nash equilibrium with free entry all firms invest at greater than efficient scale.

The differences between the two models can be intuitively explained. In the Loury's case an increase in the number of firms, by reducing the probability of success, reduces firm's expected profits. In the case of Lee and Wilde expected cost are also reduced. As we have seen the change in a, in principle, not very important assumption could reverse some results.

The models considered above were concerned both the existence of a number of identical firms and a single innovation. Reinganum (1985), assuming non-contractual cost change these two hypotheses and suppose, firstly, that in spite of identical agents there is one firm that is the current incumbent while the remaining firms are the challengers, and secondly, that the context is that of sequence of innovations. This last assumption means that the privilege position that success provides is only maintained until the next innovation is reached. In general, the essential distinction between a single innovation model and a sequence of innovations model rests in the different calculations of the relative gains for winning the lead in a particular time. In the first case the gains last forever but in the second exists the possibility of loosing this lead.

Apart from last comments, Reinganum suppose that innovations are drastic in the sense that the advantages of the new technique permit the winner to earn monopoly profits until the next innovation is introduced. The author builds a game in which she assumes the existence of t-stages and by using the concept of subgame perfect Nash equilibrium play arises to the following conclusions:

1.- The outcome is that of Schumpeterian concept of creative destruction[5] (or action-reaction) in which the monopoly that a firm has is rapidly overthrown by the winner challenger.

2.- Nash equilibrium is symmetric among the challengers, while the incumbent always invests less than the challenger because the former has a greater incentive to delay innovation and continue earning current monopoly profits.

3.- The value of being the incumbent is lower the greater the number of remaining situations and the value of being a challenger increases with the stock of remaining situations. Therefore, incumbent and challengers alike invest less in the

[5] In a model with sequence of innovations the outcome can be of two forms: creative destruction or persistent dominance. Persistent dominance implies that the incumbent maintain or extent their position of supremacy. Obviously, in this framework in some stages can be action-reaction and in other

current innovation when a higher number of future innovations are anticipated. In all cases, there is less investment than in the model of Lee and Wilde.

As Beath, katsoulacos and Ulph (1987) point out, the sequential structure of the Reinganum model does not affect her main conclusions. Because of the drasticness assumption the present value of all future profits conditional on winning or loosing are independent of the point in the sequence where the firms are placed. Vickers (1986) analyses, in the context of an auction model, the implication of considering a sequence of innovations when drasticness does not exist. In this case, the profits from winning or loosing a particular patent race are dependent on previous history, that is, the sequence in the evolution of firms is relevant.

Vickers′ results are.

1.- When market competition in the single period is of the form of Cournot competition, we will get action-reaction if technical progress is sufficiently slow.

2.- If market competition is à la Bertrand, the outcome will be always persistent dominance.

3.- Under drasticness assumption we have an indeterminacy.

The auction model of Beath, Katsoulacos and Ulph (1987) is formally similar to that of Vickers but there is a very important difference: in this case product innovation is considered. It is clear that profit maximisation implies that under process innovation

persistent dominance. As it seems clear, the evolution of the industry structure is endogenous to the process of dynamic competition.

at each stage in the sequence each firm will only ever employ the single best technology it has access (through a patent) but this is not necessary true under product innovation following the conclusions reached by Shaked and Sutton (1982).

The assumptions of the model are:

1.- Two firms.

2.- Bertrand competition in the product market.

3.- At the start of a period "*t*" the best quality product for which each firm has a patent is different. Therefore, one of the firms will have a better quality product than the other.

4.- Market structure is exogenous (result of assume exogenous pace of progress in technological knowledge and that each firm produces only one product due to diseconomies of scale).

5.- Drawing on the work of Shaked and Sutton (1982) all the assumption that characterises a Bertrand equilibrium in a vertically differentiated market.

With this framework, the authors reach to the conclusion that industry profits are a strictly concave function in the quality gap between the two firms. Thus, in a context of Bertrand competition we have action-reaction if technical change is rapid enough (in fact, it needs to be so rapid that neither firm can ever make the best response to the newly introduced product) and the outcome will be persistent dominance if the rate of product improvement is sufficiently slow (it needs to be so slow that the best response to the last improvement is outside the range of the first, although not the second, firm at the outset of the sequence).

As we can observe, these results are very different to that of Vickers for process innovation.. It is possible to demonstrate that in the later case industry profits are a convex function of the cost gap between firms and this is the explanation why the conclusions are reversed.

Among tournament models with uncertainty the most general and complete one is that of Beath, Katsoulacos and Ulph (1989a), in which it is modelled a single stage strategic R&D race between two firms to be first to introduce some new technology. In this model, the amount invested by each firm in R&D depend on the magnitude of the two incentives that we have outlined above:

1.- The profit incentive collects the desire to increase profits through the investment in R&D. Numerically it is the difference between the profits the firm would obtain if it wins the race minus the current profits. This incentive would appear even if the firm were not in a race among rivals.

2.- The competitive threat is the difference between the profits that the firm would have if it wins the race minus the profits obtained in the case in which the firm loss the race.

The relative magnitude of these two elements will determine the firms' R&D strategy and hence the outcome of the race. In this model, the possibility of the existence of asymmetry between firms is incorporated in the sense that one of the firms may have higher current profits than its rivals (possibly as the outcome of some previous race). In the same way, the model allows that the profits that each firm makes conditional on wining or loosing could be different.

Assuming no learning by doing and the exponential relationship between R&D expenditure and the probability of discovery outlined above, the model establishes that if one firm chooses a constant hazard rate the best response of the other firm is to choose a constant hazard rate.

Formally, the expected present value of profits of each firm can be written as:

Firm 1: $V(x,y) = \dfrac{Ax + By + s - \gamma(x)}{x + y + r}$.

Firm 2: $W(x,y) = \dfrac{Dx + Ey + t - \gamma(y)}{x + y + r}$.

where:

firm 1 is assumed to be the incumbent and firm 2 the follower.

x: is the "hazard rate" of firm 1.

y: is the "hazard rate" of firm 2.

$A(D)$: is the present value of future profits for firm 1 (2) if firm 1 innovates.

$B(E)$: is the present value of future profits for firm 1 (2) if firm 2 innovates

$s(t)$: current profits of firm 1 (2).

$\gamma(x)[y]$: is the function that represents the instantaneous resource cost of achieving a "hazard rate" of $x(y)$. It is assumed that this function exhibits decreasing returns in order to have a unique equilibrium.

It is assumed that $A \rangle B$; $Ar \rangle s$; $D \rangle E$ y $Dr \rangle t$.

From the first order conditions ($\frac{\partial V}{\partial x} = 0$ and $\frac{\partial W}{\partial y} = 0$) we obtain the reaction functions and hence the Nash equilibrium in hazard rates.

If we concentrate on firm 1, the reaction function must satisfy that:

$$(A - B)y + (Ar - s) + \gamma(x) = (x + y + r)\gamma^{'}(x)$$

There are two points in the reaction function in which we are interesting in:

- Let x_0 the optimal response of firm 1 when firm 2 does not spend in R&D ($y = 0$). Then, we have that $(Ar - s) + \gamma(x_0) = (x_o + r)\gamma^{'}(x_0)$. The only force that incentives firm 1 for doing R&D is the desire to increase the flow rate of profits $(Ar - s)$ taking into account the additional cost of this increase. This is the reason why x_0 is usually associated with the profit incentive.

- Let $\bar{x}$ the optimal response of firm 1 when $y \to \infty$. In this case $A - B = \gamma^{'}(x)$ is satisfied. Now, the important incentive is the difference between the profits the firm 1 would obtain if it wins the race and those it would obtain if it loss (again, taking into account marginal cost). Therefore, $\bar{x}$ is interpreted as the competitive threat.

The value of these points determine the position and form of the reaction function. The major determinant of these relative magnitudes is the ease of imitation. We can consider two cases:

1.- Imitation is not possible (the product or process innovation is perfectly protected by a patent). In this case, it is reasonable to consider that $Ar \rangle s \rangle Br$. That is, if firm 2 wins it will be true that firm 1´s profits will be lower than its current profits. In this case, $x_0 \langle \bar{x}$ and the reaction function is upward sloping. The best response of firm 1 in view of an increase in R&D of firm 2 (that increases its hazard rate) is to increase also the investment in R&D.

2.- Imitation is very easy. This implies $Ar = Br \rangle s$, and considering that the rate of interest is not too low $x_0 \rangle \bar{x}$ is accomplished. Contrary to the previous case the reaction function is downward sloping and the best response of an increase in firm 2´s hazard rate (derived from more spending on R&D) is a decrease of firm 1´s hazard rate (less spending on R&D). In this case a free rider phenomenon appears because each firm is waiting for the other to be that innovator (waiting game).

The distinct combinations for both firms give four possible cases. If we let x^* and y^* the equilibrium hazard rates that are reached we have that:

If $(A-B) \geq (D-E)$ and $(Ar-s) \geq (Dr-t) \Rightarrow x^{*} \geq y^{*}$

where:

$(A-B)$: is the competitive threat of firm 1.

$(D-E)$: is the competitive threat of firm 2.

$(Ar-s)$: is the profit incentive of firm 1.

$(Dr-t)$: is the profit incentive of firm 2.

We can relate the models we have seen up till now with this general model.

In Loury (1979) and Lee and Wilde (1980) models it is implicitly assumed that $A = D \rangle 0$; $B = E = 0$; and $s = t = 0$. The "profit incentive" and the "competitive threat" are the same for both firms and the outcome is indeterminate.

Reinganum (1985) assume that $A = D \rangle 0$; $B = E = 0$; $s \rangle 0$ and $t = 0$. In this case the "competitive threat" are identical but the incumbent has a smaller profit incentive. When this occurs, we have that $x^{*} \langle y^{*}$ (action-reaction).

Harris and Vickers (1987) develop a sequential model[6] formally very similar to this but with the assumption that $r = s = t = 0$, that is, they do not include current profits in the calculation of the expected payoff. Thus, in this model there is no profit incentive and what matters is the competitive threat.

---

[6] A sequential model means that firms are competing for the achievement of a single innovation but in a context of multistage (two or more) races.

In sequential models it is important to distinguish if they are of a "catch-up" or a "leapfrog" form. "Catch-up" implies that the follower and the leader are competing for different innovations in the sense that at each time the follower is not able to compete for obtaining the same position of the leader. If the follower wins the race all that it can obtain is the current position of the leader. Then, the point of departure is different. The contrary occurs in the "leapfrog" models where leader and follower are competing for the same innovation. Then, the follower can overcome the leader if it wins. The implicit assumption in these models is that once an innovation is patented, the knowledge that it incorporates becomes a public good.

The model of Harris and Vickers is of a "catch-up" form and the newness it incorporates in relation to precedent models is the consideration of strategic interaction between competitors as the race unfolds. The main aim of Harris and Vickers is to analyse how the efforts of competitors in a race vary with the intensity of rivalry between them. They develop two models (one dimensional and two dimensional race) in a multistage game framework which conclusions are (in the case of a two dimensional race they need additional assumptions to reach to the same results) that the leader in the race makes greater effort than the follower and that this effort increases as the gap between competitors decreases. Moreover, the effort of the follower falls if this deficit increases. In general the player with higher incentive (in this case the leader) works harder.

Due to the impossibility to express in models with uncertainty the link between equilibrium levels of R&D expenditures and the parameters of the model in a single closed form, analytical results do not exist when considering sequences of innovations. Therefore, it is necessary to resort to computer simulations.

Based on a model with an homogeneous product, constant elasticity demand curve, the consideration of a T cost-reducing innovations and a quadratic cost function, Beath, Katsoulacos and Ulph (1989b) reach to the following results:

1.- If we consider Bertrand competition in the product market and a model of "catch-up" form the outcome always will be persistent dominance. By contrast, if we have Cournot competition and "leapfrog" we will obtain action-reaction.

2.- In a model with Bertrand competition and "leapfrogging" in the early races the outcome is action-reaction but in the last races it is persistent dominance.

3.- With Cournot competition and "leapfrogging" the outcome is very changeable and depends on the rate of technical change and the interest rate.

4.- In general, Bertrand competition produces more dominance that does Cournot.

As we have seen in this section, the assumptions made in the different models of R&D have very important implications and can change the outcomes and conclusions in a very drastic manner. For this reason, we have to take into account all the considerations established to interpret the affirmations carried out in the model developed in the next section which we will serve us for the empirical testing.

III.2.- PRODUCT DIFFERENTIATION AND PROCESS R&D: THE MODEL

III.2.1.-Introduction

A firm faces two possibilities when investing in R&D: to devote resources with the intention of cost reduction (process innovation) or in order to shift its demand curve rightward (product innovation). These alternatives are not necessarily substitutes and, in fact, a firm directs its efforts towards both options. Moreover, the introduction of a better product into the market generally needs some improvements in the production process[1].

As far as we know, the literature on innovation does not take into account explicitly the obvious interrelation that in the profit function exists between product and process innovation[2]. This is because it is common to establish highly restrictive assumptions in order to simplify the tractability of the problem analysed. Some of them are to consider a homogeneous product or only one aspect of innovation (product versus process). However, the natural environment of firms that invest in R&D is normally an imperfect competitive market where product differentiation is a condition for surviving. In this sense, the optimum cost of production for the firm would depend on its level of differentiation because, as we will see, this will be one of the important factors which determine the returns achieved from process R&D.

[1] Levin and Reiss (1988) recognise that this is normally the case.

[2] There have been recently some interesting research that try to explain the factors that influence both types of innovations. See, for instance, Levin and Reiss (1988), Bertschek (1995), Cohen and Klepper (1996a), Klepper (1996), Bonanno and Haworth (1998) and Yin and Zuscovitch (1998).

All these considerations show that the relationship among the different variables affecting the decision of a firm to devote resources to innovation is more complex than previous literature suggest. We should find at least two different types of interactions at the intra-industry level. On the one hand, there exists a strategic interdependence among firms determined by their relative qualities and prices and which is responsible for market structure. On the other hand, and as a consequence of the first interaction, the firm must choose the "sharing rule" between product and process R&D. At the inter-industry level, things are even more complex because we also have to consider the impact (and interactions) of other important variables, such as technological opportunities or market dimension.

In order to demonstrate that all these points matter it seems interesting to analyse, as a first step, what the effect is of vertical product differentiation on the decision of a firm to allocate resources to R&D in process innovation. This is the most important aspect of this chapter. Until now, the essential contribution that competition among firms in a market induces in technological competition has not been explicitly considered in the sense we have established here. In this regard, the consideration of the effect on innovation of variables as could be "firm size" losses part of its significance. The reason is that the relative position of the price-quality relationship of a firm in the market determines its sales and, therefore, variables reflecting the strategic behaviour of firms substitute the aforementioned determinants. The idea is that competition among goods (firms)is a clear determinant of technological competition.

To do this, we start by considering the demand structure that comes from the model of Ulph (1991) in which differentiation arises due to the two innovating firms included have a quality gap in the specific product characteristic in which they are leaders. However, the key point of our model is that these firms need to invest in process innovation in order to introduce a better product into the market. That is, the improvement in the production process is the condition we impose to obtain a better product. At any moment, the quality of the product is taken as given. The argument is that process R&D is essential in order to introduce a higher quality product into the market and the amount devoted to this spending will depend on the degree of vertical differentiation in a specific way.

The problem we face is similar to that of Dasgupta and Stiglitz (1980) but with two important differences. On the one hand, there is Bertrand competition in the product market. On the other hand, firms are not necessarily identical because they can face distinct values for the parameters in the demand equation due to differentiation. In this sense, each firm confronts its own price-demand elasticity which, among others, is an important determinant for the effectiveness of the spending on process innovation.

The indirect effect that the reaction of the rival firm induces and the specific form of our cost function has impeded us to obtain a close analytical solution. Alternatively, we have performed numerically computed simulations in order to determine the effect of the different parameters involved. Previously, the direct impact of each factor in the variable of interest has been established (as far as possible).

III.2.2.-The model

In order to develop our model we have followed some interesting aspects of the product innovation model of Ulph (1991)[3]. However, in our case each type of good (firm) may have a different unit cost of production as a result of the assumption that the innovative firms must invest in process R&D to introduce their higher quality product into the market. The amount invested in this type of innovation will be determined by intra-industry (competition among firms) and inter-industry (market dimension and technological opportunity) variables.

It is necessary to remark that we are only interested in the effect of differentiation on the level of R&D spending in process innovation and on process R&D intensity. Then, we have started from a specification of the demand equation that includes quality gaps in its arguments, allowing us to reach our objective. However, it should be quite clear that a quality gap is mainly the result of product innovation, a decision that is not taken into account here because it exceeds the scope of this research although it has no consequence for what we want to demonstrate[4].

---

[3] This model was originally developed in order to study the relationship between the industrial structure and the rate of growth in an economy. A generalisation of this model to study the influence of both R&D technology and economies of scope between product dimensions in the effort made by firms in R&D is found in Ulph and Owen (1994).

[4] This assumption is not strange in the literature. For instance, Yin and Zuscovith (1998) take the product innovation decision as given to study what matters with process innovation and the reverse. Our objective is to stress the relevance of the interactions between product and process R&D. Interactions that have been obviated in previous literature (Levin and Reiss, 1988, Cohen and Klepper, 1996a, etc) that tried to explain the factors affecting both types of innovations. We want to demonstrate that this "omission" is not trivial.

We are succinctly going to describe the main features of the demand structure and firms' behaviour considered in the model of Ulph (1991). The assumptions of this model are:

1.- It is assumed that the good produced by each firm has two fundamental characteristics (let "**a**" and "**b**").

2.- In the market there are two innovative firms and many non-innovative ones. Each innovative firm is leader in one of the two fundamental characteristics.

3.- At each moment there exists one quality gap for the innovative firms in relation to the non-innovative ones. Thus, we will name "basic good" (let good 0) the one which embodies the second highest level of quality in both characteristics and that will be produced by the non-innovative firms.

4.- α and β denote the characteristic gaps that each innovative firm has in dimension "a" and "b" respectively. Then, the vector of characteristics gaps is $v^i = (\alpha^i, \beta^i)$ where $\alpha^i = a^i - a^0$ and $\beta^i = b^i - b^0$. Considering the simplest case in which each innovative firm is leader in one of the two characteristics, we have three types of goods: good 0 (basic good), good 1 (firm 1) with a vector of characteristic gaps $v^1 = (\alpha, 0)$, and good 2 (firm 2) with a vector of characteristic gaps $v^2 = (0, \beta)$.

5.- Each firm has a constant unit cost of production $(c\rangle 0)$. In Bertrand competition the price of the basic good is equal to the unit cost of production, that is normalised ($p^0 = c = 1$). Firms that produce the basic good obtain zero profits.

6.- On the demand side, consumers have a Cobb-Douglas utility function of the form:

$$U = \log(R) + \log(\sum_{0}^{2} q^i x^i) \qquad (1)$$

where x^i is the quantity of good "i", q^i is the quality of good "i" as perceived by the consumer and "R" is the income spent on other goods.

There are two dimensional distribution of consumers represented by the vector of weights they attach to each of the two characteristics $(v, w) \geq 0$. It is assumed that for these consumers the expression of perceived quality has the form:

$$q^i(v,w) = \exp(va^i + wb^i)\,;\ (i = 0, 1, 2) \qquad (2)$$

It is assumed that the variables v and w are independent and identically distributed with density functions e^{-v} and e^{-w} respectively.

The consumer optimisation and the fact that these goods are perfect substitutes implies that each consumer will buy the good for which the ratio $\frac{p^i}{q^i(v,w)}$ is minimised, being p^i the price of the i-th good , that is assumed strictly positive. The expression of the demand of good "i" is $x^i = \frac{M}{2p^{i(v,w)}}$; where M is income, assumed identical for all consumers.[5]

With the assumptions made, it should be quite clear that the important point are the relative qualities of the three goods as perceived by the consumer. In terms of good zero, expression [2] becomes:

$$q^i(v,w) = \exp(v\alpha^i + w\beta^i) \ ; (\mathrm{i} = 1, 2) \tag{3}$$

The next step is to obtain the expression of consumer's share, demand and profits for each firm. It should be noted that each type of firm has at each moment a positive consumer's share because of the differences in the consumer's valuation of the characteristics of each good (distinct values of "v" and "w"). The achievement of the consumer's share function is derived from the conditions of the "indifferent consumer" (in which $p^1 \rangle c$ and $p^2 \rangle c$):

Between good 0 and 1:

[5] This differs from the work of Shaked and Sutton (1982) where vertical differentiation is the result of a different distribution of income among consumers and not of differences in tastes. However, theoretical implications are equivalent.

$\frac{p^0}{q^o} = \frac{p^1}{q^1}$; these are the points for which $v \equiv V = \frac{1}{\alpha}\log(\frac{p^1}{c})$.

Between good 0 and 2:

$\frac{p^0}{q^0} = \frac{p^2}{q^2}$; these are the points for which $w \equiv W = \frac{1}{\beta}\log(\frac{p^2}{c})$.

And between good 1 and 2:

$\frac{p^1}{q^1} = \frac{p^2}{q^2}$; these are the points for which $w = \frac{\alpha}{\beta}v + \frac{1}{\beta}\log(\frac{p^2}{p^1})$.

These equalities define the area that corresponds to each type of good in the space (v,w) (see figure 1). Integrating the densities over the corresponding area, we obtain the consumer's share for each firm. Then, following Ulph (1991), we know that for firm 1, consumer's share and demand will be:

$$\begin{aligned} \sigma_1 &= p_1^{-\frac{1}{\alpha}}\left[1 - \frac{\beta}{\alpha+\beta}p_2^{-\frac{1}{\beta}}\right] \\ D_1 &= \frac{M}{2}p_1^{-(1+\frac{1}{\alpha})}\left[1 - \frac{\beta}{\alpha+\beta}p_2^{-\frac{1}{\beta}}\right] \end{aligned} \tag{4}$$

where $\eta(\alpha) = (1 + \frac{1}{\alpha})$ is the price-elasticity of demand.

The market share and demand of good 1 depend on its own price and the price the rival firm as well as their respective quality gaps (α and β). Because Bert equilibrium implies $\hat{p}_1 = c(1+\alpha)$ and $\hat{p}_2 = c(1+\beta)$ (where c = 1), it is possible to express the profits of both firms in terms of α and β and show that $\frac{\partial \Pi_1}{\partial \alpha} > 0$ and $\frac{\partial \Pi_1}{\partial \beta} < 0$ (similarly for firm 2). Then, the profits of a firm are increasing in its own quality gap and decreasing in the quality gap of the rival firm.

In the model we have briefly described, the assumption that the unit cost of production is constant and equal for all the firms allows the author to represent the relevant expressions in terms of quality gaps. But, if we allow the innovative firms to affect their production cost through process R&D, we will be able to analyse the incentives that underlie this spending. This is a more realistic assumption because we have established that the innovative firms are producing a higher quality product and they will normally need some improvements in the production process in order to obtain this.

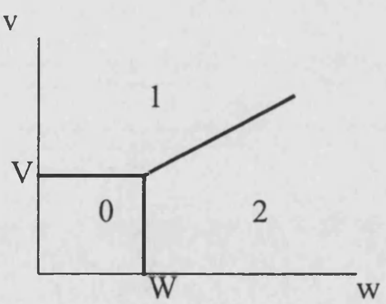


FIGURE 1

The important point we need to mention here is that, as we have seen before, the equilibrium price (Bertrand competition) of each type of firm is:

$$\hat{p}_0 = c$$
$$\hat{p}_1 = c(1+\alpha) \qquad (5)$$
$$\hat{p}_2 = c(1+\beta)$$

For firms producing the basic good the unitary cost does not change. But this is not true for the innovating firms that need process R&D to produce their higher quality product. Thus, we will suppose that for firm 1 and 2 the unit cost depends on the amount of R&D devoted by each firm to process innovation. Thus, prices can be expressed as:

$$\hat{p}_1 = c(z_1)(1+\alpha)$$
$$\hat{p}_2 = c(z_2)(1+\beta) \qquad (6)$$

where z_i (i = 1, 2) is the amount spent by each firm on process R&D.

For simplicity's sake we assume the same functional form as in Dasgupta and Stiglitz (1980) for the relationship between R&D in process innovation and the unit cost of production:

$$c(z_i) = z_i^{-\varepsilon} \qquad (7)$$

where ε is the technological opportunity of the industry (i.e. the elasticity of unit cost with respect to process R&D).

We assume technical knowledge only to be composed by the current spending on R&D by the firm[6]. We also force the two innovating firms to invest in process innovation to stay in the market ($c(0) = \infty$). Moreover, to be in accordance with the demand structure we will restrict our analysis to the case in which the unitary cost of production (and, necessarily, the price) is higher for the goods produced by the innovative firms than the ones produced by the non-innovative ones. That is, producing higher quality products will always be more costly than producing basic goods[7].

Knowing that the equilibrium prices of the two innovating firms are given by [6], and considering the case of a single innovation and linear cost in R&D, the expression of profits for firm 1 (remembering that quality is taken as given, is):

$$\Pi_1 = \frac{M}{2}\alpha(1+\alpha)^{-(1+\frac{1}{\alpha})} z_1^{\frac{\varepsilon}{\alpha}}\left[1 - \frac{\beta}{\alpha+\beta} z_2^{\frac{\varepsilon}{\beta}}(1+\beta)^{-\frac{1}{\beta}}\right] - z_1 \qquad (8)$$

The First Order Conditions $\frac{\partial \Pi_1}{\partial z_1} = 0$ and $\frac{\partial \Pi_2}{\partial z_2} = 0$ (Nash equilibrium) imply that the marginal gain of each firm from process R&D is equal to its marginal cost (in appendix 1 we have derived the properties of the corresponding reaction functions and the restrictions that must be imposed into the model). These conditions together

[6] Joshi and Vonortas (1996) study the effect that the consideration of alternative specifications for the cost function and the production function for technological knowledge has in the equilibrium level of R&D investment.

[7] This restriction is necessary in order to ensure that the price of the innovative firms is higher than that of the non-innovative ones. Although there is a discontinuity in the cost function with respect to non-innovative firms no problem exists with the analysis we are going to perform because non-innovative firms act just as a reference point being its price-quality relationship equal to 1.

determine the optimum amount the firm must devote to this type of innovation given the parameters of the model.

Focusing exclusively on firm 1 (an identical analysis for firm 2), the F.O.C. can be stated on the following form:

$$\frac{\partial \Pi_1}{\partial z_1} = \frac{\partial D_1}{\partial z_1} pcm_1 + \frac{\partial pcm_1}{\partial z_1} D_1 - 1 = 0 \tag{9}$$

where:

$pcm_1 = p_1 - c_1 = \alpha z_1^{-\varepsilon}$ is the price-cost margin of firm 1.

The marginal gain can be divided into two components: the effect of process R&D on the demand of the firm times its price-cost margin and the effect of this type of innovation on this last variable times the demand of the firm. An analysis of these two effects is necessary in order to know the impact of the distinct parameters involved.

It is easy to see that:

$$\frac{\partial D_1}{\partial z_1} pcm_1 = \varepsilon(1 + \frac{1}{\alpha}) kh\mu z_1^{(\frac{\varepsilon}{\alpha} - 1)} \tag{10}$$

where:

$$k = \frac{M}{2}$$

$$h = 1 - \frac{\beta}{\alpha+\beta} z_2^{\frac{\varepsilon}{\beta}} (1+\beta)^{-\frac{1}{\beta}}$$

$$\mu = \alpha(1+\alpha)^{-(1+\frac{1}{\alpha})}$$

Similarly:

$$\frac{\partial pcm_1}{\partial z_1} D_1 = -\varepsilon k h \mu z_1^{(\frac{\varepsilon}{\alpha}-1)} \tag{11}$$

In our model the effect of process R&D is always positive on the demand of the firm but negative on its price-cost margin. These results contradict the existing literature (e.g. Cohen and Klepper, 1996a) that considers that the price-cost margin is enhanced with the reduction of the cost of the firm and that process R&D has no (or negligible) effect on its demand[8]. However, this literature imposes the highly restrictive assumption that firms are price-takers. In our case, Bertrand competition in the product market implies prices to depend directly on cost (mark-up) and this is the reason why price-cost margin diminishes[9]. The assumption that consumers will buy the good for which the price adjusted for quality is minimised is more realistic and in concordance with non-competitive markets.

[8] The authors assume the difficulty of licensing and limited expected growth due to innovation in order to sustain their results (see also Cohen and Klepper, 1996b).

[9] It is not possible the Cournot assumption because as it seems quite obvious in the model quantity is not a decision variable for the firm.

The net effect, which is the marginal gain, can be expressed as[10]:

$$MG = \frac{\varepsilon}{\alpha} kh\mu z_1^{(\frac{\varepsilon}{\alpha}-1)} \tag{12}$$

We can see that the positive effect outweighs the negative one.

Moreover, the second order condition for a maximum implies that $\frac{\varepsilon}{\alpha} - 1\langle 0$ (see appendix 1) or, equally, the assumption of decreasing returns in marginal gain of R&D. This condition ensures a finite solution and positive profits for the two innovating firms. Now we have enough elements to graphically determine the equilibrium amount of process R&D of firm 1, taken as given the value of process R&D of the rival firm (Figure 2).

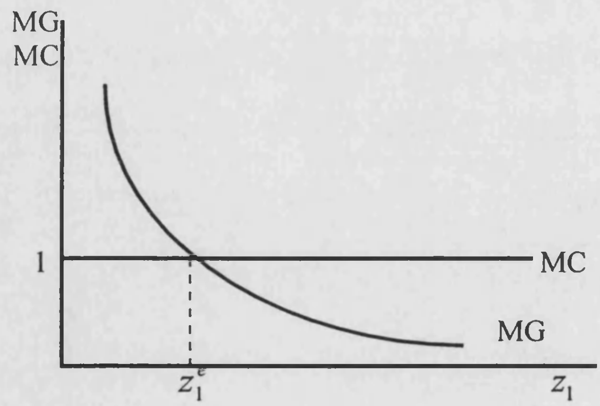


FIGURE 2

The expression (12) can be written in another way as:

[10] For convenience it has not been suppressed the parameter α, that appears in the numerator and the denominator, in order to highlight the distinct components that affect the marginal gain of process R&D.

$$MG = \left(\frac{\varepsilon}{\alpha}\right)\left(\Pi_1^*\right)z_1^{(\frac{\varepsilon}{\alpha}-1)} = (\varepsilon_{z_1}^{pcm_1} + \varepsilon_{z_1}^{D_1})(\Pi_1^*)z_1^{(\frac{\varepsilon}{\alpha}-1)} \qquad (13)$$

Between brackets we have the distinct components we can find. First, the relationship existing between technological opportunity and quality gap that reflects, as a direct impact, the effectiveness of process R&D in increasing gains. Second, the expression of profits as in Ulph (1991) but with an additional component: the process R&D of the rival firm. We will call this expression "ex-ante profits". Finally, the expression that reflects the value of the decreasing returns on marginal gain.

In order to investigate the direct effect of the different parameters it is better to express the equilibrium condition on the following form:

$$\log z_1 = (1-\frac{\varepsilon}{\alpha})^{-1}(\log\frac{\varepsilon}{\alpha} + \log\Pi_1^*) = (1-\frac{\varepsilon}{\alpha})^{-1}(\log\frac{\varepsilon}{\alpha} + \log\frac{M}{2} + \log h\mu) \qquad (14)$$

First of all, in order for z_1 to be lower than 1 (a condition that ensures that, in any case, the unitary cost of the products from the innovative firms is higher than from the non-innovative ones and which will be relaxed later) it is only necessary that the parameter representing market dimension ($\frac{M}{2}$) is small enough (see appendix 1 for further explanation).

Basing ourselves on equation (14) we study the foreseeable impact of the different parameters on cost-reducing spending, although we must resort to computed numerically simulations because we are not confident about the reaction of the rival firm and some other interactions. To do all this, we have worked out the expression of the elasticity of process R&D in relation to the different parameters in which we are interested.

III.2.3.-Comparative static

In this section, we develop the implications that our model has in relation to the inter-industry and intra-industry parameters considered, as well as two important extensions that can improve its realism.

III.2.3.1-*Intra-industry analysis*

Quality gap of firm 1

Operating in [14] we obtain that:

$$\varepsilon_{\alpha}^{z_1} = \frac{\partial z_1}{\partial \alpha}\frac{\alpha}{z_1} = (1-\frac{\varepsilon}{\alpha})^{-1}\left[-\frac{\varepsilon}{\alpha-\varepsilon}(\log\frac{\varepsilon}{\alpha} + \log\Pi_1^{*}) + \varepsilon_{\alpha}^{\Pi_1^{*}} - 1\right] \qquad (15)$$

where $\varepsilon_{\alpha}^{\Pi^{*}} = \dfrac{\partial \Pi_1^{*}}{\partial \alpha}\dfrac{\alpha}{\Pi_1^{*}}$

The expression in square brackets determines the sign of this elasticity. We can find three terms that represent the distinct effects. The first one is the effect of quality gap on process R&D because decreasing returns on marginal gain are enhanced. In principle, we expect this to be a negative effect because an increment in α clearly reduces the term $(\frac{\varepsilon}{\alpha}-1)$. However, we have an ambiguity. Recall that, for convenience, we have forced the innovative firms to have, in any case, a higher unitary cost than the non-innovative ones. This implies that the term in brackets can be negative (mainly because market dimension is restricted) and, contrary to what is expected, the whole sign positive. The intuition is the following. The higher α, the higher the negative impact (trough price-cost margin) of an increment of process R&D on marginal gain. Then, the firm knowing that its cost will always exceed a specific value, the lower the decreasing returns on marginal gain it faces the lower the incentive to invest in process R&D and the other way round (this case). This effect is more clearly weakened with market dimension, although simulations must confirm this[11].

The second term is unambiguously positive. In the model of Ulph (1991), the profits of the innovative firms were always increasing with α. This is also the case here. The only condition that must be met for this to be true is that the price of the rival firm is greater than one and, as we have said, this is ensured[12]. Thus, this elasticity is always positive. The higher the positive impact of α on "ex-ante" price cost margin and demand ("ex-ante" profits), the higher the incentive to invest in process R&D when α increases. Obviously, the higher α, the lower will be this effect. The third term does not

[11] The cost function that is employed in the next section does no restrict the value of market dimension. Then, for a high enough value of this parameter this term is negative.

[12] The only difference that exists between the expression Π_1^* and the profits of firm 1 of Ulph (Π_1) is on the price of firm 2. In the first case $p_2 = z_2^{-\varepsilon}(1+\beta)$ and in the second $p_2 = 1+\beta$. The important thing is that this price is greater than 1 (the price of the non-innovative firms) because this will drive to ensure that $sign\frac{\partial \Pi_1}{\partial \alpha} = sign\frac{\partial \Pi_1^*}{\partial \alpha} \rangle 0$.

present any controversy because it is just a constant. This term reflects the negative impact of "α" on the effectiveness of process R&D in increasing gains. The net impact of these three effects will be reinforced by technological opportunities and weakened by the degree of differentiation.

Quality gap of firm 2

Analogously:

$$\varepsilon_{\beta}^{z_1} = (1-\frac{\varepsilon}{\alpha})^{-1}\varepsilon_{\beta}^{\Pi_1^*} \langle 0 \qquad (16)$$

Following the discussion above the quality gap of the rival firm has an unambiguously negative effect due to $sign\frac{\partial \Pi_1^*}{\partial \beta} = sign\frac{\partial \Pi_1}{\partial \beta}\langle 0$.

III.2.3.2.-*Inter-industry Analysis*

Market Dimension

If we proceed in the same way as before we obtain that:

$$\varepsilon_{M/2}^{z_1} = (1-\frac{\varepsilon}{\alpha})^{-1}\varepsilon_{M/2}^{\Pi^*} = 2(1-\frac{\varepsilon}{\alpha})^{-1}\rangle 0 \qquad (17)$$

Technological Opportunity

Making operations in [14] we see that:

$$\varepsilon_{\varepsilon}^{z_1} = (1-\frac{\varepsilon}{\alpha})^{-1}\left[\frac{\varepsilon}{\alpha-\varepsilon}(\log\frac{\varepsilon}{\alpha}+\log\Pi_1^*)+\varepsilon_{\varepsilon}^{h}+1\right] \tag{18}$$

where $\varepsilon_{\varepsilon}^{h} = \frac{\partial h}{\partial \varepsilon}\frac{\varepsilon}{h}$.

This case is, in some sense, similar to that of the own quality gap. There are also three effects. The first and third one are just the reverse of the one explained in equation [15]. The second one is ambiguous due to the effect of rivalry.

Thus, as far as possible, the foreseeable impact of the distinct parameters in the equilibrium value of process R&D has been established. As we have seen there exist a high number of interactions among the different parameters that raise some doubts about the relative importance of the different effects, although it is expected that indirect effects due to rivalry are minor in relation to direct ones.

Remains to consider the expression of R&D intensity (proportion of R&D in relation to sales) on process innovation which, in fact, shows the real effort of the firm for this type of spending.

From F.O.C. it seems straightforward that:

$$\frac{z_1}{D_1} = \alpha c(z_1)(\eta_{z_1}^{D_1} + \eta_{z_1}^{c(z_1)}) = \varepsilon c(z_1) \tag{19}$$

then:

$$R.I. = \frac{z_1}{p_1 D_1} = \frac{\varepsilon}{1+\alpha} \tag{20}$$

Consequently, for each firm the R&D intensity in process innovation is directly related to technological opportunity and inversely related to its own quality gap. In this respect, what matters in the effort that leads the innovative firms to cost reduction is the difficulty with which the innovation is obtained and the relative degree of vertical product differentiation.

Moreover: $$\eta_{\alpha}^{R.I.} = \frac{\partial R.I.}{\partial \alpha}\frac{\alpha}{R.I.} = -\frac{\alpha}{1+\alpha} \tag{21}$$

The greater the quality gap, the more important is the negative response of the R&D intensity in process innovation to a one-percent-increment in the quality gap.

III.2.3.3.-*Extensions*

Cost depending on quality gap

We have considered the case in which the unitary cost of production depends exclusively on process R&D. However, it is more realistic to assume that it is increasing with quality gap. In this regard, the production process will be more or less complex depending on the quality of the product the firm sells[13].

We consider the simplest case in which the quality gap affects linearly the cost of production:

$$c(\alpha, z_i) = \alpha z_i^{-\varepsilon} \tag{22}$$

A greater quality gap implies a higher cost of production and, consequently, a negative effect on the demand of the firm. Moreover, it should be noted that:

$$\frac{\partial c(\alpha, z_i)}{\partial z_i} = -\varepsilon \alpha z_i^{-(1+\varepsilon)} \tag{23}$$

that is, the effectiveness of process R&D in lowering cost is increasing with the value of the quality gap.

Operating as before we obtain that:

$$\log z_1 = (1 - \frac{\varepsilon}{\alpha})^{-1} \left[\log \frac{\varepsilon}{\alpha} + \log \Pi_1^* - \frac{1}{\alpha} \log \alpha \right] \tag{24}$$

We find a new term that encompasses the net impact of the two effects outlined above, that is:

[13] In essence, and considering the variables in which we are interested, we have a similar structure of profits as in Bertscheck (1995) in the sense that some measure of product quality enters the demand equation and affects cost, and that an increment in this variable is interpreted as a product innovation.

1.- $-\eta(\alpha)\log\alpha$ which reflects the negative effect of a higher cost in demand.

2.- $\log\alpha$, which reflects the greater effectiveness of process R&D in lowering cost when the quality gap increases.

In order to establish the parallelism with the previous case we can work out again the corresponding elasticity. It is easy to see that:

$$\varepsilon_\alpha^z = (1-\frac{\varepsilon}{\alpha})^{-1}\left[-\frac{\varepsilon}{\alpha-\varepsilon}(\log\frac{\varepsilon}{\alpha}+\log\Pi^{**})+\varepsilon_\alpha^{\Pi^{**}}-1+(\log\alpha-\frac{1}{\alpha})\right] \qquad (25)$$

The effect is ambiguous but it is clear that the new term is increasing with α. We must resort again to computed numerically simulations in order to know the real effect. The impact of the other parameters is unchanged.

A new form of the cost function

The reader may be worried about the fact that the value of market dimension must be bounded in order to maintain the coherence with the demand structure. We can relax this assumption establishing a new form for the cost function that explicitly determines a production cost which is higher for the innovative firms than for the non-innovative ones.

Thus, considering that the cost function has the form:

1.- $c(z_i) = 1 + z_i^{-\varepsilon}$; when cost does not depend on quality gap and

2.- $c(z_i) = 1 + \alpha z_i^{-\varepsilon}$; when cost depends on quality gap.

From F.O.C., we obtain, respectively:

$$\log(1 + z_i^{-\varepsilon}) + \frac{\alpha(1+\varepsilon)}{1+\alpha}\log z_i = \frac{1}{\eta(\alpha)}\log\left[\varepsilon h(1+\alpha)^{-\eta(\alpha)}\right] \tag{26}$$

and

$$\log(1 + \alpha z_i^{-\varepsilon}) + \frac{\alpha(1+\varepsilon)}{1+\alpha}\log z_i = \frac{1}{\eta(\alpha)}\log\left[\varepsilon\alpha h(1+\alpha)^{-\eta(\alpha)}\right] \tag{26'}$$

As before, the same second order conditions can be applied here, although it might be possible to relax them in some way (see appendix 2).

The problem we face is that a more complex expression is obtained for cost-reducing R&D that does not allow us to analyse, as before, the different incentives we can find. However, there is no reason to think that there exist essential changes in relation to previous analyses except for the indirect effect that comes through z_i because now the elasticity of the cost function with respect to process R&D is:

$$\varepsilon_{z_1}^{c(z_1)} = -\frac{\varepsilon z_1^{-\varepsilon}}{1+z_1^{-\varepsilon}} \tag{27}$$

when cost does not depend on quality and:

$$\varepsilon_{z_1}^{c(z_1)} = -\varepsilon \frac{\alpha z_i^{-\varepsilon}}{1+\alpha z_i^{-\varepsilon}} \tag{28}$$

when cost depends on quality.

In contrast, we can now study the effect of market dimension more deeply, because we are not any longer restricted in this way.

If we consider R&D intensity, F.O.C. conditions show quite straightforwardly that:

$$R.I. = -\varepsilon_{z_1}^{c(z_1)} \frac{1}{1+\alpha} \tag{29}$$

Then, when cost does not depends on quality gap, we see that:

$$R.I. = \frac{\varepsilon}{1+\alpha} \frac{z_i^{-\varepsilon}}{1+z_i^{-\varepsilon}} \tag{30}$$

In this case, market dimension and rivalry have effects on process R&D intensity through z_i. As previous discussions suggest, the first parameter will have a negative effect and the opposite will occur with rivalry. As before, the direct effect of technological opportunity is positive and that of differentiation negative. However, in this case there exist indirect effects that may compensate to some extend.

If quality gap affects cost, it is easy to see that:

$$R.I. = \varepsilon \frac{\alpha}{1+\alpha} \frac{z_i^{-\varepsilon}}{1+\alpha z_i^{-\varepsilon}} \qquad (31)$$

We can see how (vertical) differentiation can induce a positive effect on R&D intensity. This is logical, to have a more differentiated product implies a higher cost; then, in order to obtain the relationship between price and quality that maximises profits it is most likely that the firm has the incentive to increase the effort on process R&D.

III.2.3.4.- *Simulation results*

As above mentioned, it has been necessary to perform simulations in order to know the effect of the different parameters of the model. We have focused on the most interesting case in which the cost function for the innovative firms implies a unitary cost that is always higher than those for the non-innovative ones.[14]

We have taken 0.05, 0.1 and 0.15 for low, medium and high technological opportunity industries. For market dimension, we have considered very low (10 and 20) and very high (1,000) values in order to see the importance of this variable when it interacts with other parameters of the model. For quality gaps we have taken values equal or higher than 0.2 to ensure that second order conditions are always satisfied.

In tables 1 and 2 the equilibrium values of process R&D for symmetric ($\alpha = \beta = 0.2$ and $\alpha = \beta = 0.25$) and asymmetric ($\alpha = 0.25$ and $\beta = 0.2$) equilibriums are reflected, when costs do not depend on quality gap and when they depend on quality gap respectively.

At the outset, process R&D increases with quality gap reflecting that positive effects[15]outweigh the negative one. Therefore, it is interesting to analyse if there exist a point beyond which the opposite occurs. This is reflected in table 3. The simulations have been performed taking consecutive higher values of the quality gap with a difference of 0.05 points. Thus, if we find in a cell the values 1.5-1.55, this means that for a value of the quality gap of 1.55 the equilibrium value of process R&D starts to be lower than for the preceding value of the quality gap. It is important to remark that beyond this "turning point" the equilibrium value of process R&D always decreases with the quality gap. The intuition is that when the differentiation level is high enough, the price of the goods (directly related to its cost of production) has less strategic relevance.

Taking the comparative static analyses and considerations of previous sections as a reference, the main results we can extract from tables 1, 2 and 3 are:

1.- When cost does not depend on quality gap, there exists the possibility that, in small markets, if technological opportunities increase process R&D decreases ("negative" effect of lower decreasing returns on marginal gain). It seems that this does not occur when cost depends on quality gap.

---

[14] The author has also performed simulations for the case when $c(z_i) = z_i^{-\varepsilon}$ and $c(z_i) = z_i^{-\varepsilon}(1+\alpha)$ (only when market dimension takes values equal to 10 and 20) obtaining a similar behaviour that is explained in next paragraphs.

2.- The point in which an increment in quality gap decreases the equilibrium value of process R&D ("turning point") is always greater for the case in which cost depend on quality gap. We know that there are two new effects: an "effectiveness" effect and a "demand" effect. Because a larger quality gap decreases the price-demand elasticity and increases the effectiveness of process R&D in lowering cost, the larger the quality gap the more likely it is that the positive effect will outweigh the negative one.

3.- In the asymmetric equilibriums the "turning points" are always located at a larger value of quality gap than in the symmetric equilibriums. The explanation is that in the asymmetric equilibrium for each value of the quality gap, the firm with the highest quality gap has more "ex-ante" profits than in the symmetric equilibrium case. Thus, at the intra-industry level, the ratio between quality gaps matters in considering the net effect of differentiability on process R&D.

4.- When cost does not depend on quality gap, an increment in market dimension decreases the "turning point". This does not occur in the case in which cost depends on quality.

5.- When market dimension is small, an increment in technological opportunities increases the "turning point", but the opposite occurs if market is big. In the last case the interaction between technological opportunity and market dimension[16] exercises a

[15] Recall that for low values of market dimension it is likely that the negative effect of lower decreasing returns on marginal gain becomes a positive one.

[16] The greater the market dimension the greater the impact of the negative effect of quality gap on decreasing returns on marginal gain.

powerful negative effect. This does not occur apparently when cost depend on quality gap, because (again) the effect of market dimension is less powerful in this case.

6.- From the comments above, we can see that the "turning point" is larger when cost depend on quality, reflecting the greater effectiveness of process R&D in lowering cost (net of negative demand effect) when quality gap increases and the fact that technological opportunity and market dimension (and its interactions) have less impact on the equilibrium amount of process R&D.

We have established the impact of the different parameters of the model on the level of process R&D, but it remains to consider how this affects the effort the firm devotes to process R&D, that is, the R&D intensity on process innovation for each firm. In tables 4 and 5 we have the values of this index for the cases considered in table 1 and 2. In the last section, we have clearly established the effect of market dimension and the quality gap of the rival firm. It is quite clear that the direct effect of technological opportunity is greater than the indirect one and, then, we can be confident about the positive effect of this variable on R&D intensity both when cost depends on quality gap and when it does not. Consequently, it would be interesting to study the effect of own quality gap more deeply.

We have seen (equation 30) that when cost does not depend on quality gap the direct effect of own product differentiation is always negative. Moreover, the indirect effect comes through its impact on the equilibrium value of process R&D. We know that till the "turning point" the direct effect is reinforced by the indirect one[17], and process R&D intensity is, for sure, continuously decreasing with differentiation. Beyond the "turning point" the indirect and the direct effect go in opposite directions. It would be interesting to investigate whether there is a point in which the former outweighs the latter. Making simulations with $\alpha=10$ we can see that this is not the case.

In contrast, when the unitary cost depends on quality gap we have obtained (equation 31) that the direct effect is positive. Till the "turning point" the indirect effect is definitely negative. Making simulations we can see that at this point the R.I. is greater than at the starting point ($\alpha=\beta=0.2$), revealing that the direct effect is always greater than the indirect one.

Therefore, an interesting result of this model is that R&D intensity in process innovation is decreasing with quality gap when the unitary cost does not depend on quality gap and the opposite occurs when they depend on quality gap. That is, the effort devoted to cost reduction is only inversely related with the quality gap embodied in the product if the complexity of the production process is not affected by the quality of the goods, an assumption that seems quite strong but that has been widely used in the literature.

---

[17] Due to " z_i " is increasing with "α", and that $\frac{z_i^{-\varepsilon}}{1+z_i^{-\varepsilon}}$ is always increasing with $z_i^{-\varepsilon}$.

TABLE 1

Equilibrium Values of Process R&D

Costs are independent on quality gap

M.D.	T.O.	α	β	Process R&D
10/20/1000	0.05	0.2	0.2	0.001228 / 0.002707 / 0.22307
		0.25	0.25	0.003134 / 0.006715 / 0.478245
		0.25	0.2	0.0031493-0.0012205 / 0.006753225-0.002689226 / 0.4821025-0.221067
	0.1	0.2	0.2	0.000894 / 0.0023871 / 0.439435
		0.25	0.25	0.003612 / 0.008707 / 1.012787
		0.25	0.2	0.00362453-0.0008900001 / 0.008745069-0.002374344 / 1.022835-0.434283
	0.15	0.2	0.2	0.0001852 / 0.000829079 / 0.69985
		0.25	0.25	0.00241 / 0.007242265 / 1.697673
		0.25	0.2	0.00241483-0.000184526 / 0.00726652865-0.00082518 / 1.719763-0.68942

TABLE 2

Equilibrium values of process R&D

Costs are dependent on quality gap

M.D.	T.O.	α	β	Process R&D
10/20/1000	0.05	0.2	0.2	0.010244 / 0.0205714 / 1.030881
		0.25	0.25	0.012243 / 0.0245715 / 1.228608
		0.25	0.2	0.01238946-0.01011611 / 0.0248734-0.02031 / 1.245711-1.01611
	0.1	0.2	0.2	0.01977 / 0.0402943 / 2.0464786
		0.25	0.25	0.02377889 / 0.0483418 / 2.43556
		0.25	0.2	0.024054306-0.01952979 / 0.04892685-0.03978543 / 2.4724588-2.0148741
	0.15	0.2	0.2	0.02806 / 0.0586794 / 3.021995
		0.25	0.25	0.0341239 / 0.0708828 / 3.586247
		0.25	0.2	0.03451595-0.0277183 / 0.0717512-0.0579216 / 3..645166-2.970648

TABLE 3

Critical values of α (asymmetric equilibrium β=0.2) and α=β (symmetric equilibrium) beyond which process R&D decreases with quality.

M. D.	T.O.	Cost independent on quality		Cost dependent on quality	
		Symmet. Equil.	Asymmet. Equil.	Symmet. Equil..	Asymmet. Equil.
10	0.05	1.50-1.55	1.80-1.85	2.05-2.10	2.60-2.65
	0.1	1.55-1.60	1.90-1.95	2.10-2.15	2.60-2.65
	0.15	1.60-1.65	1.95-2.00	2.10-2.15	2.60-2.65
20	0.05	1.45-1.50	1.80-1.85	2.05-2.10	2.60-2.65
	0.1	1.50-1.55	1.85-1.90	2.05-2.10	2.60-2.65
	0.15	1.55-1.60	1.85-1.90	2.05-2.10	2.60-2.65
1000	0.05	1.35-1.40	1.75-1.80	2.05-2.10	2.60-2.65
	0.1	1.25-1.30	1.55-1.60	2.05-2.10	2.60-2.65
	0.15	1.20-1.25	1.45-1.50	2.10-2.15	2.65-2.70

TABLE 4

Process R&D Intensity (%)

Costs are independent on quality gap

M.D.	T.O.	α	β	Process R&D intensity (%)
10/20/1000	0.05	0.2	0.2	2.429184/ 2.389023/ 2.161436
		0.25	0.25	2.286292/ 2.248874/ 2.036877
		0.25	0.2	2.286054-2.429495/ 2.248595-2.389359/ 2.036476-2.161905
	0.1	0.2	0.2	5.571889/ 5.387648/ 4.337876
		0.25	0.25	5.095968/ 4.931327/ 3.997459
		0.25	0.2	5.095327-5.572717/ 5.173122-5.575958/ 3.995484-4.340328
	0.15	0.2	0.2	9.799959/ 9.293843/ 6.417252
		0.25	0.25	8.54179/ 8.12178/ 5.761959
		0.25	0.2	8.54105-9.801116/ 8.120463-9.295529/ 5.75615-6.424285

TABLE 5

Process R&D Intensity (%)

Costs are dependent on quality gap

M.D.	T.O.	α	β	Process R&D Intensity (%)
10/20/1000	0.05	0.2	0.2	0.83728/ 0.8142/ 0.693565
		0.25	0.25	0.950203/ 0.925199/ 0.793432
		0.25	0.2	0.957133-0.830937/ 0.924765-0.814619/ 0.792993-0.693982
	0.1	0.2	0.2	1.903758/ 1.801196/ 1.307971
		0.25	0.25	2.132086/ 2.022983/ 1.489092
		0.25	0.2	2.130285-1.905554/ 2.021165-1.802991/ 1.487271-1.309688
	0.15	0.2	0.2	3.1844/ 2.928975/ 1.811016
		0.25	0.25	3.519052/ 3.252639/ 2.053185
		0.25	0.2	3.5148-3.188764/ 3.24831-2.93335/ 2.049028-1.815001

III.2.3.5.-Appendix

Appendix 1

a) We will concentrate on firm 1 but an identical analysis is valid for firm 2.

The condition $\frac{\partial \Pi_1}{\partial z_1} = 0$ determines the expression of the Reaction Function of firm 1 , that is:

$$z_1 = \left\{ \varepsilon \frac{M}{2} (1+\alpha)^{-(1+\frac{1}{\alpha})} \left[1 - \frac{\beta}{\alpha+\beta} z_2^{\frac{\varepsilon}{\beta}} (1+\beta)^{-\frac{1}{\beta}} \right] \right\}^{(\frac{\alpha}{\alpha-\varepsilon})} \qquad (1)$$

Let:

$$k = \frac{M}{2}$$

$$\phi(x) = (1+x)^{-\frac{1}{x}}; x = \alpha, \beta$$

$$h_1 = \frac{\beta}{\alpha+\beta}$$

$$\delta_1 = \frac{\varepsilon}{\beta}$$

$$\xi_1 = \frac{\alpha}{\alpha-\varepsilon}$$

where:

$k \rangle 0$
$\phi(x) \rangle 0$
$h_1 \rangle 0$
$0 \langle \delta_1 \langle 1$
$\xi_1 \rangle 1$

Then:

$$z_1 = \left[\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)} (1 - h_1 \phi(\beta) z_2^{\delta_1}) \right]^{\xi_1} \qquad (2)$$

and:

$$\frac{\partial z_1}{\partial z_2} = -\xi_1 \left[\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)} (1 - h_1 \phi(\beta) z_2^{\delta_1}) \right]^{\xi_1 - 1} (\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)} h_1 \phi(\beta) \delta_1 z_2^{\delta_1 - 1}) \qquad (3)$$

where it is accomplished that:

$\frac{\partial z_1}{\partial z_2} \langle 0$ if $(1 - h_1 \phi(\beta) z_2^{\delta_1}) \rangle 0$, that is, if $z_1 \rangle 0$. Cost-reducing R&D of both firms are strategic substitutes.

$\frac{\partial z_1}{\partial z_2} = 0$ if $z_1 = 0$, that is, when the firm is not in the market.

Moreover:

$$\frac{\partial^2 z_1}{\partial z_2^2} = \xi_1(\xi_1 - 1)\left[\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)}(1 - h_1\phi(\beta)z_2^{\delta_1})\right]^{\xi_1 - 2}(\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)} h_1\phi(\beta)\delta_1 z_2^{\delta_1 - 1})^2$$
$$-\left[\delta_1(\delta_1 - 1)\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)} h_1\phi(\beta)z_2^{\delta_1 - 2}\right]\xi_1\left[\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)}(1 - h_1\phi(\beta)z_2^{\delta_1})\right]^{\xi_1 - 1} \quad (4)$$

where:

$\frac{\partial^2 z_1}{\partial z_2^2} \rangle 0$ (convex function) if $z_1 \rangle 0$ and $\frac{\partial^2 z_1}{\partial z_2^2} = 0$ if $z_1 = 0$.

Similar expressions hold for firm 2.

In the reaction function of firm 1 the sections with the axis are:

$z_1^0 = \left[\varepsilon k \frac{\phi(\alpha)}{(1+\alpha)}\right]^{\frac{\alpha}{\alpha-\varepsilon}}$ when $z_2 = 0$ and $\bar{z}_2 = \left[\frac{\alpha+\beta}{\beta\phi(\beta)}\right]^{\frac{\beta}{\varepsilon}}$ when $z_1 = 0$.

Similarly, for firm 2 we have:

$z_2^0 = \left[\varepsilon k \frac{\phi(\beta)}{(1+\beta)}\right]^{\frac{\beta}{\beta-\varepsilon}}$ when $z_1 = 0$ and $\bar{z}_1 = \left[\frac{\alpha+\beta}{\alpha\phi(\alpha)}\right]^{\frac{\alpha}{\varepsilon}}$ when $z_2 = 0$.

For a symmetric equilibrium ($\alpha = \beta$) we can face two cases:

a) $z^0 \rangle \bar{z}$ (Figure 3 illustrates) and this is accomplished when $k \rangle \frac{(1+\alpha)}{\varepsilon\phi(\alpha)}\left[\frac{2}{\phi(\alpha)}\right]^{\frac{\alpha-\varepsilon}{\varepsilon}}$. In this case we have three possible equilibriums: A, B, and C. The interior solution is not stable. We therefore eliminate this possibility by restricting the value of the market dimension.

b) $z^0 \langle \bar{z}$ (if the last inequality is reversed). Then, in this case a stable unique equilibrium exists with an interior solution (Figure 4). Thus, if the market is small enough the two firms will compete.

It is not trivial to remark that the higher the technological opportunities the higher will be the possibility that market dimension reaches to its critical level. This is in accordance with previous literature which establishes that industries with higher technological opportunities are more concentrated.

b) The second order condition is $\frac{\partial^2 \Pi_1}{\partial z_1^2} \langle 0$. In our case:

$$\frac{\partial^2 \Pi_1}{\partial z_1^2} = \varepsilon k \frac{\phi(\alpha)}{1+\alpha}\left(\frac{\varepsilon}{\alpha} - 1\right) z_1^{\left(\frac{\varepsilon}{\alpha}-2\right)}\left(1 - h_1 \phi(\beta) z_2^{\delta_1}\right) \tag{5}$$

We will have a maximum when $\frac{\varepsilon}{\alpha} \langle 1$ (similarly for firm 2 with respect to its own quality gap).

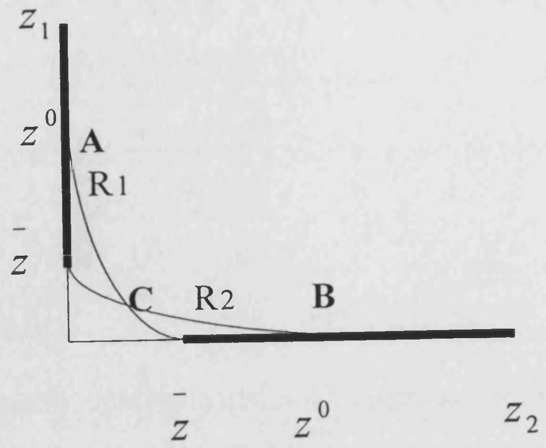


FIGURE 3

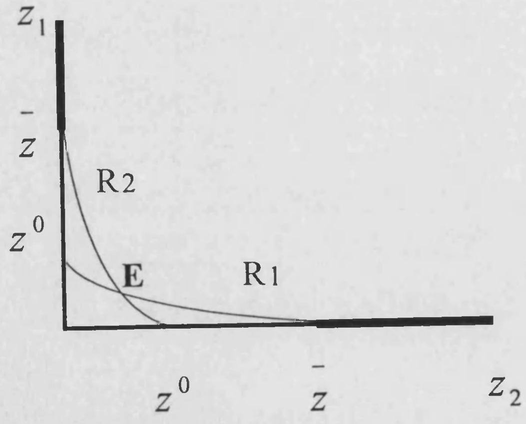


FIGURE 4

Appendix 2

With the new form of the cost function, we have that:

$$\frac{\partial^2 \Pi_1}{\partial z_1^2} = (1+z_i^{-\varepsilon})^{-(1+1/\alpha)} z_i^{-(2+\varepsilon)} \left[\varepsilon(1+\frac{1}{\alpha})(1+z_i^{-\varepsilon})^{-1} z_i^{-\varepsilon} - (1+\varepsilon) \right] \qquad (1)$$

This expression is negative if:

$$\frac{z_i^{-\varepsilon}}{1+z_i^{-\varepsilon}} \langle \frac{\alpha(1+\varepsilon)}{\varepsilon(1+\alpha)} \qquad (2)$$

Because process R&D will be always greater than zero, it is ensured that this condition is satisfied if $\frac{\varepsilon}{\alpha}\langle 1$. This is a sufficient but not a necessary condition .

Appendix 3

Uniqueness and stability are ensured (see Seade -1980- and Spencer and Brander -1983) if :

i) $A = \frac{\partial^2 \Pi_1}{\partial z_1^2}\frac{\partial^2 \Pi_2}{\partial z_2^2} - \frac{\partial^2 \Pi_1}{\partial z_1 \partial z_2}\frac{\partial^2 \Pi_2}{\partial z_2 \partial z_1} \rangle 0$; that is, own effects of process R&D on marginal gain dominate cross effects.

And:

ii) $B = \frac{\partial^2 \Pi_1}{\partial z_1 \partial z_2} \langle 0$ (similarly for firm 2). The increment in the rival process R&D reduces own marginal gain.

It is straightforward to see that condition ii) is satisfied. Unfortunately we are not able to obtain a simple enough expression to explore what matters with expression i). Therefore, we have decided to calculate this expression for each of the simulation cases. In every case the result obtained has been satisfactory.

III.3.- Practical implications of the model

As we have established in Chapter I, the objective of this research is twofold. On the one hand, we attempt to verify if the variable "firm size" is relevant for technological activity or, by contrast, is just a reflection of it and, therefore, a consequence of the competitive environment in which the firm is located and that leads it to have a given relationship between the price and quality of its product. On the other hand, we are interested in testing if the variable "quality" influences the incentives the firm has for the reduction of the unit cost of production or, in particular, if it affects resources spent on this purpose and, consequently, the firm's process innovation performance.

The theoretical model developed in last sections suggests a quadratic relationship between process R&D and quality gap. This implies the existence of a point beyond which we find a trade-off between quality and process R&D within the firm[18]. This point is called "turning point". As we have demonstrated, the exact value of this point depends on the degree of differentiation of the rival firm, on market dimension and on technological opportunities in different ways as well as on the interactions existing among these variables.

We have made some simplifications in the model that have to be taken into account in the empirical implementation because of the possible implications that may exist when working with data. We can mention mainly two. The first one is to consider that the unit cost of production (productivity) depends on the expenses on process R&D by the firm. Although many researchers exist that highlight the importance of this type of investment on productivity evolution it is quite evident that there are other factors that influence it. For this reason, the reader must be conscious that we are working with this relevant simplification. In any case, we demonstrate in Chapter V the relevance of the variable under consideration in the empirical implementation.

Perhaps, the most important simplification has been to take the variable "quality" as given, without considering that this variable is the result of a decision that implies an optimisation process by the firm. Given the structure of the model, the inclusion of this decision (assuming that the quality gap is a function of the expenses on product R&D of the firm) make it completely intractable and does not seems to give us

[18] The author is conscious that to measure productivity with products of different qualities is not technically correct and the radical distinction that we make between productivity and quality is

relevant information for our specific purpose[19]. In any case, for an adequate specification of the empirical model it is necessary to correct the existence of this endogeneity because not taking this fact into account would lead to undesirable bias. Following this premise, the econometric framework assumes that the independent variables are weakly exogenous.

All in all, in the empirical section we will test the implications of the proposed theoretical model trying to solve the problems appearing with some additional assumptions.

III.4.- Conclusions

We have made a first attempt to investigate the effect of a firm's vertical differentiation in the incentives it has for cost reduction. Assuming that the spending on process innovation is necessary in order to introduce a higher quality product into the market, we have found three distinct types of effects when there is an increment in the quality gap of the firm: "ex-ante profits" effect, "decreasing returns in marginal gain" effect and "price-demand elasticity" effect.

When the differentiation level is low, process R&D increases with own quality gap but it reaches a point where this relationship is reversed. This critical point, which we will call "turning point", depends on the quality gap of the rival firm, market

restrictive. However, in chapter V we clarify, at least to some extend, this aspect.

[19] Yin and Zuscovitch (1998) study product and process innovation decisions separately, assuming in each case that the other strategy is taken as given. When they allow firms to choose both strategies simultaneously, conclusions do not change.

dimension and technological opportunities in different ways. If we allow the unitary cost to be affected by the quality gap, it seems that a larger quality gap is needed for this negative relationship to appear. Moreover, process R&D intensity always decreases with the quality gap when the unitary cost of production does not depends on quality, but this result is reversed when cost is affected by the quality gap. Technological opportunities have a clear positive effect on the effort devoted by firms to process R&D.

The main result of this research relies in the existence of a point beyond which we detect a trade-off between own quality gap and process R&D within the firm. In this respect, due to process R&D directly affects production cost and, from here, it is very likely a negative impact on productivity evolution, we are able to affirm that a relation of substitution can exist between quality and productivity into the firm. It should be noted that this relationship of substitution comes from the own market competition mechanism.

We want to point out two important features of our model. The first one is about the existence of interdependence among firms. It is quite obvious that, in a specific market, products are normally differentiated and what matters is the perception of their relative prices and qualities by consumers. Then, strategic interdependence among firms must be considered, because in some circumstances it can be more determinant than the variables normally established in the literature. The second one refers to the existence of an important interrelation between product innovation (implicitly encapsulated in quality gaps) and process innovation, even when we assume that the quality of the product does not enter the production cost function. It is important to remark that theoretical models did not use to take these two considerations into account.

As far as we know, the interactions and effects aforementioned have only been partially considered in the literature to date. Our aim has been to shed light on the connection that exists among aspects related with market competition and technological competition in order to bring attention to some important variables.

By introducing two factors that have not been taken into account previously, such as the strategic interdependence among firms in a market and the corresponding interrelation between product and process innovation, we have given an alternative to some aspects that, even nowadays, confuse the literature as, for instance, the relationship between firm size and innovation.

CHAPTER IV: TESTING THE MODEL WITH SPANISH FIRM DATA

CHAPTER IV: TESTING THE MODEL WITH SPANISH FIRM DATA

IV.1.- Introduction

In the theoretical and empirical literature on innovation it has been quite common to consider the expenses on R&D in a generic manner or just in one of its two possible aspects: product and process R&D. This has implied taking into account, alternatively, the incentives that a firm has for the improvement of the quality of its products or for the reduction of its unit cost of production. However, a firm obtains innovations in both directions and to focus only in one aspect gives an excessively restrictive explanation of the reality. For this reason, in Chapter III, a first attempt is made to fill this gap developing a model in which, in order to introduce a better product into the market, the two existing innovative firms are forced to invest in process R&D.

The objective we pursue in this chapter is to test if there exist a point beyond which there is a trade-off between quality and productivity within the firm. This main proposition is based on the predictions of the aforementioned theoretical model that establishes strategic interdependence among firms and a direct connection between process and product innovation. This theoretical model specifies that the productivity growth of a firm (measured by the evolution of its unit cost of production) is a direct consequence of the expenses the firm directs to process innovation (an input) whose reflection would be in the number of process innovations the firm obtains (an output). We have an approximation of the latter data for a sample of Spanish manufacturing firms. The measure of vertical product differentiation is a difficult task but, as we will show in the following sections we have at our disposal variables that, according to some authors, are reasonable approximations. These variables are the number of product innovations per "line of business" or advertising expenses as a fraction of total sales, both easily obtainable from the survey.

The above premises are vias through which we have tried to relate the theoretical model to the empirical one in order to extract conclusions, a task that necessarily implies resorting to additional assumptions that allow us to reach our objective. As usually occurs, the empirical implementation of any theoretical model is not absent of difficulties. In our case, problems are even greater given the known peculiarities of this topic as well as the obstacle of measuring the variables established in our model. Nevertheless, we are going to use a vast Spanish firm data source as is the "Encuesta de Estrategias Empresariales" (Survey of Firm Strategies) that provides information which facilitates the solution of this types of handicaps, at least to some extend.

Below, we will detail the steps we have followed to adapt the theoretical model to the empirical one taking into account that we have a panel data sample with a discrete dependent variable (number of process innovations) that requires an adequate econometric treatment in order to extract the maximum benefit.

IV.2.- The Survey of Firm Strategies (SFS)

The SFS is a panel data conducted by the "Fundación Empresa Pública". It incorporates a sample of more than 2,000 Spanish firms[1] analysed since 1990. The authors wanted that this invaluable data source was as representative as possible to ensure that the population inferences extracted from it were considered as valid[2].

The main aim of the survey is the knowledge, through a wide range of variables, of the strategic behaviour of firms in their respective markets. This necessarily involves an investigation into the decisions that firms take as a response to the competitive environment in which they are located. To do this, this survey is composed of 8 sections in which categorical variables (the firm answers among a number of alternatives) as well as numerical ones are included. The sections of the survey as a result of the types of questions formulated are:

1.- *Activity, products and production process.* This encompasses the main characteristics of the firm such as the society organisation, geographic location of the industrial and non-industrial establishments, foreign capital participation, main activity, types of products, etc.

2.- *Clients and suppliers.* There is information about the type of commercial agreements of firms, advertising activities, etc.

[1] In particular, 2,188 firms in 1990, 2,359 in 1991, 2,438 in 1992, 2,539 in 1993 and 2,595 in 1994.

[2] For a detailed explanation of the characteristics of this survey see Fariñas and Jamandreu (1994).

3.- *Prices and costs.* This incorporates information about the procedures of estimation of the production cost of the firm, its price policy and the respective competitors influence, etc.

4.- *Markets.* Questions are related to the type of markets in which the firm operates, their evolution and the relative performance of the firm.

5.- *Technological activities.* Analyses everything that is around the innovative aspect of the firm. Therefore, there are data about variables that are considered to be inputs of the technological process such as R&D expenses, services acquired or technological payments, as well as data on innovative output as patents, number of process and product innovations, etc.

6.- *Foreign trade.* This examines the export and import activities of the firm and the corresponding destination and origin markets.

7.- *Employment.* Gives information about the number of employees of the firm, types of labour contracts, classifications according the kind of activities the employees do, qualifications, etc.

8.- *Accounting data.* In this last section, we have data about investments, assets and liabilities of the company etc.

The sample period is 1990-94. In the sample selection of firms we have followed two main criteria. On the one hand, we have chosen the firms that contain information about all the variables we are interested in during the five years of the study. On the other hand, among these firms it was necessary to ensure that their main activity was not in any way different during the sample period, that is, the NACE code (at three digit level) of their most important line of business was the same in the five years of the study. Not taking this fact into account could have led to serious mistakes. By doing this, we have a sample of 1062 firms that are distributed among sectors as table A (in the appendix) shows.

Apart from performing the regressions with all types of firms, we have also manipulated the data in two different ways in order to extract additional conclusions. The first one is to rule out those firms we have considered as outliers. We have established that firms with more than 10 product innovations (per line of business) in a year are exaggerating their technological performance[3]. The second one is to restrict our sample to those firms that have obtained product innovations in the given period. That is, only for firms we consider to have some degree of differentiation of their products. We will call these firms "differentiated firms".

As we can see, the information contained in the SFS is the most appropriate in order to test the theoretical model, in which the important thing is the strategic competition among firms.

IV.3.- The econometric model

The econometric model has two essential features. On the one hand, we have a panel data, that is, we have data about the characteristics that a given number of "n" individuals observed during a period of time "T" present, in our case, over a period of

[3] Some firms report for hundreds of product innovations per "line of business".

five years. These types of models allow to control for the individual effects[4] (random or fixed) of the units analysed. This is especially interesting in studies on innovation where the unobserved heterogeneity among the units of analysis that comes, for instance, from different degrees of appropriability conditions, is quite evident. On the other hand, the dependent variable (number of process innovations) is a discrete one which implies that we are working with non-linear models.

The analysis of panel data models in which the endogenous variable is discrete is a recent field of study in econometrics[5]. We have the additional feature that the dependent variable presents the zero value in a high number of cases. In this respect, we have to resort to a probability distribution with a functional form taking into account this aspect, as is the case of the Poisson model. Therefore, the econometric specification which is more in accordance with our aim will follow the Poisson regression model[6].

Let y_{it} the observed event (i.e. number of process innovations) where "i" are individuals and "t" time, the probability density function conditioned to the observable characteristics of firms is[7]:

[4] As it is well known, the random effects model assumes that the individual effects are randomly distributed along the cross-section observations. The fixed effects model assumes that the differences among the distinct individuals are in parametric changes (constant term) in the regression, implying the existence of correlation among the individual effects and the rest of the regressors.

[5] The problem that arises with panel data is to find a way to eliminate the individual effect in order to obtain consistent estimators. There have been some authors that have proposed various solutions as, for instance, to condition the maximum likelihood function to a sufficient statistic, through the simulation of an estimator or by two steps methods, all of them with a high degree of complexity. See Chamberlain (1980,1984) and Börsch-Supan and Hajivassilou (1993)

[6] For a discussion of these kind of models see, for instance, Cameron and Trivedi (1986).

[7] It is assumed that the occurrence of the events is random and time independent.

$$pr(Y_{it} = y_{it} / X_{it}) = \frac{e^{-\lambda_{it}} \lambda_{it}^{y_{it}}}{y_{it}!} \quad (1)$$

where $\lambda_{it} = E(Y_{it}) = V(Y_{it})$ is the called Poisson parameter.

The usual assumption is that this parameter depends on the independent variables of the model following the functional form $\log \lambda_{it} = X_{it}^{'}\beta$. Then, $E(Y_{it}) = V(Y_{it}) = e^{X_{it}^{'}\beta}$, where the vector of characteristics may encapsulate, apart from the variables established by the theoretical model, individual effects (η_i) and time effects (v_t). Thus, $X_{it}^{'}\beta = \beta_0 + \beta_1 X_{1it} + ... + \beta_k X_{kit} + \eta_i + v_t$.

Therefore the model we have to estimate is:

$$Y_{it} = e^{X_{it}^{'}\beta} + u_{it} \quad (2)$$

where u_{it} is the "residual"[8].

In the simplest version, the Poisson model, apart from the restrictive assumption that the mean of the process is equal to its variance, does not take into account the individual effects. Hausman, Hall and Griliches (1984), in an article that serves as a reference in this topic and in which the relationship that exist between the achieved number of patents and the spending on R&D is studied, propose estimators that relax

[8] In fact, the randomness in the model comes from the Poisson specification for the Y_{it} because a deterministic relationship exists between the Poisson parameter and the independent variables.

the assumptions aforementioned. On the one hand, they assume that the variance differs form the mean following a given functional form obtaining as a result the called "Negative Binomial Models". On the other hand, in order to eliminate the fixed effects[9], they propose a conditional maximum likelihood approach in which the probability of occurrence of the events is conditioned on the sum along time of the dependent variable. In any case, the solutions given by Hausman et al (1984) are valid only when the regressors are strictly exogenous or, similarly, when they are not correlated with the error term neither contemporaneously nor with its lags.

If, by contrast, the regressors are correlated with the lags of the error term we have regressors that are weakly exogenous or predetermined[10]. Chamberlain (1993) propose an estimator that allows for weak exogeneity of the regressors and that also eliminates the fixed effects[11]. In this case, the author obtains an orthogonality condition that must be satisfied by the model through a transformation of the original specification which implies a quasi-differentiation of it.

The original model can be written as follows:

$$Y_{it} = e^{X_{it}^{*}\beta+\eta_i} + u_{it} \qquad (3)$$

[9] In innovation models does not seems justified the assumption of random effects. If, for instance, the firms with greater ability in the achievement of patents (due to non observable reasons) invest more in R&D because this activity is more profitable for them, the model has to be fixed effects. In any case, in order to confirm this point, the authors suggest a statistical test based on the serial correlation of the residuals.

[10] In innovation models it is quite restrictive to assume strict exogeneity of the regressors.

[11] In a similar manner, Blundell et al. (1995) propose an estimator that encompasses these characteristics but, in this case, measuring the unobserved heterogeneity directly through the use of the information contained in the past history of the dependent variable. However, as the authors recognise, this method is not valid when, as in our case, the panel dimension is small.

If the regressors are weakly exogenous, it is the case that:

$$E(u_{it} / X_{i1},......., X_{it}, \eta_i) = 0$$

Moreover, it is true that:

$$Y_{it+1} = e^{X_{it+1}^{*}\beta} e^{\eta_i} + u_{it+1} \qquad (4)$$

Obtaining the fixed effects from (4):

$$e^{\eta_i} = \frac{Y_{it+1} - u_{it+1}}{e^{X_{it+1}^{*}\beta}} \qquad (5)$$

and substituting (5) into (3) it is easy to check that:

$$Y_{it} = (e^{X_{it}^{*}\beta - X_{it+1}^{*}\beta})Y_{it+1} - (e^{X_{it}^{*}\beta - X_{it+1}^{*}\beta})u_{it+1} + u_{it} \qquad (6)$$

That can be written as follows:

$$Y_{it} = Y_{it+1} e^{(X_{it}^{*} - X_{it+1}^{*})'\beta} + v_{it} \qquad (7)$$

The restriction the model must accomplish is that:

$$E(v_{it} / X_{it}) = E(Y_{it} - Y_{it+1}e^{(X^{*}_{it}-X^{*}_{it+1})'\beta} / X_{i1}......X_{it}) = 0 \text{ for } t = 1,........,T-1 \qquad (8)$$

The problem we have with this orthogonality condition is that it is non linear in the parameters of interest β. Therefore, a non linear adaptation of the standard estimation is required. This is done by Montalvo (1993), who proposes the use of the Generalised Method of Moments (the sample moments are equalised to the population ones) in order to obtain the estimators. The estimator proposed by Montalvo (1993) is less dependent on the restrictive distributional assumptions needed for estimation in precedent models and allows us to calculate robust standard deviations for the estimated parameters.

Equation (8) gives us the basis of this method because this is the condition that a given sample moment must satisfy. Using the GMM we can face two distinct situations. The first one is when we have the same number of parameters as equations reflecting the corresponding restriction. In this case, the model is exactly identified. The second, more common one, is when the researcher has more equations reflecting the restriction than parameters, facing a problem of overidentification of the model. In this case, we should find a way that, at the same time that uses all the available information in order to improve efficiency, makes the diverse estimations existing in an overidentified system compatible.

Suppose a model in which the number of restrictions "J" is higher than the number of parameters to estimate "K", $\beta = (\beta_1,......,\beta_k)$. The orthogonality conditions are of the type:

$$E\left[m_j(y_i,x_i,\beta)\right]=0\ ;\quad j=1,........J \tag{9}$$

The sample counterpart is:

$$\bar{m}_j(y,X,\beta)=\frac{1}{n}\sum_i m_j(y_i,x_i,\beta) \tag{10}$$

Therefore:

$$\bar{m}_j=\frac{1}{n}\sum_i m_j(y_i,x_i,\beta)=0;\ \ j=1,.......J \tag{11}$$

will not have a unique solution because the model is overidentified.

The way to solve this problem is to minimise a criterion function, as, for instance, the square sum similarly to the standard procedure of the Ordinary Least Squares. That is, $Min.q=Min.\sum_j \bar{m}_j^2=\bar{m}(\beta)\,\bar{m}(\beta)$. Due to the fact that the sample moments that lead to the restrictions are composed by the addition of the corresponding observations we have, in fact, random variables whose variance is possible to estimate. Following the logic of the Generalised Least Squares, when there are more restrictions than parameters it is possible to resort to a weighed procedure in which the weights are inversely proportional to the variance of the moments.

We define W a diagonal matrix whose elements are w_{jj} = asymptotic variance $(\bar{m}_j)$. Therefore, the estimators are defined by choosing the value of β that minimises $q = \bar{m}(\beta)' W^{-1} \bar{m}(\beta)$. Hansen (1982) demonstrates that W is the optimal weighed matrix. Moreover, if W is a positive definite matrix and $\text{plim}\,\bar{m} = 0$, the estimator of β is consistent.

Under these conditions it is possible to demonstrate that $\hat{\beta} \xrightarrow{a} N(\beta, \Sigma)$, where $\Sigma = \left[G' W^{-1} G\right]^{-1}$, being $G^j = \dfrac{\partial v_j}{\partial \beta'}$.

The Montalvo (1993) model follows the above analysis. Then, the GMM estimator of β in the quasi-differenced model (7) is obtained by minimising $\left[\sum_{i=1}^{N} v_i' Z_i\right] \hat{W}_n^{-1} \left[\sum_{i=1}^{N} Z_i' v_i\right]$ where:

$$\hat{W}_N = \frac{1}{N} \sum_{i=1}^{N} Z_i' \hat{v}_i \hat{v}_i' Z_i$$

$$v_i = \begin{bmatrix} y_{i1} - e^{(X_{i1} - X_{i2})'\beta} y_{i2} \\ \\ y_{iT-1} - e^{(X_{iT-1} - X_{iT})'\beta} y_{iT} \end{bmatrix}$$

$$Z_i = \begin{bmatrix} z_{i1} - 0 - 0 - 0 - - - - 0 \\ 0 - z_{i2} - 0 - 0 - - - - 0 \\ - - - - - - - - - - - - \\ 0 - 0 - 0 - 0 - 0 - 0 - z_{iT-1} \end{bmatrix}$$

being Z_i a matrix of instruments whose elements $z_{it} = (1, x_{i1}, \ldots, x_{it})$.

The estimated variance-covariance matrix of the parameters is given by:

$$\Sigma = \frac{1}{N}\left\{\left[\sum_{i=1}^{N} Z_i' \frac{\partial v_i}{\partial \beta}\right]' \hat{W}_N^{-1}\left[\sum_{i=1}^{N} Z_i' \frac{\partial v_i}{\partial \beta}\right]\right\}^{-1}$$

It is possible to test the adequacy of the overidentifying restrictions. In the exact identified cases $q = m'W^{-1}m$ would be exactly zero because we can find a set of estimates for which "m" is zero. If the parameters are overidentified these equations will imply substantive restrictions. In this case, if the hypothesis of the model that lead to the moment equations in the first place are incorrect, at least some of the sample moment restrictions will be systematically violated. This is the basis for a test of overidentifying restrictions whose null hypothesis is that the restrictions are satisfied and in which $q \xrightarrow{d} \chi^2_{J-K}$.

IV.4.- The empirical model

Following the essence of the theoretical model, if we are able to find a measure of product differentiation directly related to quality and a measure of process innovation reflecting the reduction in the unit cost of production, there should exists a quadratic relationship between these two variables within the firm. This result is a direct consequence of assuming strategic interdependence among firms in a market as well as a direct interrelation between product and process innovation.

Apart from this result, other consequences can be extracted from the model. Process innovation is positively affected by market dimension (or, in more general terms, an approximation of the "pull of demand") and inversely related with a measure of the degree of product differentiation of the rest of the firms in the market (rivalry). Technological opportunities have ambiguous effects on the level of process innovations.

Therefore, we should find the most adequate way of testing these results. This implies the use of the correct source of data, to construct the variables that best reflect the essence of the model and to apply them to the chosen econometric framework. The SFS provides us with valuable information that is enough to reach to our objective. The variable we are going to explain (dependent variable) has to reflect that type of spending on innovation directed to the improvement of the production process. From our point of view, the number of process innovations achieved by the firm in a year is a good approximation of this variable because the theoretical model assumes that there exists a direct relationship between the technological input (process R&D) and technological output (reduction in cost). However, at this first stage we find a problem. We have the exact number of process innovations achieved by a firm only for 1990. For the rest of the years, we only know if the innovation is a new machine, a new method of production or both. The solution adopted to this problem is to consider a dependent variable with only three possible values:

$Y_{it} = 0$ if the firm has not obtained a process innovation.

$Y_{it} = 1$ if the firm has obtained a new machine or a new method.

$Y_{it} = 2$ if the firm has obtained both, a new machine and a new method.

For 1990, the firms that declared two or more process innovations (not many cases) have a value of 2.

The independent variables we are going to use should reflect vertical product differentiation, the "pull of demand" and rivalry. With respect to technological opportunities, the normal thing is to use dummies by industrial sectors with a disaggregation established by the researcher. Given that we are speaking about a categorical variable, for the panel data analysis its impact is encapsulated in the individual effects. This is the usual procedure used, for instance, by Geroski (1990).

The pioneering article about how to measure "product differentiation" is that of Caves and Willianson (1985). The point is that firms (brands) in a market face downward sloping demand curves satisfying the structural condition of imperfect substitution among competing brands. There are two main type of models, not necessarily substitutes of each other, that are able to explain this aforementioned feature of product differentiation: "product attribute" and "information" models. In the first case, the degree of imperfect substitution among brands will be greater the higher the number of primary attributes of the good and the variety of consumers' taste. In the second case, heterogeneous preferences among brands at any given set of prices is the consequence of differing information sets. In both cases, the increment in the price of one brand does not imply the loss of all buyers, but a fraction of them. The data analysis drives these authors to conclude that both types of explanations are valid.

The empirical implementation of this theoretical framework to the Spanish case is carried out by Suarez (1995) that uses the same set of data as ours for 1990[12]. The author mainly uses categorical variables that are not valid for our case because we estimate with a fixed effects panel data. However, we can find two variables, each one representing a different theoretical perspective, that are in order: the number of product innovations obtained by a firm in a year and advertising expenses as a fraction of total sales.

The essence of our theoretical model establish product differentiation as a result of the differences in quality between the differentiated (innovative) and the non-differentiated (non-innovative) firms. Therefore, it seems that it is more in accordance with the "complex attribute" perspective than with the "informational" one. Thus, we have considered the first possibility (the number of product innovations) as the variable that best reflects the "quality gap" of a firm[13]. The difference between the quality of a differentiated firm (number of product innovations) and the quality of a non-differentiated one (zero product innovations) is the quality gap of the first one. However, our measure of quality have to be defined for a line of business or single product and we do not have this information because data are defined at the firm level. In this case, it is necessary to find a solution. We have decided to divide the number of product innovations reported by each firm by the number of products it declares to have, to a maximum of 10 products[14]. The resulting value is the one which we use in order to

[12] This study shows how the sample can be divided in three types of firms: firms in which differentiation is achieved by "good" attributes, firms that differentiate through the informational channel and firms that do not differentiate their products.

[13] The advertising variable has not been significant in any of our estimations.

[14] In the survey, the number of product lines is restricted to 10. The number of firms with 10 (or more) product lines is very small.

measure the quality gap of each firm[15]. The prediction is that there exist a quadratic relationship between the dependent variable and this one. Therefore, the square of the defined variable is also included in the regression.

Continuing with the definition of the variables at the intra-industry level it is necessary to build on a variable representing "rivalry", following the essence of the theoretical model. In our model "rivalry" is defined as the quality gap of the rival firm. In this sample, each three digit industry (the most disaggregate classification that we have at our disposal) is constituted by a given number of innovative firms and not only two as in our theoretical model. Therefore, the best way of measuring this variable for each firm is to work out the average number of product innovations of the rest of the differentiated firms in the industry. This new variable is not void of problems. Apart from a generic one about the importance of the product innovation (that can be also applied to process innovations and, in general, to the whole research in this field), we observe that this variable, on the one hand, does not reflect in a correct way the relative position of each firm in relation to the degree of rivalry by industries and, on the other hand, it would not be well calculated if we do not have information about all the firms in the industry. Due to having filter the data (see section IV.2) it is advisable to homogenise these values in some way. In this sense, for each firm we have divided the corresponding value by the average of the industry to which it belongs avoiding any kind of industry bias. This transforms our variable into an index in which the non-differentiated firms will have a value of one (in industries with at least one differentiated

[15] However, this correction has not been done for process innovations. There are two reasons. The first one is that we do not know the exact number of process innovations. The second one is that it is quite sensible to think that the production process is the same or quite similar for all the product lines.

firm) and where the position of the differentiated firms will be in relation to this value, both at the cross-section level and at the time level.

Summarising, the "rival" variable is defined as follows:

Differentiated firms.

$$rival_{it} = \frac{\dfrac{\sum_{j \neq i} p_{jt}}{n_t - 1}}{\dfrac{\sum_{\forall i} p_{it}}{n_t}} = \frac{\sum_{j \neq i} p_{jt}}{\sum_{\forall i} p_{it}} \frac{n_t}{n_t - 1}$$

Non-differentiated firms.

$\text{rival}_{it} = 0$ (if there is not any differentiated firm in the industry) or 1 (if there exist differentiated firms in the industry).

where:

p_{jt} = number of product innovations per line of business of firm j in period t.

n_t = number of differentiated firms in the industry in period t, where differentiated implies to have a positive value of product innovations.

At the inter-industry level, we had two determinants of process innovation: technological opportunities and market dimension. As we have said before, the former is usually controlled by dummies and, therefore, is nullified at the time level because is a characteristic of the industry that presumably remains constant during the five years of the sample[16]. The second variable tries to reflect the known hypothesis of Schmookler about the importance of the "pull of demand" as opposed to the Rosenberg emphasis in relation to the "push of technology" (encapsulated in technological opportunities). It is not easy to find a non-categorical variable that reflects the importance of demand on innovation. We have decided to use "capacity utilisation" to measure the pressure that demand exercises on production and, then, on innovation. Although this is a variable at the firm level and not at the industry level, if we think in Keynesian terms it reflects quite accurately what we want to measure.

Finally, we are going to include in our model a measure of firm size. As is usual, this will be the number of employees the firm has at the end of the year. In our theoretical model, this variable is not included explicitly. The reason is that we assume that it is endogenously determined by "strategic competition" among firms in a market (the respective price-quality relationships), and can be substituted by variables reflecting product differentiation, rivalry etc. Including this variable we are able to test the validity of our proposition.

Summarising, the empirical model consists in applying the Montalvo (1993) econometric framework to the data obtained from the SFS with the variables defined in this section.

Therefore:

[16] However, it is fair to emphasise that Jaffe (1989) finds a certain degree of endogeneity in this variable in the medium and long-run.

$$npr_{it} = e^{(\beta_1 DIF_{it} + \beta_2 DIF_{it}^2 + \beta_3 rival_{it} + \beta_4 ocu_{it} + \beta_5 employment_{it})} + u_{it}$$

where:

npr_{it} = number of process innovations (0,1,2) of firm *i* in period *t*.

DIF_{it} = number of product innovations per line of business (vertical product differentiation) of firm *i* in period *t*.

$rival_{it}$ = relative measure of rivalry of firm *i* in period *t*.

ocu_{it} = output capacity utilisation ("pull of demand") of firm *i* in period *t*.

$employment_{it}$ = number of employees (measure of firm size) of firm *i* in period *t*.

We expect that:

$$\beta_1 \rangle 0,\ \beta_2 \langle 0,\ \beta_3 \langle 0,\ \beta_4 \rangle 0,\ \beta_5 = 0$$

The descriptive statistics for the variables and samples used in the estimations (mean and standard deviation) are reported in table 1.

Table 1: Descriptive Statistics

Variable	Sample 1 (1062)	Sample 2 (1109)	Sample 3 (465)	Sample 4 (423)
npr	0.46 (*0.73*)	0.40 (*0.69*)	0.61 (*0.79*)	0.63 (*0.81*)
DIF	2.56 (*25.61*)	0.46 (*1.34*)	1.08 (*1.90*)	1.09 (*1.90*)
rival	0.86 (*0.37*)	0.80 (*0.41*)	-	0.82 (*0.41*)
ocu	79.1 (*15.75*)	-	-	78.7 (*14.97*)
employment	243.7 (*590.46*)	220.9 (*569.10*)	339.8 (*779.50*)	363.7 (*814.60*)

Additionally, considering the simplest version of our theoretical model, process R&D intensity is directly related to technological opportunity and inversely related to vertical product differentiation (quality gap) following the expression:

$$R_i = \frac{\varepsilon}{1+\alpha_i} \qquad (12)$$

where:

R_i : process R&D intensity of firm "i".

ε : technological opportunities of the industry.

α_i : quality gap of firm "i".

This is the case of the cost function not affected by the quality of the product[17]. More complex versions include the indirect effect of the quality gap of the rival firm (rivalry) and market dimension. The foreseeable impact of the first one on process R&D intensity is positive and that of the second negative.

To test the validity of the predictions about process R&D intensity is not an easy task. We do not have at our disposal for all the years of the sample a sensible measure of process R&D intensity because, as already explained, we do not know exactly the exact number of process innovations achieved by each firm. This information is only available for 1990 and, as a consequence, we have been forced to focus in this year, which implies a cross-section analysis.

[17] Numerical simulations reveal that process R&D intensity is increasing with quality gap when the unitary cost of production is affected by this variable.

In order to calculate a proxy of our dependent variable we have followed the essence of the procedure used in other research (Levin and Reiss, 1988). The firm expenses on R&D are directed both to process and product innovations. Then, the assumption is that the proportion spent in each kind of R&D is directly connected with the proportion of innovations achieved of each type in relation to the total number of innovations. It seems quite clear that acting in this manner may have some bias but an alternative does not exist.

So, our dependent variable will be the following:

$$R_i = \frac{(\frac{np_i}{np_i + npd_i}) * RD_i}{s_i}$$

where:

np_i : number of process innovations of firm "i".

npd_i : number of product innovations of firm "i".

RD_i : total R&D of firm "i".

s_i : sales of firm "i".

At this stage we find yet another problem. It is not necessarily true that the firms reporting a positive value of process innovations also declare a positive value of R&D. There are at least two reasons. The first one is that firms are normally very optimistic about what is a process innovation considering as such whatever little improvement that occurs in the production process. The second one is that the innovation process can be performed in an informal manner without specific resources directed to this task.

Because of this fact, for our regression we have to take the firms with both a positive number of process innovations and a positive value of R&D. The first condition is satisfied by 195 firms of the 1134 firms with values for all the variables we are interested in. Among them, 134 firms report positive expenses on R&D. Therefore, this will be our "small" sample size.

For the purpose of the regression, note that taking logarithms in (12) we have:

$$r_i = \log R_i = \log \varepsilon - \log(1 + \alpha_i) \qquad (13)$$

As a consequence, we will take the logarithm of R_i as a dependent variable. For the independent variables we have to comment some important aspects. Throughout the literature, the proxy for technological opportunities has been the use of dummies by industrial sectors (see, for instance, Scherer, 1982). Although to proceed in this manner is not absent of critiques it has been an easy and effective way to capture this variable. Thus, we have decided to use dummies by sectors as table 2 shows[18]. It seems clear that we cannot take logarithms on these variables and the interpretation of the corresponding parameters estimated is valid only to establish the ranking of technological opportunities by sectors.

[18] It is possible to act in another way grouping the different sectors in three groups of high, medium and low technological intensity. For the Spanish case see, for instance, Paricio (1993).

For the regressor corresponding to vertical product differentiation we will take that derived from the theoretical model, $dif = \log(1 + DIF)$. Based on equation (13), the prediction is that the parameter affecting this expression should be equal to -1.

As already mentioned, some extensions of the model (in particular, those affecting the assumptions about the cost function) include, at least indirectly, the differentiation level of the rival firms and the impact of market dimension.

TABLE 2

NACE	SECTOR	Nº FIRMS	VARIABLE
22	Production and preliminary processing of metal	8	S1
24	Non-metallic mineral products	9	S2
25	Chemical industry	13	S3
31	Manufacture of metal articles	13	S4
32-33-39	Agricultural and industrial machinery, office machinery.	11	S5
34-35	Electrical machinery	17	S6
36-37-38	Automobiles and engines, other means of transport	18	S7
41-42	Food, drink and tobacco industry	20	S8
43-45	Textile industry, leather and leathergoods industry and footwear and clothing industry	4	S9
46-47	Wooden industry, paper printing and publishing	10	S10
48	Industry of rubber and plastics	9	S11
49	Other manufacturing industries	2	S12

In the first case and in order to establish the parallelism with own quality gap we use the variable $riv = \log(1 + rival)$, in which the variable "rival" is calculated as explained above but now within the new aforementioned sample of 1134 firms. In the second case, the variable that proxy market dimension will be $md = \log(ocu)$, where "ocu" has already been explained. Finally, we use $emp = \log(employment)$, as a proxy for firm size, a variable not considered in our theoretical background but normally taken into account in the literature.

The model to estimate is therefore:

$$r_i = \sum_{i=1}^{13} \beta_i S_i + \beta_{14} dif_i + \beta_{15} riv_i + \beta_{16} md_i + \beta_{17} emp_i + u_i \qquad (14)$$

We expect that:

$$\beta_{14} = -1, \ \beta_{15} \rangle 0, \ \beta_{16} \langle 0, \ \beta_{17} = 0.$$

IV.5.- Results

The results of the estimation are reported in table 3 for the panel data analysis about a firm's process innovation performance and in table 4 for the cross-section one about process R&D intensity. The first three columns of table 3 correspond to the cases that present the estimates of the parameters belonging to the five variables chosen for the entire period. The rest of the columns present the estimations for those firms with a number of product innovations "per line of business" inferior or equal to 10, both when we take all the firms in the sample and when we only take "differentiated firms" as defined previously. The differences observed in sample sizes are due to the availability of data for the number of variables chosen.

The most important result is the confirmation of the existence of a quadratic relationship between the number of process innovations the firm obtains and our measure of vertical product differentiation (DIF). In all the cases the coefficients have the correct signs and are highly significant. When we take a more restrictive measure of product differentiation ($DIF \leq 10$) this relationship becomes much more narrow. This result is directly in accordance with the main proposition of the theoretical model.

If we consider the effect on process innovation of the rest of the variables some relevant comments are in order. First of all, the evidence shows that there must exist an interdependence (some kind of covariation) between our measure of "rivalry" and employment. The estimations (most of them not reported) showed dramatically changes in the parameters estimated of the "rival" variable when we eliminate "employment" from our regression. In fact, the regressions showed a correct (and significant) sign of this parameter when employment is not present in the regression. When employment enters the equation, the sign is reversed and, in some cases, with significant values (see columns 1, 3, 4 and 5). From our point of view the interpretation of this result is quite straightforward. Our theoretical framework states that the demand the firm faces is dependent, among other things, on the product quality of the rival firm. In this sense, if we are able to assume (and we are) that the demand of the firm is directly related to its size, whose employment is usually its measure, it should not be surprising that rivalry and employment have some kind of interrelation (jointly with the other considered variables), making it incompatible for both of them to be in a regression at the same time because of collinearity problems. We believe this to be yet further confirmation of the model we are testing.

In general, and with the results obtained, it seems that "rival" better explains the behaviour of firms in relation to process innovations when we consider the entire sample (all types of firms). That is, the parameter that correspond to this variable is highly significant (much more than employment, that also shows the sign expected in other studies) and, even more important, the value of the chi-square test for overidentifying restrictions is clearly reduced when this variable enters the equation and employment is excluded. By contrast, when we consider only differentiated firms, things are quite different because now employment seems to be an important determinant of the cost-reducing innovations for the same reasons explained above. In this case "rival" is non-significant although shows the correct sign.

A similar argument as that explained in relation to rivalry can be applied to "output capacity utilisation". When we take the entire sample this variable has the expected sign and is significant (at least at 10% level). In the case when the sample is only composed by the differentiated firms this variable becomes insignificant, however showing the correct sign. Additionally, when we have only taken the cases for which $DIF \leq 10$ this variable is far from significant[19] (not showed). This fact leads us to think that for those firms which are highly differentiated, "the pull of demand" may act as important incentive for process innovation, reducing the negative impact of vertical differentiation.

Therefore, a different behaviour is observed depending on the type of firms under study. When we take all types of firms the important thing in order to obtain process innovations is not essentially the size of the firm but the intensity of competition that other firms exercise in the market. This is the case that the theoretical model describes. By contrast, once the firm have reached some degree of differentiation the

[19] Therefore, this variable has been excluded from the regression and now the sample size is 1109.

relevance of competition of other firms decreases and becomes essential the argument of "cost-spreading" of Cohen and Klepper (1996a), that is, the cost of innovation per unity produced is the key variable (apart from the effect of own quality).

The explanation of this phenomenon may be the following. If you are not vertically differentiated, that is, if your product does not have any kind of "brand loyalty" your decisions about reduction in cost (price) that imply the attraction of new consumers would depend on the "brand loyalty" of your competitors. The higher the vertical differentiation of other firms the lower the possibility of obtaining additional demand for your products when price is reduced. However, if you have some degree of differentiation that implies a certain "brand image", additional reduction in prices are more able to shift consumers from other firms to yours and, in this case, the relevant point in your decision is size[20].

The chi-square test for overidentifying restrictions shows that only for case (6) and (8), and if we are more willing to accept the null hypothesis than is normally the case, we are confident that the specification of the model is correct. These cases coincide with that of the sample composed only by differentiated firms. Logically, when we also have non-differentiated firms (those with zero value of the DIF variable for the entire period) there are no changes in the value of an independent variable making the choice of its lagged values as instruments an inappropriate way to proceed[21]. In any case, it should be noted that the reduction in the value of the chi-square statistic when

[20] At this point, it is convenient to remember that Jaffe (1986) finds that the negative effect of externalities because of rivalry seems to play a greater role in those firms with lower effort on R&D.

taking the correct set of variables is quite relevant. Following this criteria, our preferred specifications for each kind of sample are equations (3), (4) and (6).

With these estimates we are able to perform a practical exercise that provides us with an approach of the relevance of the results obtained. Taking, for instance, the estimations presented in equation (4) we can substitute the "rivalry" variable for its average value in the sample (see table 1). Figure 1 shows the estimated relationship between "process innovation" and "product differentiation" for the typical firm. The "turning" point, that is, the point beyond which we detect a trade-off between quality and productivity into the firm is located at 5.5 product innovations per line of business. In our sample of 1109 firms the 6.58% of them are at the right hand side of this point at least in one year of the sample. If we take just differentiated firms (as would seem more logical) this percentage rises to 15.7%.

The results of the estimation about R&D intensity and the descriptive statistics for the cross-section analysis are reported in table 4. We have performed OLS estimates robust for heteroskedasticity. The first surprising thing is that when the variable "ocu" enters the equation without any other manipulation the dummy variables are non-significant. As our observation of the descriptive statistics of the data and of the different regressions reveal, the explanation of this fact is that this variable is almost a constant term (see its standard deviation) and, therefore, the existence of a

[21] Although the Montalvo method is more appropriate where a long history of the dependent variable is not available, it presents some problems when the explanatory variables move slowly over time. This shortcoming is reduced when focusing only on differentiated firms.

multicollinearity problem is quite likely[22]. The solution adopted has been to eliminate the dummy variable corresponding to the "Food, drink and tobacco" industry , which will serve as a reference point for the ranking of technological opportunities among sectors because this is clearly the sector with lower cost-reducing technological performance. Once these comments have been taken into account, among the different specifications presented our preferred one is equation (4).

TABLE 3
Poisson fixed effects estimates with predetermined independent variables
Sample period: 1990/94
Dependent variable: Number of process innovations.

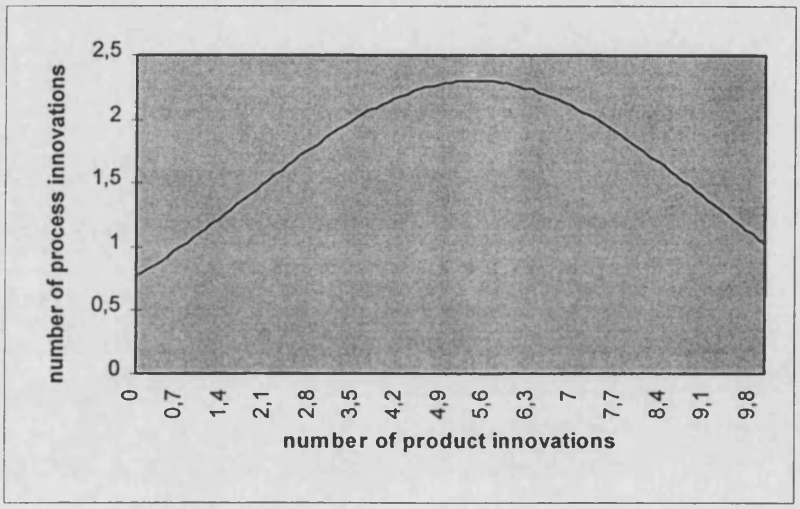
variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dif	0.027* (0.0085)	0.035* (0.0088)	0.026* (0.0084)	0.41* (0.057)	0.46* (0.058)	0.39* (0.05)	0.378* (0.052)	0.392* (0.053)
Dif^2	-0.00016* (3.67e-05)	-0.0002* (3.81e-05)	-0.00016* (3.7e-05)	-0.038* (0.007)	-0.033* (0.0068)	-0.033* (0.0066)	-0.034* (0.006)	-0.035* (0.006)
rival	0.16 (0.1)	-	-0.26* (0.095)	-0.34* (0.09)	0.21* (0.1)	-	-0.094 (0.1)	-
ocu	0.0077* (0.0031)	0.0156* (0.0031)	0.0052** (0.0031)	-	-	-	0.0051 (0.0045)	0.0055 (0.0043)
employ.	0.00032** (0.00018)	0.00035** (0.00019)	-	-	0.0002 (0.00026)	0.0005* (0.00023)	-	0.00047* (0.00023)
Firms	1062	1062	1062	1109	1109	465	423	423
χ^2_m	65	60	43.29	40.12	65	24.4+	31.98	28.25+
m	19	16	16	13	16	13	16	16
$DIF \leq 10$	NO	NO	NO	YES	YES	YES	YES	YES

* significant at 5% level.
** significant at 10%. level
+ non significant at 2.5% level.

[22] We have also observed that when we also include a constant term in the regression (eliminating one of the dummy variables) if "ocu" enters as a regressor the intercept is far from significant, contrary to that occurred when "ocu" is eliminated.

As we can see, the percentage of the variance of the dependent variable explained by the regression is about 32%, which can be considered as a reasonable good value. The results are in agreement with the theoretical framework although the "rival" variable presents the incorrect sign[23] (but it is non-significant at 5% level) and the correct and significant value for the parameter of "ocu" cannot be taken seriously for the reasons explained above.

FIGURE 1



In fact, if we carefully observe the results obtained, they are in line with the specification presented in equation (12). The coefficient affecting "dif" is negative and close to 1 (in particular, it is not possible to reject the null hypothesis that this parameter is equal to -1) and the parameter affecting the variable measuring the "size" of the firm is non-significant. In any case, it seems that exercises a negative (but not significant) effect on process R&D intensity, probably because it is associated with a high level of vertical product differentiation. With respect to technological opportunities the results

[23] In this case, it is not detected the covariation problem with firm employment explained above. It should be noted that the variables have suffered some transformations.

obtained are quite sensible. On the one hand, firms in "machinery", "chemical", "manufacture of metal articles" and "automobile" industries[24], seem to have some advantages or greater incentives for the investment on process innovation. On the other hand, the "production and preliminary processing of metal" and the "textile" and "footwear and clothing" industries apparently do not behave differently from the sector taken as a reference.

From our theoretical point of view, the most interesting conclusion we can extract from these results is that due to the variable *dif* has a negative parameter estimated, this would imply that, from the sample used, the quality of the product does not enter in a significant manner the production cost function. This, in principle, non-realistic consequence of the estimation performed can be explained in some way. The most likely explanation is that the greater part of the product innovations the firm declares to have obtained are of an incremental nature in the sense that they do not imply a really relevant change in the characteristics of the good. In this case, they do not substantially alter the unitary cost of production of the respective good as opposed to that which would occur in the case of drastic innovations.

Although we have obtained "good" results from this analysis (in the case of the variable *dif* a surprisingly accurate estimated parameter value) we are conscious of important shortcomings related to sample size, variables construction, etc.

[24] The sector "other manufacturing industries" has the higher parameter value. This is difficult to interpret because the diversity of firms included in this sector, although in our case only 2 firms are in the sample.

TABLE 4

OLS-Heteroskedasticity consistent covariance matrix.

Dependent variable: log of process R&D intensity. Sample: 134 firms

Variable	mean	st. dev.	(1)	(2)	(3)	(4)
Intercept	-	-	-	-	-2.19 (-6.34)	-
r_i	-2.34	0.61				
ocu	1.89	0.07	-0.94 (-1.48)	-	-	-1.11 (-6.87)
riv	0.24	0.12	-0.74 (-1.79)	-0.71 (-1.7)	-0.71 (-1.7)	-0.77 (-1.78)
dif	0.32	0.36	-0.74 (-5.27)	-0.71 (-5.23)	-0.72 (-5.3)	-0.75 (-5.32)
emp	2.57	0.57	-0.13 (-1.3)	-0.13 (-1.26)	-0.13 (-1.26)	-0.14 (-1.45)
S1			-0.19 (-0.15)	-1.95 (-5.12)	0.23 (1.31)	0.15 (0.85)
S2			0.31 (0.23)	-1.51 (-4.54)	0.68 (2.89)	0.67 (2.78)
S3			0.45 (0.35)	-1.34 (-3.68)	0.85 (4.15)	0.81 (3.95)
S4			0.39 (0.32))	-1.36 (-4.23)	0.83 (4.55)	0.74 (4.3)
S5			0.45 (0.36)	-1.35 (-3.67)	0.83 (4.02)	0.81 (4.06)
S6			0.27 (0.21)	-1.53 (-5.00)	0.65 (4.32)	0.62 (4.14)
S7			0.38 (0.31)	-1.37 (-4.45)	0.81 (5.05)	0.73 (4.66)
S8			-0.36 (-0.28)	-2.19 (-6.34)	-	-
S9			0.26 (0.2)	-1.51 (-3.4)	0.68 (1.53)	0.61 (1.43)
S10			0.1 (0.08)	-1.71 (-5.59)	0.48 (3.04)	0.46 (2.98)
S11			0.29 (0.23)	-1.53 (-4.96)	0.66 (4.63)	0.65 (4.56)
S12			0.67 (0.54)	-1.11 (-3.59)	1.07 (8.78)	1.02 (8.58)
adj-R^2			0.32	0.31	0.31	0.33
F-stat			5.17	5.30	5.30	5.57
Prob. F-stat			0.00	0.00	0.00	0.00
Jarque-Bera test			4.3 (0.11)	2.56 (0.27)	2.56 (0.27)	4.65 (0.10)

Note: t-ratio between brackets.

IV.6.- Conclusions

Some American authors have recently been worried about the poor evolution of productivity in the USA economy in the last decades. The reason for this can be found in different factors but it seems that those associated with innovation are of some relevance. However, following this line of research, almost nobody has paid attention to market behaviour. In an industry, firms compete with the aim to obtain profits, as much as they can, and the two ways to arrive to this objective are prices and quality. Process innovation acts in the first direction by reducing the unit cost of production of the firm and, therefore, increasing its productivity. Product innovation, influences in the second direction by improving the characteristics of the product the firm sells.

Intuitively, process and product innovations are related because both enter the price-quality relationship of the products of a firm which is a key variable in the evolution of profits due to the existence of strategic interdependence among firms in a market. Our theoretical model analyses this interrelation finding a quadratic relationship between process innovation and vertical product differentiation. Data on manufacturing Spanish firms confirms this theoretical proposition and states a point (that we have called "turning point") beyond which the firm has less incentive to pursue process innovations and, therefore, its productivity evolution will suffer.

Thus, we can find in the own market mechanism a possible explanation of the slowdown in productivity. However there is no reason to be worried about this because the other part of the story is the improvement in quality and, in turn, on welfare.

IV.7.- Appendix

TABLE A

THREE DIGIT LEVEL NACE (MANUFACTURING SECTORS)*	
221(11)	Iron and steel industry.
222 (4)	Manufacture of steel tubes.
223 (3)	Drawing, cold rolling and cold folding of steel.
224 (5)	Production and preliminary processing of non-ferrous metals.
241 (14), 247 (13)	Manufacture of clay products for constructional purposes.
242 (8)	Manufacture of cement, lime and plaster.
243 (18), 244 (12), 245 (1), 249 (3)	Other minerals and non-metallic derivatives.
246 (11)	Manufacture of glass and glassware.
251 (10), 252 (4), 253 (17), 254 (38), 255 (13)	Chemical products
311 (7), 312 (4), 313 (7), 314 (22), 315 (9), 316 (53), 319 (13)	Manufacture of metal articles.
321 (4), 322 (2), 323 (3), 324 (8), 325 (15), 326 (5), 329(13)	Manufacture of agricultural and industrial machinery.
330 (4), 391 (3), 392 (1), 393 (5)	Manufacture of office machinery.
342 (18), 343 (5), 345 (8), 346 (11), 347 (17), 351 (6), 352 (1), 353 (3), 354 (6), 355 (5)	Manufacture of electrical machinery.
362 (6), 363 (35)	Manufacture of automobiles and engines.
371 (10), 372 (8), 381 (2), 382 (3), 383 (5)	Manufacture of other means of transport.
413 (39)	Processing and preserving of fruit and vegetables.
414 (8)	Manufacture of dairy products.
411 (2), 412 (3), 415 (17), 416 (7), 417 (11), 418 (2), 419 (62), 420 (3), 421 (7), 422 (2), 423 (11)	Manufacture of other foods.
424 (4)	Distilling of ethyl alcohol from fermented materials; spirit distilling and compounding.
425 (9)	Manufacture of wine of fresh grapes.
426 (2)	Other beverages obtained from fermentation of fruit juices.
427 (6)	Brewing and malting.
428 (14)	Manufacture of soft drinks, including the bottling of natural waters.
429 (5)	Manufacture of tobacco products.
431 (7), 432 (5), 433 (7), 435 (12), 436 (5), 439 (6), 453 (56), 455 (9), 456 (1)	Manufacture of textile products; clothing.
441 (5), 442 (7), 451 (19), 452(1)	Manufacture of products from leather and leather substitutes and manufacture of footwear.
461 (2), 462 (5), 463 (15), 464 (5), 465 (3), 466 (1), 468 (41)	Manufacture of wooden furniture.
471 (2), 472 (6)	Manufacture of pulp, paper and board.
473 (18), 474 (49), 475 (12)	Paper products, printing.
481 (9), 482 (43)	Manufacture of rubber products.
491 (7), 492 (1), 493 (3), 494 (5), 495 (3)	Other manufacturing industries (jewellery, musical instruments, photographic, toys...).

Note: Between brackets there is the number of firms in the sample to a total amount of 1062 firms.

CHAPTER V: THE IMPACT OF PROCESS INNOVATIONS ON FIRM'S PRODUCTIVITY GROWTH

CHAPTER V: THE IMPACT OF PROCESS INNOVATIONS ON FIRM'S PRODUCTIVITY GROWTH

V.1.- Introduction

The study of the impact that technology could have on productivity growth experimented a relevant development when it was observed at the end of the seventies a clear slowdown in this ratio in occidental economies. This worry emerged due to the possible adverse consequences that this fact could have on the behaviour of inflation and competitiveness and, in general, on the standard of living of the industrialised societies. The interest of the authors has been essentially focused in trying to discover what the role is of the amount directed to the research and development of new products and processes on productivity evolution. The research conducted is from distinct stages, mainly at the country and sectorial levels and, to a lesser extend, at the firm level.

To do this, the diverse works have included, in addition to physical capital and labour, a measure of knowledge capital (normally a weighted sum of past R&D) as an input of the productive process and have tested the sign and significance of this variable in the corresponding regression. The results obtained of doing this exercise are not conclusive and differ in an important manner depending, for instance, on the country under study, the characteristics of the sample used (i.e. type of firms) or the period of analysis, as well as other circumstances such as to consider or not the assumption of constant returns to scale, the existence of externalities, etc.

Our perspective, however, is slightly different. In Chapters III and IV we have outlined the convenience of distinguishing the distinct impact that process and product innovations have on the profit function of a firm. This is logical if we realise that the effect of a process innovation is to reduce the unit cost of production of the good, implying a productivity improvement, and that of a product innovation is to shift the corresponding demand curve rightward (vertical product differentiation) allowing the firms to charge a higher price-cost margin. Acting in this manner, we have reached the theoretical and empirical conclusion of the existence, for a wide sample of Spanish manufacturing firms, of a quadratic relationship between an approximated measure of the number of process innovations a firm declares to have obtained in a given year and its vertical product differentiation (number of product innovations). That is, we have detected a point, corresponding to a specific degree of vertical product differentiation, beyond which the firm has less incentive for a reduction in its unit cost of production and, therefore, its process innovation performance decreases.

From this point of view we can extract one tentative (at least, partial) explanation for the aforementioned fall in the rate of growth of productivity in modern economies. In this sense, the own evolution in the development of the market mechanism that leads to a great variety and the characteristics of the good the firm sells (the possibility of vertically differentiate it) influences its cost-reduction incentives. The crucial point in order to sustain this conclusion relies in the consideration that the variable we have taken in previous chapters as a dependent one reflecting the process innovation performance of a firm determines, to a greater or lesser extent, its productivity evolution. If this is revealed to be true, we would have been able to give an alternative way to expound the problem.

This is the main contribution of this chapter. Based on the same data source used in the previous chapter and including our approximated measure of the number of process innovations obtained by a firm in a given year in its production function, we test the relevance of this variable both at the cross-section level and at the time dimensional one. Previously, a traditional approach with R&D intensity is conducted in order to make some comparisons.

Although the problems with the measurement of the variables are non-negligible throughout this study (in particular, the identification of implausibly high decreasing returns to scale at the time dimension) the results obtained are satisfactory and robust enough to affirm that the postulated existing trade-off between quality and productivity within the firm is a reasonable argument.

V.2.-Theoretical background

The point of departure of this type of analysis is normally the traditional Cobb-Douglas production function extended with a measure of knowledge (or research) capital as an input of the productive process in order to account for the improvement of technology at the firm level (see, for instance, Griliches and Mairesse, 1984). That is:

$$Q_{it} = Ae^{\lambda t} K_{it}^{\alpha} L_{it}^{\beta} R_{it}^{\delta} e^{eit} \qquad (1)$$

where Q_{it} is the output of firm "i" in period "t", A is a constant, λ measures the rate of disembodied technical change, K_{it} and R_{it} are respectively physical and knowledge capital of firm "i" in period "t", L_{it} is labour employed, α, β and δ are the corresponding elasticities of the three defined inputs and e_{it} is the error term.

When the data available exists for a sufficient period of time, the measure of the knowledge capital is usually achieved by a weighted sum of past (deflated) R&D. If this is the case, the empirical analysis is carried out by a cross-section or panel data regression of equation (1) in its logarithmic version. Unfortunately, the time dimension of our data source is just five years (see next section) and, consequently, it is not possible to construct a reliable variable reflecting research capital.

There is, however, an alternative way of dealing with this problem and it is to consider equation (1) in its growth rate form. Therefore, if we take logarithms in equation (1) and we differentiate with respect to time, we obtain:

$$q_{it} = \lambda + \alpha k_{it} + \beta l_{it} + \delta r_{it} + w_{it} \qquad (2)$$

where lower case variables indicate rate of growth.

Being δ the elasticity of knowledge capital with respect to output, we have that $\delta = \frac{\delta Q}{\delta R}\frac{R}{Q}$. If we assume the equality of marginal products across firms ($\frac{\delta Q}{\delta R}$) allowing δ to vary among them, this would lead the rate of growth of productivity to depend on R&D intensity ($\frac{RD}{Q}$). That is:

$$\delta r = (\frac{\delta Q}{\delta R}\frac{R}{Q})(\frac{\Delta R}{R}) = \frac{\delta Q}{\delta R}\frac{\Delta R}{Q} = \rho\frac{\Delta R}{Q} \cong \rho\frac{RD}{Q}$$

where it is assumed there is no depreciation in R&D ($\Delta R = RD - \eta R$; $\eta = 0$).

Following this procedure, equation (2) is reformulated as follows:

$$q_{it} = \lambda + \alpha k_{it} + \beta l_{it} + \rho\frac{RD}{Q} + w_{it} \qquad (3)$$

where the variable of interest in equation (3) is not a measure of knowledge capital but a measure of R&D intensity.

A second issue to take into account is about the assumption of constant returns to scale in the Cobb-Douglas production function[1] ($\alpha + \beta = 1$). Introducing this possibility into the regression, the equation to estimate is now in terms of labour productivity and takes the form:

$$(q_{it} - l_{it}) = \lambda + \alpha(k_{it} - l_{it}) + \gamma l_{it} + \rho\frac{RD}{Q} + w_{it} \qquad (4)$$

or simplifying the notation:

$$ql_{it} = \lambda + \alpha kl_{it} + \gamma l_{it} + \rho rd_{it} + w_{it} \qquad (4')$$

where $\gamma = \alpha + \beta - 1$, setting it equal to zero when assuming constant returns to scale and leaving it free if this is not the case. Equation (4′) will be the basis of a first stage in the

[1] There is a controversy in the definition of constant returns to scale about the inclusion in the production function of the parameter affecting the research capital. Following Griliches and Lichtemberg (1984), we have decided not to include it in order to avoid double counting with labour and physical capital inputs,

analysis performed in section 4. See, for instance, Wakelin (1998), that uses this procedure in a recent study for UK manufacturing firms.

As previously noted, the contribution of this chapter relies in considering the analysis made above from a different point of view. In our case, two additional features are in order. The first one is in direct connection with the assumption of Blundell et al. (1993) that, in spite of constructing knowledge capital using firm research efforts (R&D), they pay direct attention to effective innovations. The reasoning behind this substitution is that the process of learning is by doing successfully rather than just the resources directed to R&D. Following this criteria, the increment in knowledge stock is given by:

$$\Delta R = I - \eta R \Rightarrow \Delta R = I \text{ if we continue assuming } \eta = 0 \qquad (5)$$

where "I" is the number of innovations achieved by a firm in a given year.

The second novelty is the distinction we make between product and process R&D. As Griliches and Mairesse (1984) recognise, the knowledge capital has to be constructed with the R&D investment on *productivity,* clearly referring to process R&D. However, the authors do not take into account this aspect along their study probably due to data availability[2]. In our case, it is possible, at least in some way, to correct this shortcoming and to construct a variable that approximately measured the process innovation performance of a firm. Therefore, in the construction of knowledge capital

[2] This fact is justified arguing that the price correction of the output variable cannot account for intra-sectorial differences in price movements that, from the authors' opinion, mostly reflect quality changes. In this sense, the study encompasses not only process but also product innovations. We will turn to this aspect in next pages.

we will also consider, in principle, process innovations only. Thus, $\Delta R = pci$, where "pci" is the number of process innovations that a firm obtains in a given year.

Acting in this manner and starting again from equation (2), we have that:

$$\delta r = (\frac{\delta Q}{\delta R}\frac{1}{Q})\Delta R = \theta pci \qquad (6)$$

assuming now that what is constant across firms is the rate of return of innovations in percentage points.

Substituting, the final expression is of the form:

$$ql_{it} = \lambda + \alpha kl_{it} + \gamma l_{it} + \theta pci + w_{it} \qquad (7)$$

Equation (7) gives the basis for a test of our theory. We expect the parameter θ to be positive and significant, not establishing "a priori" any assumption about its relative importance compared with the impact of physical capital. We have also include in some regressions the number of product innovations the firm declares to obtain in a given year (*pdi*) in order to validate the assumption we have made about its limited relevance in this types of studies.

V.3.- Data and the measurement of variables

As in Chapter IV the data source is the called *"Encuesta de Estrategias Empresariales"* (Survey of Firm Strategies) conducted by the *"Fundación Empresa*

Pública". As previously mentioned, the sample period for which we have data is five years (1990-94) and the number of firms surveyed exceeds 2,000 although for reasons of missing observations and outliers this number is considerably reduced for our estimations.

The measure of the different variables we are interested in is as follows:

- The variable reflecting output (Q_{it}) is normally measured by the firm amount of sales in the given year. However, we have made a correction in this value because it may not accurately reflect the real production of a firm if the sales stock variation is high and there are important changes from year to year. Accordingly, we have accounted for this fact and our output variable includes not only the sales of the firm but also its stock variation. The inflation correction has been done using the output deflator constructed from the data contained in the National Accounts of Spain (*Contabilidad Nacional de España, CNAE*) with the sectorial level disaggregation described in the left hand side of table 1.
- The physical capital stock (K_{it}) of a firm is represented by its total fixed gross assets. It has been deflated correcting its current rate of growth by the national investment inflation rate collected in the publication *"Boletín Económico del Banco de España"* (Bank of Spain).
- The labour input (L_{it}) is compound by the total number of employees of a firm at the end of the year.

Unfortunately, our data availability does not permit us to correct these last two variables for the workers and capital used for research activity, incurring in double counting when we include R&D intensity in the regression probably underestimating its parameter value.

In our estimations we use two different variables measuring the technological input. As discussed above, the first one is R&D intensity (R&D expenses over total sales). For the construction of this variable we have taken the total amount spent by each firm on R&D, that is, we have considered not only internal expenses but also external ones. The second one is the number of process innovations a firm obtains in a year. Although we do not have the exact data for our sample period we have constructed a variable already used in the previous chapter that reasonably approximates the process innovation performance of a firm. The information we have is if the firm has obtained or not a process innovation in a given year and, if this is the case, we know if it consist in a new machine, a new method of production or both. Following the main criteria used in Chapter IV, our "process innovation" variable *(pci)* will take the value "0" if the firm has not obtained a process innovation, the value "1" when the firm has obtained a new machine or a new method and a value of "2" when it has obtained both, a new machine and a new method.

Finally, in some regressions the total number of product innovations achieved by a firm in a year *(pdi)* has also been included as a control variable for our theory. There also exists in relation to this regressor some relevant comments that we will outline in the next section.

Table 1
Sector classification

Sector (CNAE)	Price-deflator classification	Sector (CNAE)	Regression classification
1 (221,222,223)	Iron and steel industry.	1 (22)	Extraction of metallic minerals.
2 (224)	Production and preliminary processing of non-ferrous metals.		
3 (242)	Manufacture of cement, lime and plaster.	2 (24)	Non-metallic mineral products.
4 (246)	Manufacture of glass and glassware.		
5 (241,247)	Manufacture of clay products for constructional purposes.		
6 (243,244,245, 249)	Other minerals and non-metallic derivatives.		
7 (251/255)	Chemical products.	3 (25)	Chemical products.
8 (31)	Manufacture of metal articles.	4 (31)	Manufacture of metal articles.
9 (32)	Manufacture of agricultural and industrial machinery.	5 (32)	Manufacture of agricultural and industrial machinery.
10 (33,39)	Manufacture of office machinery.	6 (33,39)	Manufacture of office machinery.
11 (34,35)	Manufacture of electrical machinery.	7 (34,35)	Manufacture of electrical machinery.
12 (361,362,363)	Manufacture of automobiles and engines	8 (36)	Manufacture of automobiles and engines
13 (37,38)	Manufacture of other means of transport.	9 (37,38)	Manufacture of other means of transport.
14 (413)	Processing and preserving of fruits and vegetables.	10 (41,42)	Food, drink and tobacco industry.
15 (414)	Manufacture of dairy products.		
16 (411,412, 415/23)	Manufacture of other food.		
17 (424/428)	Beverages.		
18 (429)	Tobacco.		
19 (43, 453/56)	Manufacture of textile products, clothing.	11 (43, 453/56)	Manufacture of textile products, clothing.
20 (441,442,451, 452)	Manufacture of leather products and footwear.	12 (44,451,452)	Manufacture of leather products and footwear.
21 (46)	Manufacture of wooden furniture.	13 (46,47)	Manufacture of wooden furniture and paper industry.
22 (471,472)	Manufacture of pulp, paper and board.		
23 (473,474,475)	Paper products, printing.		
24 (481,482)	Manufacture of rubber products.	14 (48)	Manufacture of rubber products.
25 (49)	Other manufacturing industries.	15 (49)	Other manufacturing industries.

The sample size used in each regression depends on the availability of data of the corresponding variables for each firm and for the entire period. Nevertheless, we have decided to omit those firms that have experienced a rate of growth of labour productivity or of the capital to labour ratio greater than 100% in a given year. This is because we have considered that these observations could have some kind of problems such as errors of measurement, the existence of mergers, or some other circumstances that could affect in an important manner our estimates[3].

V.4.- Results

As already mentioned, we have firm data of the variables we are interested in during a period of five years: 1990-1994. However, because we are working with rates of growth the sample is reduced to four observations for each firm. This is the typical example of a panel data model. When working with panel data we mainly have three different types of estimators: between-units estimator, within-units estimator and a weighted sum of both. The first one accounts for the cross-section variation in the sample and is constructed using the firm means. The within-units estimator, also called fixed effects model, pays attention to the time dimension and assumes that each firm has a specific (individual) effect that does not vary over time and that is correlated with the corresponding regressors. In order to account for this problem the fixed effects model uses the deviations of the observations from their specific firm means. Alternatively, if the assumption is that the individual effects are randomly distributed across the cross-

[3] Griliches and Mairesse (1984) demonstrate that mergers of firms have a relevant impact in this type of study.

sectional units we are in a context of a random effects model (GLS estimator) that considers with different weights the two aspects outlined above[4].

We have analysed both the time dimension of the data and the cross-sectional one. The great advantage that the first type of estimator has over the second one is that it take into account the unobserved heterogeneity existing among the different units of analysis, which is a good thing in these types of studies. The descriptive statistics for the distinct samples used figure in table 2. The difference that exists in sample size between the cross-section and panel data models is due to a distinct criteria in the application of the decision to eliminate those firms with a variation in labour productivity or in the capital-labour ratio greater than 100%: in the case of the cross-section regression this restriction is relaxed because it is taken in relation to the average of these rates of growth throughout the entire period[5].

Logically, the mean value of the different variables is almost identical for the two types of samples studied. However, the standard deviations for the panel data case approximately doubles that of the cross-sectional one except for the technological variables for which it is only slightly higher. This result implies that R&D intensity and the innovation performance of a firm (product or process) are much more stable over time than other indicators such as those considered here, probably reflecting that labour is an input with a higher variability than is normally considered to have.

[4] The classical OLS regression can also be performed but in this case assuming the inexistence of individual effects and just an overall constant. In this case, much more weight is directed to the between-units variation.

[5] This does not qualitatively affect the conclusions but the fit of the regression (R^2) is reduced considerably in the panel data estimates.

For the period analysed, the mean of the annual rate of growth of labour productivity is about 5% and that of the capital-labour ratio and labour 8% and -2% respectively. These are very high values if we compare them, for instance, with the calculations of Wakelin (1998) for a sample (much more small than ours) of UK manufacturing firms corresponding to the period 1988-92 (1.7%, 5% and -1%, respectively). By contrast, the ratio measuring R&D intensity is considerably higher for the UK sample (0.79% versus 1.6%). This probably reveals that in Spain the technological innovation process is conducted in an informal way to a greater extend than in other countries of our economic environment as well as that the Spanish firm directs less effort to innovative activity .

The sectorial evolution that is obscured for this general values is shown in table 3 with the sectorial classification given in the right hand side of table 1. This decomposition has been done for the first sample used in our regressions (813 firms) and also includes the mean sectorial values of R&D intensity and our variable measuring the "number of process innovations". As it can be observed, the sectorial variability is quite important. The sector with a higher average annual rate of growth of labour productivity is that of the "automobile industry" followed by "extraction of metallic minerals", "electrical machinery" and "chemical products". On the other extreme, we find "metal articles" and "other means of transport". However, the data considered to be of greater interest in this table are derived from four correlations (not showed) that have been calculated from some of the variables listed (each one with 15 observations). The correlation that exists between (the rate of growth of) labour productivity and the capital-labour ratio with respect to R&D intensity by sectors are respectively 0.18 and 0.05, whereas with respect to the "number of process innovations" the values reach to 0.51 and 0.54[6]. Although this is clearly a very basic analysis it is an indicator of what we could find in our regressions.

Table 2
Descriptive Statistics
(mean and standard deviation)

	Sample (firms)	ql	kl	l	rd	pci	pdi	corr (kl/l)	corr (pci/pdi)
cross-section	813	0.048	0.082	-0.020	0.0079	0.54	-	-0.44	-
		(0.09)	*(0.13)*	*(0.08)*	*(0.019)*	*(0.59)*			
	762	0.047	0.080	-0.022	-	0.53	3.66	-0.38	0.05
		(0.08)	*(0.11)*	*(0.08)*		*(0.59)*	*(25.2)*		
	683	0.046	0.082	-0.023	-	0.49	0.61	-0.38	0.34
		(0.08)	*(0.12)*	*(0.08)*		*(0.57)*	*(1.17)*		
panel data	778	0.049	0.081	-0.023	0.0079	-	-	-0.51	-
(observations)	*(3112)*	*(0.22)*	*(0.24)*	*(0.16)*	*(0.022)*				
	655	0.046	0.082	-0.023	0.0072	-	-	-0.52	-
	(2620)	*(0.22)*	*(0.24)*	*(0.16)*	*(0.022)*				
	815	0.049	0.081	-0.022	-	0.56	-	-0.51	-
	(3260)	*(0.22)*	*(0.24)*	*(0.16)*		*(0.77)*			
	680	0.046	0.081	-0.023	-	0.49	0.62	-0.51	0.26
	(2720)	*(0.22)*	*(0.24)*	*(0.16)*		*(0.74)*	(1.56)		

The parameters estimated of the cross-section regression are showed in table 4. In order to perform this regression we have taken for each firm the average annual rate of growth of each variable except for *pci* and *pdi* that is the arithmetic mean between 1991 and 1994. We have followed the equation specifications given in expressions (4′) and (7). The first three columns of this table do not take into account the parameter λ,

[6] However, there is not a problem of collinearity in the regressions between the capital to labour ratio and the "number of process innovations" because the correlation between these two variables is

which represents disembodied technical change and which reflects those characteristics of the sector that remain constant over time[7] (for instance, technological opportunity or spillover conditions). For the rest of the columns, this sector specific effect is accounted for by the inclusion of 15 dummies in the regression (see table 1).

Column (1) includes the classical R&D intensity variable (*rd*) and does not assume constant returns to scale. The parameter estimated of the physical capital is in line with that obtained for other countries which are approximately located in the interval (0.2, 0.3). This is the case of Griliches and Mairesse (1984) for USA, Cuneo and Mairesse (1984) for France, Odagiri and Iwata (1988) for Japan and Wakelin (1998) for UK. The assumption of constant returns to scale is clearly rejected, a result also found in other countries but now the effect is stronger than in other cases[8]. The fact of assuming or not constant returns to scale influences some of our estimations in so an important manner that we have decided to present the results considering both alternatives. The variable we are most interested (*rd*) has a positive and significant impact on productivity growth, showing a higher marginal impact than that observed in other countries. For instance, the parameter estimated of Wakelin (1998) for UK is 0.35, although it is necessary to remember that in this case the average value of this variable

significantly reduced in our samples.

[7] Firm-specific effects with respect to the level of productivity are removed by the first differencing. However there could remain those related with the *rate of growth* of productivity. It is quite clear that we cannot account for them at this cross-sectional level and we have to postpone the discussion to our panel data estimates.

[8] The diverse authors have tried to give alternative explanations to this result. Some of them are related with the exclusion of materials in the production function, the omission of labour and capital intensity of utilisation variables, the use of sales instead of value added to measure production, etc. Griliches and Mairesse (1984) also include in this list the simultaneity in the determination of output and employment and propose an alternative estimation. Unfortunately, it is necessary a measure of knowledge capital to perform it.

is twice that of Spain. Therefore, the marginal impact is greater in Spain but the total (average) effect is higher in the UK.

In column (2) we perform the regression with our alternative measure of the technological input (*pci*). The corresponding parameter estimated is positive and highly significant (much more than R&D intensity) and the impact of the capital to labour ratio is considerably reduced[9]. Even more important, the F-statistics reflecting the joint significance of the regression is twice that of the precedent case and the same occurs with the adjusted-R^2. If we put these technological variables together -column (3)- the estimated coefficient of our preferred technological measure and its significance almost do not suffer any change and that of R&D intensity simply vanishes from the model

Column (4) only differs from column (1) in the inclusion of the sectorial dummies. It is clear that when considering sector-specific effects the coefficient on R&D intensity turns out to be small and far from significant[10]. However, although experimenting a decline, the coefficient on the "number of process innovations" variable remains highly significant -column (5)- denoting that even when accounting for differences among sectors the measure of the process innovation performance of a firm have a relevant impact on its own productivity growth. Moreover, the inclusion of dummies also reduces the parameter affecting the capital to labour ratio. If we assume constant returns to scale -column (6)- the coefficient affecting our technological variable suffers from a discrete fall but the parameter estimated of the physical capital increases

[9] It is convenient to remember that there is not a problem of collinearity between these two variables. In fact in this sample its correlation coefficient is only 0.11.

[10] Other authors have also obtained this result. This effect is normally attributed to the existence of sector spillovers.

a lot. For an explanation of this phenomenon it is enough to see in table (2) the existing correlation between the annual rate of growth of the capital-labour ratio and the rate of growth of labour. In any case, the assumption of constant returns to scale increases the relative importance of the physical capital in relation to the knowledge capital.

One of the key points of our contribution relies in the distinction made between product and process innovation. In this sense, the assumption is that, in principle, only process innovations would affect the rate of growth of firm's productivity[11]. Therefore, there would exist an effect of product innovations on productivity only to the extend that they affect process innovations. As mentioned in the introduction, the detected relationship between these two variables is a quadratic one, that is, there exists a point, called "turning point", beyond which the process innovation performance of a company decreases with the number of product innovations it obtains. Following this reasoning, the foreseeable impact of the number of product innovations on a firm's productivity is not so clear because, in fact, we are not able to know exactly the relative weight of the firms located to the right of their specific turning point, apart from the fact that this is really an indirect effect.

In order to test the impact of this variable in our regressions we have taken the average annual value of the total number of product innovations obtained by a firm in the period considered (*pdi*). In column (7) we see that this variable has a negative impact on productivity growth although this is not significant. This result probably

[11] As noted above, Griliches and Mairesse (1984) argue that to the extend that the inflation correction does not account for intra-sectorial differences in price movements reflecting quality changes, their study encompasses both product and process R&D. For our point of view, this is not necessarily true

reveals that the impact of those firms beyond the "turning point" in the sample is strong enough to induce this negative parameter estimated[12]. Curiously, the parameter estimated corresponding to the capital-labour ratio losses its significance at 5% level. However, if we assume constant returns to scale it is significant but with a smaller coefficient than the estimated without the use of this regressor. The coefficient on "*pci*" slightly declines and remains highly significant.

In previous work, when studying the relationship between product and process innovations, we tried some regressions restricting our sample by eliminating those firms that we considered to be exaggerating their product innovation performance. Therefore, we did not consider those firms with more than 10 product innovations "per line of business" in a given year[13]. By doing this, the relationship between these two variables became narrower. In the case at hand, we have been much more restrictive and we have eliminated those firms with a total number of product innovations that in a given year exceed the value of 10, calling the new variable *rpdi*. As we can see in table (2), acting in this manner increases the correlation between product and "process" innovations to a point where we can start to think about a collinearity problem. In fact, presumably the probability that the number of firms beyond the "turning point" in this sample is negligible is quite high.

because the effect of a process innovation could also be a reduction in price and, therefore, compensate the above effect.

[12] In fact, if we also include the square of the *pdi* variable a quadratic relationship appears although the coefficients are non-significant.

[13] Note that because now we are working with firm's productivity growth we have taken the total number of product innovations as a dependent variable.

The result of this experiment is shown in columns (9) and (10). As we can observe, "*pdi*" has a much greater coefficient than before and this is significant. In column (9), the coefficient on *pci* suffers a decline but remains with a marginal impact that doubles that of product innovations. Things change if we assume constant returns to scale because in this case the coefficient on process innovations losses its significance in favour of the capital-labour ratio[14]. This last result is quite disappointing, although as we have already explained not very strange, but before trying to give any additional explanation we have to confirm it in our panel data estimates.

Table 3
Descriptive Statistics by sectors

Sector (Firms)	**ql**	**kl**	**l**	**pci**	**rd**
1 (23)	0.092	0.093	-0.051	0.65	0.005
2 (58)	0.027	0.085	-0.021	0.375	0.004
3 (61)	0.062	0.082	-0.010	0.61	0.026
4 (77)	0.017	0.059	-0.013	0.49	0.004
5 (43)	0.030	0.079	-0.038	0.61	0.017
6 (6)	0.050	0.048	-0.058	0.54	0.014
7 (75)	0.065	0.079	-0.014	0.68	0.015
8 (39)	0.100	0.120	-0.032	1.06	0.015
9 (23)	0.019	0.100	-0.046	0.87	0.016
10 (132)	0.043	0.074	-0.007	0.49	0.002
11 (88)	0.047	0.084	-0.038	0.45	0.005
12 (25)	0.029	0.041	0.006	0.33	0.003
13 (103)	0.049	0.084	-0.016	0.39	0.003
14 (43)	0.056	0.090	-0.010	0.56	0.004
15 (17)	0.058	0.140	-0.017	0.56	0.004

[14] This does not occurs if we eliminate only the firms with more than 10 product innovations on average in the given period. However, we have deliberately chosen the most adverse situation.

Table 4

Cross-section estimates

Ordinary Least Squares corrected for heteroskedasticity

(Dependent variable: average annual rate of growth of labour productivity)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
kl	0.21 *(7.22)*	0.14 *(4.50)*	0.14 *(4.44)*	0.09 *(2.97)*	0.08 *(2.64)*	0.19 *(4.16)*	0.058 *(1.79)*	0.12 *(3.48)*	0.06 *(1.82)*	0.13 *(3.49)*
l	-0.29 *(-5.15)*	-0.32*(-5.49)*	-0.32*(-5.28)*	-0.33*(-5.33)*	-0.34*(-5.50)*	-	-0.25*(-4.88)*	-	-0.25*(-4.68)*	-
rd	0.51 *(1.98)*	-	0.033 *(0.13)*	0.032 (*0.13)*	-	-	-	-	-	-
pci	-	0.039 (*9.22)*	0.038 *(8.70)*	-	0.021 *(4.38)*	0.018 *(3.62)*	0.019 *(4.18)*	0.017 (3.52)	0.013 *(2.52)*	0.009 *(1.74)*
pdi	-	-	-	-	-	-	-0.82 E-04 *(-1.42)*	-0.76 E-04 *(-1.30)*	-	-
rpdi	-	-	-	-	-	-	-	-	0.006 *(2.03)*	0.007 *(2.40)*
firms	813	813	813	813	813	813	762	762	683	683
dummies	no	no	no	yes	yes	yes	yes	yes	yes	yes
F-stat	*30.08 (0.00)*	67.02 *(0.00)*	44.64 *(0.00)*	13.71 *(0.00)*	14.91 *(0.00)*	10.03 *(0.00)*	9.75 (0.00)	7.71 (0.00)	8.95 (0.00)	7.03 (0.00)
adj-R^2	0.067	0.14	0.14	0.21	0.23	0.15	0.17	0.13	0.17	0.13

Note: T-ratios between brackets except for the F-stat reflecting probability value.

Table 4

Panel data estimates

Period: 1990-94

(Dependent variable: annual rate of growth of labour productivity)

	Fixed effects					Random effects				
Variables	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
kl	0.016 *(0.75)*	0.023 *(0.99)*	0.019 *(0.89)*	0.022 *(0.94)*	0.019 *(0.86)*	0.22 *(13.67)*	0.22 *(12.99)*	0.22 *(14.9)*	0.22 *(12.92)*	0.22 *(13.69)*
l	-0.57 *(-17.03)*	-0.55 *(-15.57)*	-0.56 *(-17.36)*	-0.55 *(-15.91)*	-0.55 *(-16.01)*	-	-	-	-	-
rd	-0.77 *(-2.53)*	-	-	-	-	-0.19 *(-1.13)*	-	-	-	-
rrd	-	-0.57 (-1.68)	-	-	-	-	0.032 *(0.17)*	-	-	-
pci	-	-	0.02 *(2.69)*	-	0.018 *(2.08)*	-	-	0.016 *(3.53)*	-	0.012 *(2.22)*
rpdi	-	-	-	0.0037 *(0.95)*	0.0024 *(0.60)*	-	-	-	0.0051 *(2.00)*	0.0037 *(1.46)*
firms	778	655	815	680	680	778	655	815	680	680
adj- R^2	0.059	0.063	0.057	0.062	0.064	0.048	0.052	0.052	0.052	0.054

Note: T-ratios between brackets.

The problem that appears with panel data estimates of equations (4′) and (7) is that if we perform the regression by a simple OLS, implying that we assume just an overall constant term in the model, or alternatively, if we take into account the individual effects (random or fixed) of each cross-sectional unit. Theoretically, the assumption of individual effects implies that firm-specific characteristics that are constant over time influence not the level of productivity but its growth rate[15]. If, as some authors argue, the ability to innovate persists over time and is firm-specific, this assumption seems quite sensible. In fact, the corresponding test statistic strongly rejects the assumption of considering the same intercept across units. Therefore, our model must be fixed or random effects. The discrimination between these two cases is usually derived from the Hausman test, in which it is tested the orthogonality of the individual effects and the regressors. An additional example of the difference that exists of assuming or not constant returns to scale is the fact that when we assume the existence of them the model has to be fixed effects whereas random effects have to be used if this is not the case.

Our panel data estimates are showed in the second part of table (4). The first relevant thing to take into account is that, at the time level, the correlation between the rate of growth of the capital to labour ratio and the rate of growth of labour notably increases and, consequently, in the fixed effects model the coefficient affecting the physical capital is quite small and far from significant[16] whereas in the random effects model a more sensible and significant parameter estimated is found. Now, R&D

[15] We can assume, for instance, that the parameter of disembodied technical change is firm specific letting it as λ_i.

[16] Other authors have also obtained worse results in the within-units estimates. The explanation of this fact has already been outlined in footnote 8.

intensity exercises a negative effect on the rate of growth of labour productivity. This result is less strange than it seems at first sight because other authors, depending on the sample and period used, have also obtained a similar result. However, the coefficient of this variable, although negative, is usually non-significant. This clearly occurs in our random effects model but not in the fixed effects one in which it is highly significant. From the perspective of our theory, the explanation of this fact is derived from the effect exercised by those firms with a level of vertical product differentiation that is beyond the "turning point". In this case, its effect is not smoothed by the calculation of annual average rates.

Consequently, we have decided for this case to eliminate again those firms with more than 10 product innovations in a given year. The variable representing the R&D intensity in this new sample is called *rrd*. As it can be observed, in the fixed effects model its coefficient, although it remains negative, is reduced and now non-significant. In contrast, in the random effects model it turns out to be positive but non-significant.

If we focus on our technological measure, it again appears positive and significant with a marginal effect very similar to that obtained in the cross-section estimates, experimenting a small decline when we assume constant returns to scale because of the increment in the relevance of the physical capital. If we include in the regression the "number of product innovations" variable (not presented in the table) its effect is now positive but very small and far from significant, detecting again a quadratic (but non-significant) relationship if we also include the square of this variable. As before, we have again decided to eliminate those firms with higher product innovation performance. Contrary to that occurred in the cross-section regression, this variable has completely lost its relevance in the within firms estimations. Including again in the regression our *pci* variable it just suffers from a slight fall in the corresponding coefficient and its significance. At this point, it is convenient to remember that our theoretical predictions made reference to relationships occurred within the firm and, to a lesser extend, across firms, because it is necessary to take into account specific firm and market characteristics such us degree of rivalry, technological opportunities, market dimension..., that were considered as given. In this respect, the fixed effects model provides the best way to account for the mentioned features.

For its part, the random effects model gives a positive and significant parameter estimated of the *rpdi* variable if it stands in the regression alone reflecting the influence that the between-firms estimates exercises in this estimator. If we also include our *pci* variable the significance of *rpdi* vanishes, experimenting the former a non-drastic decline but it continuos to be highly significant.

From the comments above, it appears that the variable we have constructed to approximate the process innovation performance of a firm *(pci)* has a stable, consistent and permanent effect on the rate of growth of its labour productivity. We have just found an exception in which this variable has lost its significance and it has been for a very special case, specially considering that, by construction, this variable has probably a relevant constraint if we compare it with *pdi*, because we really do not have the exact number of process innovations of a firm and we do not have the possibility to compare this measure with the alternative. In any case, when we make a deeper study with panel data the aforementioned shortcoming does not appear as a problem.

Finally, we should give an approximation of the relative importance of our technological variable. In fact, this implies to compare the impact of the knowledge capital in relation to the physical capital. Given the assumptions of section II and the special features of our variable this is not an easy task. However, we can use a rudimentary and simple way to provide an approximation of their respective effects. We can simply multiply the corresponding coefficient estimated by the average value of the variable in the sample and we will have the estimated average impact of the corresponding regressor. If we divide this number by the average value of the dependent variable in the sample we obtain the percentage of this last term explained by the first one. We will do this for equations (5) and (6) of the cross-section estimations and for equation (3) of the random effects model. We do not take into account the fixed effects estimation because in this case the physical capital is non-significant. The results are showed in table (5).

Table 5

Impact of physical and knowledge capital on labour productivity growth in percentage terms

Variables	kl	pci
Cross-section		
Equation (5)	13.66%	23.62%
Equation (6)	32.45%	20.25%
Panel data		
Equation (3)	36.36%	18.28%

As noted above, the conclusion essentially depends on the assumption about constant returns to scale but the effect of our preferred technological variable cannot be considered, in any case, as negligible. Above all when the measure of this variable is quite restrictive and its parameter estimated probably is underestimating the real effect.

V.5.- Conclusions

In the present chapter we have tried to disentangle what the impact is of the number of process innovations a firm declares to obtain in a given year on the rate of growth of its labour productivity. This focus is the consequence of two considerations. On the one hand, a clear differentiation between the role exercised by product and process innovations on a firm's performance. As it is well known, the first one is directed to the improvement of the quality of the product whereas the second one lies in the reduction of the unit cost of production and, consequently, on productivity evolution. On the other hand, the assumption that the knowledge capital of a firm is mainly derived from its "successful" innovation process and not just from the amount spent on R&D. In this sense, we have considered to be more adequate to use the process innovation performance of a firm to account for the impact that knowledge capital has on productivity growth rather than considering, as other studies do, the R&D intensity.

The "cross-section" and "panel data" estimations demonstrate that our preferred technological variable has the predicted effect and is significant, showing that this result is robust under a wide range of specifications. Moreover, except for a special case in which we have performed some restrictions in the sample, the product innovation performance of a firm does not have a significant impact on our dependent variable. This implies not just that, on average, firms are telling the truth but that our predictions about the existence of a point beyond which the firm faces a trade-off between quality and productivity is reasonable and sensible.

CHAPTER VI: CONCLUSIONS

CHAPTER VI: CONCLUSIONS

It is widely accepted that innovation is one of the main forces of economic growth and improvement of welfare in modern societies. As demonstrated by historical events, the emergence or decline of firms in dynamic economies is a consequence of the appearance of new or better products and production processes. For this reason, in the sixties, Economic Theory started to pay attention to the technological innovation phenomenon. For a long time, the studies focused on testing the hypothesis about this area which were established by the Schumpeter writers.

In fact, until recently, the research conducted in this field has been directed to the study of the economic determinants of innovative activity or, more precisely, to the incentives that a firm has to spend resources on R&D in order to obtain an innovation. In the beginning, the two main candidates were firm size and market concentration, as a reflection of a certain degree of "monopoly power" that was considered to be one of the essential factors for investing in innovation. The research continued with the inclusion into the models of other variables reflecting the "pull of demand", the "push of technology" or externalities, determinants more narrowly connected with the expected profitability of an innovation or with the degree of difficulty to obtain it. It is observed that, once taken into account these other factors, the first ones lost a great part of their relevance, probably revealing that they are a consequence and not a cause of the innovation process. Moreover, theoretical models also demonstrate that concentration and innovation are endogenously determined. In Chapter II we have made a revision of this literature establishing what we consider to be its virtues and shortcomings.

However, as we have pointed out throughout this research, in the different studies undertaken it has not been common to clearly distinguish the two aspects in which innovation can materialise: process innovation and product innovation. These two types of innovations have different incidence on firms performance. The first one is directed to the reduction of the unitary cost of production of the good whereas the second one improves the quality of the products the firm sells. Because both have a distinct impact on profits and in different ways, the standard assumption of considering innovation as a unitary whole may lead us to ignore some important connections of causality between these technological variables. Our aim is to differentiate both factors and to discover the link existing between them.

In Chapter III, we develop a model in which the incentives a firm has to invest in process innovation are determined paying special attention to the incidence that own vertical product differentiation exercises in the variable of interest. The point of departure comes from some interesting aspects of the product innovation model of Ulph (1991). In particular, this model establishes that the market share of a firm is determined by the relative position that the price-quality relationship of its product has in relation to that of the rival firms given consumer tastes. The resulting demand structure implies that each firm has a strategic interdependence with the rest of the firms in the market and that is the aspect of the model of Ulph in which we are more interested. Therefore, given the quality of the good, the firm will wish a specific price for its product that, in a context of Bertrand competition it will directly depend on cost. If we assume, as in Dasgupta and Stiglitz (1980), that the unitary cost of production is a function of the expenses on R&D by the firm, we can investigate the effect that (own and rival) quality has on this spending. In fact, the originality of our model lies in assuming the need for the spending on cost-reducing R&D in order to introduce a higher quality product into the market. Thus, we establish the existing relationship between the degree of product differentiation of a firm and its expenses on process R&D, as well as the effect of the rest of the parameters of the model: quality gap of the rival firm (*rivalry)*, market dimension and technological opportunities.

Our theoretical model shows that the incentive for cost reduction is increasing with vertical product differentiation until a point, that we have called "turning point", beyond which this relationship is reversed. This is because, as quality increases, the negative effect exercised on the price-elasticity of demand and on decreasing returns on marginal gain of process R&D grows in relation to the positive effect on "ex-ante" profits. Therefore, our main contribution lies in demonstrating that a quadratic relationship should exist between these two variables, with the identification of a point in which there starts to be a trade-off between quality and productivity within the firm. Moreover, the quality gap of the rival firm exercises a negative effect on cost reduction because "ex-ante" profits are reduced with this parameter contrary to that which occurs with market dimension whereas technological opportunities have ambiguous effects. In this model, the strategic interdependence among firms in the market and the interrelation between product and process innovation gives no explicit role to firm size that, as we have pointed out, is assumed the result of the existent relative position of the price-quality relationship of each firm. In this respect, the argument of cost-sharing used in other studies to justify the importance of the "ex-ante" output (firm size) is substituted by that which we have called "ex-ante" profits.

The results of the theoretical model are tested in Chapter IV. The estimations are based on a panel data analysis of Spanish manufacturing firms for the period 1990-94 collected from the so-called *"Encuesta de Estrategias Empresariales"* (Survey of Firm Strategies). Although the empirical specification reveals some important shortcomings as, for instance, the lack of knowledge about the real relevance of innovations reported by firms, several important conclusions can be extracted from the econometric estimations.

The different estimations reported show us that we can be quite confident that the main result of the theoretical model is confirmed by the data. A significant quadratic relationship is obtained between a measure of the cost-reducing innovation performance of the firm (number of process innovations) and our preferred measure of its vertical product differentiation (number of product innovations per line of business). Thus, this demonstrates to be the first proof of the aforementioned trade-off between a reflection of the quality of the product of a firm and a variable that, by definition, determines its productivity growth, that is the main proposition we have tried to confirm.

The implications of this result are the following. The estimations performed imply that, in a given market, there are some firms for which the quality of their products is so high that the price (cost) is not a strategic variable. Consequently, these firms have less incentive to perform process innovations and its productivity evolution will suffer from this fact. Therefore, the firm that has created its own "niche" in the market will probably have a poorer productivity evolution. The point beyond which this occurs depends on the particular characteristics of each industry (technological opportunities, degree of rivalry, etc...). If we take this reasoning at an aggregate level, we can extract the conclusion that as the variety of the good increases and products become less homogeneous the rate of growth of firm productivity experience a decline.

Apart from this result, other interesting comments are necessary. Depending on the sample chosen (all the firms or only the "differentiated" ones) the predictions about the rest of the variables of the model are or are not accomplished. In particular, the degree of vertical product differentiation of the rival firms in the market (*rivalry*) will have a significant impact on the process innovation performance of a firm when we consider the whole sample but its relevance is substituted by a measure of "firm size" when we only consider the sample based on differentiated firms. The interpretation we have given to this result is that the firm takes into account the degree of rivalry in the market at the time of investment in order to search for a reduction in its unit cost of production if it does not really have a "brand loyalty" to their products. The reason is the stronger impact that, in this case, this variable presumably has on the foreseeable effect that a reduction in price has on the attraction of new consumers. By contrast, once obtained a certain degree of "brand loyalty" in the market, the largest firms have advantage for cost-reducing innovation. This provides an important nuance for those works that have studied the relationship existing between size and innovation.

Moreover, cross-section analysis has been performed to study the factors influencing process R&D intensity. The results obtained about the sectorial influence of this variable are quite sensible. On the one hand, "machinery", "chemical", "metal articles" and "automobiles" are the sectors with higher performance on this type of spending. On the other hand, we find the "food, drink and tobacco industry". As the results also suggest, the unit cost of production is not significantly affected by the quality of the product which leads us to assume that product innovations are, in a great part, incremental.

As mentioned above, the main conclusion of the theoretical and empirical models presented is the identification of a point at which there starts to appear a relationship of substitution between quality and productivity within the firm. In order to sustain this conclusion, it is essential to investigate the validity of our intuitive premise which consists in assuming that the used proxy of the process innovation performance of a firm, a measure of the number of process innovations a firm obtains in a year, really determines its productivity evolution. In Chapter V we demonstrate that the selected variable is a clear determinant of the labour productivity growth of a firm, showing much better results than the standard R&D intensity.

Summarising, what we have demonstrated is that the productivity growth of a firm is determined in a direct manner by its process innovation performance and that, at the same time, this variable is strongly influenced in an specific way by its degree of vertical product differentiation. This has led us to establish the following proposition: when the degree of vertical product differentiation of a firm is high enough it faces a trade-off between quality and productivity. This is probably an additional explanation of the productivity slowdown observed since the decade of seventies in occidental economies.

The research conducted here has had a clear purpose: to show that the studies that have tried to explain the factors influencing innovation by focusing on it in a generic manner or only in one of its two possible aspects (product or process) could be seriously misleading. This is because they have ignored the strategic interdependence existing among firms in a market that, in the final analysis, is responsible for the incentives the firm has in order to improve the quality of its product or reduce its cost of production.

We have tried to fill, although partially, this gap on the existing literature. A lot of things remain to be explained but we would be happy if we have opened a new door for a better understanding of our reality.

REFERENCES

REFERENCES

- Angelmar, R. (1985): "Market Structure and Research Intensity in High Technological Opportunity Industries", The Journal of Industrial Economics, Vol. XXXIV, N° 1, pp. 69-79.

- Audretsch, D. and Feldman M. (1996) : "R&D Spillovers and the Geography of Innovation and Production", The American Economic Review, vol. 86, N° 3, pp. 630-640.

-Beath, J., Katsoulacos, Y. and Ulph, D. (1987): "Sequential Product Innovation and Industry Evolution", Economic Journal, vol. 97 (Conference 1987), pp. 32-43.

-------------------- (1989a): "Strategic R&D Policy", Economic Journal, vol. 99 (Conference 1988), pp. 74-83.

--------------------- (1989b): "The Game-Theoretic Analysis of Innovation: A Survey", Bulletin of Economic Research, 41:3, pp 163-184.

- Bertschek, I. (1995): "Product and Process Innovation as a Response to Increasing Imports and Foreign Direct Investment ", The Journal of Industrial Economics, Vol. XLIII, N° 4, pp 341-357.

- Blundell, R., Griffith, R. and Van Reenen, J. (1993): "Knowledge Stocks, Persistent Innovation and Market Dominance: Evidence from a Panel of British Manufacturing Firms", Institute for Fiscal Studies, Working Paper Series N° W93/19.

- Blundell, R., Griffith, R. and Van Reenen, J. (1996): "Dynamic Count Data Models of Technological Innovation", The Economic Journal, 105, pp. 333-344.

- Bonanno, G. and Haworth, B. (1998): "Intensity of Competition and the Choice between Product and Process innovation", International Journal of Industrial Organisation, 16, pp. 495-510.

- Börsch-Supan, A. and Hajivassilion, V. (1993): "Smooth Unbiased Multivariate Probability Simulators for Maximum Likelihood Estimation of Limited Dependent Variable Models", Journal of Econometrics , 58, pp. 347-68.

- Cameron, A. and Trivedi, P. (1986): "Econometric Models Based on Count Data: Comparisons and Applications of Some Estimators and Tests", Journal of Applied Econometrics, Vol. 1, pp. 29-53.

- Caves, R. E. and Willianson, P.J. (1985): "What is the Product Differentiation Really?", The Journal of Industrial Economics, Vol. XXXIV, pp.113-132.

- Chamberlain, G. (1980): "Analysis of Covariance with Qualitative Data", Review of Economics Studies, N° 47, pp. 225-38.

- -------------------(1984): "Panel Data", in *Handbook of Econometrics*, ed. by Z. Griliches, M.D. Intriligator, vol. II, pp. 1247-1317, Amsterdam, North-Holland.

- -------------------(1993): "Feedback in Panel Data Models", mimeo, Econometric Society Summer Meeting, Boston, June.

- Coe, D.T. and Helpman, E. (1995): "International R&D Spillovers". European Economic Review, N° 39, pp. 859-887.

- Cohen, W. M. (1995): "Empirical Studies of Innovative Activity", in *Handbook of the Economics of Innovation and Technological Change*, Ed: Paul Stoneman, Blackwell.

- Cohen, W. M., Levin, R.C. and Mowery, D.C. (1987): "Firm Size and R&D Intensity. A Re-Examination", The Journal of Industrial Economics, Vol. XXXV, N° 4, pp. 543-565.

- Cohen, W. M. and Levinthal, D.A. (1989): "Innovation and Learning : The Two Faces of R&D", The Economic Journal, 99, pp. 569-596.

- Cohen, W. M. and Klepper, S. (1996a): "Firm Size and the Nature of Innovation within Industries: The Case of Process and Product R&D", Review of Economics and Statistics, pp. 232-243.

---------------------------------- (1996b): "A Reprise of Size and R&D", The Economic Journal, 106, pp. 925-51.

- Comanor, W. S. (1967): "Market Structure, Product Differentiation, and Industrial Research", Quarterly Journal of Economics, 87, pp. 639-656.

- Culbertson, J.D. (1985): "Econometric Test of the Market Structural Determinants of R&D Investment: Consistency of Absolute and Relative Firm Size Models", The Journal of Industrial Economics, Vol. XXXIV, pp. 101-108.

- Cuneo, P. and Mairesse, J. (1984): "Productivity and R&D at the Firm Level in French Manufacturing" in *R&D, Patents and Productivity*, edited by Z. Griliches, University of Chicago Press: Chicago.

- Dasgupta, P. and Stiglitz, J. (1980): "Industrial Structure and the Nature of Innovative Activity", Economic Journal, 90, pp. 266-293.

- Dosi, G. (1988): "Sources, Procedures and Microeconomic Effects of Innovation", Journal of Economic Literature, vol. XXVI, pp. 1120-1171.

- Fisher, F. and Temin, P. (1973): "Returns to Scale in Research and Development: What does the Schumpeterian Hypothesis Imply?, Journal of Political Economy, 81, pp. 56-70.

- Fariñas, J.C. and Jamandreu, J. (1994): "La Encuesta de Estrategias Empresariales: Características y Usos", Economía Industrial, nº 299, pp. 109-19.

- Galbraith, J.K. (1956): "American Capitalism", Houghton Mifflin, Boston.

- Geroski, P.A. (1990): "Innovation, Technological Opportunity and Market Structure", Oxford Economic Papers, 42, pp. 586-602.

- -------------- (1991): "Innovation and the Sectoral Sources of UK Productivity Growth", The Economic Journal, 101, pp. 1438-51.

- Gilbert, R. and Newbery, D. (1982): "Pre-emptive Patenting and the Persistence of Monopoly", American Economic Review, 72, pp. 514-26.

- Griliches, Z. and Mairesse, J. (1984): "Productivity and R&D at the Firm Level" in *R&D, Patents and Productivity*, edited by Z. Griliches, University of Chicago Press: Chicago.

- Griliches, Z. and Lichtenberg, F. (1984): "R&D and Productivity Growth and the Industry Level: Is There Still a Relationship" in *R&D, Patents and Productivity*, edited by Z. Griliches, University of Chicago Press: Chicago.

- Hansen, L. (1982): "Large Sample Properties of Generalised Method of Moments Estimators", Econometrica, 50, pp. 1029-1054.

- Harris, C. and Vickers, J. (1987): "Racing with Uncertainty", Review of Economics Studies, Vol. 54, N. 1, pp. 1-21.

- Hausman, J., Hall, B. H. and Griliches, Z. (1984): "Econometric Models for Count Data with an Application to the Patents-R&D Relationship", Econometrica, vol. 52, N° 4, pp. 909-38.

- Henderson, R. and Cockburn, I. (1996): "Scale, Scope, and Spillovers: The Determinants of Research Productivity in Drug Discovery", Rand Journal of Economics, vol 27, N°1, pp. 32-59.

- Jaffe, A.B. (1986): "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value", American Economic Review, vol. 76, N° 5, pp. 984-1001.

- Jaffe, A.B. (1988): "Demand and Supply Influences in R&D Intensity and Productivity Growth", The Review of Economics and Statistics, 72, pp. 431-437.

- Jaffe, A.B. (1989): "Characterising the "Technological Position" of Firms, with Application to Quantifying Technological Opportunity and Research Spillovers", Research Policy, 18, pp. 87-97.

- Joshi, S. and Vonortas, N. S. (1996): "Two-Stage R&D Competition: An Elasticity Characterisation", Southern Economic Journal, Vol. 62, n°4, pp. 930-37.

- Klepper, S. (1996): "Entry, Exit, Growth, and Innovation over the Product Life Cycle", The American Economic Review, Vol. 86, N° 3, pp. 562-583.

- Kohn, M. and Scott, J. (1982): "Scale Economies in Research and Development: the Schumpeterian Hypothesis", The Journal of Industrial Economics, Vol. XXX, N° 3, pp. 239-249.

-Lee, T. and Wilde, L. (1980): "Market Structure and Innovation: A Reformulation", Quarterly Journal of Economics, vol. 94, pp. 429-36.

- Levin, R. and Reiss, P.C. (1984): "Test of a Schumpeterian model of R&D and Market Structure", in *R&D, Patents and Productivity*, edited by Z. Griliches, University of Chicago Press: Chicago.

- Levin, R. and Reiss, P. (1988): "Cost-Reducing and Demand-Creating R&D with Spillovers", Rand Journal of Economics, vol. 19, N°4, pp. 538-556.

- Levin, R., Cohen, W. and Mowery, D. (1985): "R&D, Appropiability, Opportunity, and Market Structure: New Evidence on Some Schumpeterian Hypotheses", AER - Papers and Proceedings-. vol 75, Nº 2, pp. 20-29.

- Levin, R., Klevorick, A., Nelson, R. and Winter, S. (1987): "Appropriating the Returns from Industrial R&D", Brooking Papers on Economic Activity, pp. 783-820.

- Loury, G.C. (1979): "Market Structure and Innovation", Quarterly Journal of Economics, 93, pp. 395-410.

- Lunn, J. (1986): "An Empirical Analysis of Process and Product Patenting: A Simultaneous Equation Framework", The Journal of Industrial Economics, Vol. XXXIV, Nº3, pp. 319-330.

- Montalvo, J. (1993): "Patents and R&D at the Firm Level: A New Look", Revista Española de Economía, Monográfico "Investigación y Desarrollo".

- Odagiri, H. and Iwata, H. (1986): "The Impact of R&D on Productivity Increase in Japanese Manufacturing Companies", Research Policy, 15, pp. 13-19.

- Pakes, A. and Schankerman, M. (1984): "An Exploration into the Determinants of Research Intensity", in *R&D, Patents and Productivity*, edited by Z. Griliches, University of Chicago Press: Chicago.

- Paricio, J. (1993): "Determinantes de la actividad tecnológica en la industria", Revista de Economía Aplicada, 1, pp. 103-23.

- Pavitt, K., Robson, M. and Townsend, J. (1987): " The Size Distribution of Innovating Firms in the UK: 1945-1983", The Journal of Industrial Economics, Vol. XXXV, Nº 3, pp. 297-316.

- Reinganum, J.F. (1985): "Innovation and Industry Evolution", Quarterly Journal of Economics, Vol. 100, pp. 81-99.

- Rosen, R.J. (1991): "Research and Development with Asymmetric Firm Sizes", Rand Journal of Economics, Vol. 22, N° 3, pp. 411-429.

- Rosenberg, N. (1974): " Science, Invention and Economic Growth", Economic Journal, N° 84, pp. 90-108.

- Scherer, F.M. (1982): "Demand-Pull and Technological Invention: Schmookler Revisited", The Journal of Industrial Economics, Vol. XXX, N° 3, pp. 225-237.

- Scherer, F.M. (1983): "Concentration, R&D, and Productivity Change", Southern Economic Journal, 50, pp. 221-25.

- Schmookler, J. (1962): "Economic Sources of Inventive Activity", Journal of Economic History , 22, 1-10.

- --------------- (1966): "Invention and Economic Growth", Cambridge, Mass., Harvard University Press.

-Schumpeter, J.A. (1950): "Capitalism, Socialism and Democracy", Harper & Row, New York.

- Scott, J. (1984): "Firm versus Industry Variability in R&D Intensity", in *R&D, Patents and Productivity*, edited by Z. Griliches, University of Chicago Press: Chicago.

- Seade, J. (1980): "The Stability of Cournot Revisited", Journal of Economic Theory N° 23, pp. 15-27.

- Shacked , A. and Sutton, J. (1982): "Relaxing Price Competition through Product Differentiation", Review of Economic Studies, vol. 49, N° 1, pp. 3-14.

- Shrieves, R.E. (1978): "Market Structure and Innovation: A New Perspective", Journal of Industrial Economics, 26, pp. 329-47.

- Spencer, B.J. and Brander, J.A. (1983): "International R&D Rivalry and Industrial Strategy", Review of Economic Studies , 50, pp. 707-722.

- Sterlacchini, A. (1989): "R&D, Innovations and Total Factor Productivity Growth in British Manufacturing", Applied Economics, 21, pp. 1549-62.

- Suárez Gálvez, C. (1995): "La Diferenciación de Producto: Una Aproximación Empírica a la Industria Española", Economía Industrial, nº 304, pp. 119-26.

- Thompson, P. (1996): "Technological Opportunity and the Growth of Knowledge: A Schumpeterian Approach to Measurement", Journal of Evolutionary Economics, 6, pp. 77-97.

-Ulph, D.T. (1991): "Endogenous Growth and Industrial Structure". Discussion Paper. University of Bristol.

-Ulph, D.T. and Owen, R. (1994): "Racing in two Dimensions", The Journal of Evolutionary Economics, vol. 4, pp. 185-206.

-Vickers, J. (1986): "The Evolution of Industry Structure when there is a Sequence of Innovations", The Journal of Industrial Economics, 35, pp. 1-12.

-Wakelin, K. (1998): "Productivity Growth and R&D Expenditure in UK Manufacturing Firms", 25th Annual E.A.R.I.E. meeting, University of Copenhagen, August.

- Yin, X. and Zuscovitch, E (1998): "Is Firm Size Conducive to R&D Choice? A Strategic Analysis of Product and Process innovations", Journal of Economic Behaviour and Organisation, 35, pp. 243-62.

RESUMEN

PRODUCT DIFFERENTIATION AND PROCESS R&D: THE TRADE-OFF BETWEEN QUALITY AND PRODUCTIVITY IN THE SPANISH FIRM

RESUMEN

El progreso tecnológico es un factor fundamental para el crecimiento económico y la mejora en el bienestar de la sociedad, por lo que resulta especialmente atractivo para los economistas el conocimiento de los mecanismos que lo impulsan y condicionan. Por este motivo, desde hace un par de décadas ha surgido un interés creciente en la literatura por el estudio de los determinantes que influyen en la asignación de recursos por parte de las empresas a la Investigación y Desarrollo (I+D) de nuevos productos y procesos productivos que conduzcan a una posible innovación.

A partir de los escritos de Schumpeter, una parte significativa de la literatura académica ha dirigido sus esfuerzos a profundizar en el estudio de los hipotéticos efectos positivos que una mayor "concentración del mercado" y "tamaño de la empresa" ejercen sobre la actividad innovadora. La "concentración del mercado" implica, por un lado, que las empresas disponen de un volumen de recursos propios elevado que les otorga una ventaja financiera mientras que, por otro lado, el mayor poder de monopolio confiere una mayor capacidad de cara a la apropiabilidad de los beneficios de la innovación. El interés por el "tamaño" se debe a la posible existencia de economías de escala en las actividades de I+D así como a su carácter de coste fijo para la empresa. De acuerdo con esta perspectiva, cuanto mayor es el número de empleados dedicados a actividades de mejora tecnológica mayor es su eficiencia, dado que las posibilidades existentes para una mejor división del trabajo se amplían de forma considerable. Del mismo modo, la productividad de una plantilla dedicada a la I+D es mayor en una empresa grande, debido a que la diversificación de actividades que se generan en su seno es superior. Además, cuanto mayor es el volumen de ventas de una empresa, menor resulta el coste (fijo) de la innovación por unidad de producto, lo que incentiva el destino de recursos a la misma. Este último aspecto es el que se denomina "argumento del reparto del coste" ("cost-spreading argument"), utilizado con frecuencia por algunos autores en defensa del efecto beneficioso que el tamaño de la empresa tiene sobre la innovación (i.e. Cohen y Klepper, 1996b).

En todo caso, la incidencia real que ejercen en la innovación las variables que se enmarcan en el concepto schumpeteriano de "empresa monopolística" no está resuelta y parece que la actividad tecnológica viene influida por otros determinantes cuya justificación económica es más sólida. Dos son los factores que han demostrado tener un mayor impacto en la decisión de destinar recursos a la innovación: las condiciones de demanda a las que se enfrenta la empresa o "tirón de la demanda" ("the pull of demand") y el entorno tecnológico en el que se desenvuelve la misma o "empuje de la tecnología" ("the push of technology"). Ambos elementos ofrecen una explicación más satisfactoria de los incentivos que mueven a una empresa en su evolución tecnológica que aquellos que se derivan de una determinada estructura de mercado.

Los fundamentos de dichos determinantes son los siguientes. El rendimiento que obtiene la empresa de la investigación está relacionado directamente con el número de unidades de producto que incorporan la nueva tecnología, por lo que, cuanto mayor sea el mercado potencial al que se enfrenta la empresa mayor será su incentivo a realizar

I+D (Schmoockler, 1966). Dicho argumento descansa en el supuesto de que el conocimiento científico está lo suficientemente extendido y desarrollado como para que todas las industrias sean capaces de acceder a él a un coste similar, dirigiendo, por tanto, su esfuerzo innovador hacia aquellos segmentos del mercado que pueden resultar más provechosos. Asimismo, como ya se ha apuntado, el gasto efectuado por parte de las empresas en I+D puede tener la consideración de coste fijo, por lo que en este caso es igualmente aplicable el argumento del "reparto del coste". Entornos tecnológicos más fértiles hacen, por otra parte, que la productividad de los recursos destinados a la innovación sea mayor y, en consecuencia, se incrementa la disposición de las empresas a dedicar esfuerzos a dicho gasto (Rosenberg, 1974). Por esta razón, las empresas situadas en aquellas industrias con mejores oportunidades tecnológicas tendrán una menor dificultad en transformar los inputs de la investigación en innovaciones presentando, por tanto, un progreso tecnológico más acentuado.

Los estudios empíricos muestran que ambos factores son relevantes en la explicación de la actividad innovadora de las empresas si bien divergen en cuanto a la medición de la importancia relativa de cada uno de ellos, tal y como se especifica en el Capitulo II.

Además de los determinantes de la innovación ya mencionados, existen otros dos aspectos del proceso de avance tecnológico que, por su propia naturaleza, han sido analizados con menor profundidad: la incertidumbre y los efectos externos. Cuando una empresa decide invertir una determinada cantidad de recursos en I+D, se enfrenta a un entorno de incertidumbre considerable porque, en realidad, desconoce los resultados que obtendrá de los mismos y el tiempo que empleará en alcanzarlos. Se trata, pues, de una inversión con un alto riesgo. Además, es bien conocido el carácter de bien público que, en un buen número de casos, presenta la innovación, lo que, si bien por un lado reduce los beneficios a obtener de la misma e induce a su protección a través, por ejemplo, de patentes, por otro, puede presentar efectos positivos si, como apunta Jaffe (1986), el coste de innovar se reduce por el efecto externo que genera la investigación de las empresas situadas en un espacio tecnológico colindante. Surge, así, el denominado "problema de la apropiabilidad".

La actividad innovadora ha sido definida de forma genérica en la mayor parte de los estudios aludidos (por ejemplo, gastos en I+D) de forma que no estamos seguros del tipo de innovación y las vías de transmisión del progreso técnico. Aunque la literatura no siempre lo define con claridad, cuando una empresa innova lo puede hacer por dos vías distintas. La primera es aquella cuya finalidad es la reducción de los costes unitarios de producción mediante la mejora del proceso productivo; es lo que se denomina innovación de proceso. La segunda va encaminada a la mejora de la calidad de los bienes (diferenciación vertical) o a la introducción de nuevos productos en el mercado; es lo que se llama innovación de producto.

Los modelos teóricos se han centrado por lo general tan sólo en alguno de los dos tipos de innovación o bien han tratado los gastos en I+D como un todo, independientemente del efecto diferenciado que cada uno de ellos tiene sobre los beneficios de la empresa. Siendo un hecho constatado que las empresas obtienen patentes en los dos tipos de innovación (o, en todo caso, destinan recursos a ambos) abordar sólo un aspecto puede dar una visión parcial del problema. Además, una innovación de producto lleva normalmente aparejada una innovación de proceso (Levin y Reiss, 1988), razón por la que el análisis se complica aún más. Por ello, recientemente han empezado a elaborarse en la literatura modelos teóricos que intentan explicar la relación existente en el seno de una empresa entre el gasto en I+D destinado a la innovación de producto y el dedicado a innovación de proceso (Bonanno y Haworth, 1998, o Yin y Zuscovitch, 1998). En el terreno empírico se han hecho, paralelamente, algunas aproximaciones de los determinantes que influyen en cada tipo de innovación (Lunn, 1986, Levin y Reiss, 1988, Berstcheck, 1995, Cohen y Klepper, 1996a o Klepper, 1996).

En última instancia, el objetivo de la innovación (de proceso o producto) es la consecución de una mejor posición de la empresa frente a los rivales reales o potenciales y éste debería ser, en definitiva, el origen de la justificación económica de su actividad tecnológica. Es esencial considerar, por este motivo, el efecto diferencial que los distintos tipos de innovación tienen sobre el coste y la calidad del producto porque es indudable que éstos serán los factores primordiales en los que la empresa basará su posición competitiva.

Siguiendo este razonamiento, parece lógico pensar que las variables "tamaño de la empresa" y "concentración del mercado" son, esencialmente, el resultado de la posición relativa que las distintas empresas ocupan en su relación calidad-precio con respecto a sus competidores. Si consideramos que tanto el precio como la calidad del producto se ven influidos por los recursos que la empresa destina a la innovación, no es de extrañar la conexión de endogeneidad que la literatura postula entre concentración e I+D, así como la confusión existente acerca de la dirección en la cual la dimensión de la empresa incide sobre su actividad tecnológica.

Siguiendo estas premisas y basándonos en el modelo de innovación de producto de Ulph (1991), suponemos que la cuota de mercado de la empresa viene determinada por la posición que, en términos de precio y calidad, ocupa su producto en relación a los productos de las empresas rivales. Así, dada una distribución de los gustos de los consumidores, cada uno de ellos elegirá aquel bien para el cual se minimiza la relación precio-calidad. La función de demanda individual que se obtiene incorpora en sus argumentos, aparte del precio y calidad propios, el precio y la calidad de la empresa rival, por lo que, existe una interdependencia estratégica entre empresas en el mercado, aspecto del modelo de Ulph objeto de nuestro principal interés. Si tomamos como dadas las calidades de los bienes, la empresa deseará establecer aquel precio que maximice sus beneficios que, en un contexto de competencia de Bertrand, dependerá directamente del coste de producción. Si además suponemos, como hacen Dasgupta y Stiglitz (1980), que el coste unitario de producción de la empresa está determinado por su gasto en I+D en innovación de proceso, seremos capaces de investigar acerca de los determinantes que influyen en dicha variable.

El modelo teórico se desarrolla en el capítulo III. Partiendo de los supuestos señalados sobre el comportamiento de empresas y consumidores, introducimos la decisión de gasto en I+D de proceso por parte de la empresa con el fin de investigar la influencia de los distintos parámetros del modelo (diferenciales de calidad de la empresa analizada y la rival en relación a las empresas no innovadoras, tamaño del mercado y oportunidades tecnológicas) en el incentivo que la empresa posee para reducir su coste de producción. Nuestro principal objetivo se centra en conocer el efecto que la propia diferenciación (vertical) del producto ejerce sobre el incentivo a invertir en innovación de proceso. Es éste un aspecto que no ha sido tratado en la literatura sino de forma tangencial y, en todo caso, obviando la interrelación existente por motivos estratégicos entre calidad y coste[1].

Debido a la interdependencia estratégica entre empresas y a que, siguiendo a Ulph, se considera competencia de Bertrand en el mercado de productos (el precio del bien depende directamente tanto del coste unitario de producción como del diferencial de calidad), ha sido necesario recurrir a simulaciones numéricas para contrastar la importancia relativa de los incentivos que el análisis teórico ha detectado acerca del impacto que la diferenciación propia ejerce sobre el gasto en I+D en innovación de proceso. Las simulaciones revelan la existencia de una relación cuadrática entre dichas variables, siendo ésta la aportación más novedosa de la investigación. Así, el modelo teórico muestra cómo el incentivo que una empresa tiene para la reducción del coste de producción se incrementa con la diferenciación vertical de su producto (calidad) hasta un punto, al que hemos denominado "turning point" (punto de inflexión), más allá del cual sucede justamente lo contrario. La explicación de este hecho se debe a que, a medida que se incrementa el diferencial de calidad del bien, el efecto negativo ejercido sobre la elasticidad-precio de la demanda así como sobre los rendimientos decrecientes

[1] En términos generales, la literatura no ha tomado en consideración el efecto que la diferenciación del producto pueda tener en la innovación tecnológica. Algunos apuntes en esta materia, sobre todo respecto a la influencia que la diferenciación pueda tener en la relación concentración-gasto en I+D, los encontramos en Comanor (1967) y Shrieves (1978).

en el ingreso marginal del I+D en innovación de proceso crece en relación al efecto positivo que ejerce sobre lo que se ha denominado beneficios "ex-ante".

Otros resultados del modelo muestran como el diferencial de calidad de la empresa rival incide de forma negativa sobre el incentivo que la empresa tiene a la reducción del coste unitario de producción debido a que los beneficios "ex-ante" caen con este parámetro, contrariamente a lo que sucede con el tamaño del mercado (empuje de la demanda) mientras que las oportunidades tecnológicas tienen un efecto ambiguo. Asimismo, el efecto del diferencial de calidad propio sobre la intensidad del I+D en innovación de proceso (I+D sobre ventas) será positivo o negativo en función de si suponemos que la calidad del producto entra a formar parte de la función de costes de la empresa o no.

Como se ha indicado anteriormente, una parte importante de la literatura ha dirigido su atención a las variables "tamaño de la empresa" y "concentración del mercado" como determinantes de la actividad tecnológica de las empresas. En nuestro caso, dichos factores no se consideran de forma explícita en el modelo sino que la variable "diferenciación vertical del producto" (en relación al precio) las sustituye. Por tanto, es interesante contrastar si esta sustitución es adecuada. Si así fuera, el debate acerca de la conveniencia de una determinada estructura de mercado como impulsora de la actividad innovadora tendría mucho menor sentido, cobrando mayor importancia las características del bien en cuestión y las posibilidades que el mismo brinda a la competencia estratégica entre empresas. Desde esta perspectiva, se pretende demostrar que los determinantes de la actividad innovadora están relacionados directamente con la competencia estratégica entre empresas, lo que implica interdependencia entre innovación de producto y proceso.

El interés central de la investigación se centra, adicionalmente, en comprobar si se cumplen las predicciones del modelo teórico propuesto, esto es, nuestra intención es averiguar el grado de influencia que la diferenciación vertical de producto tiene en las ganancias de productividad de las empresas y si, llegado un punto, existe o no una relación entre ambas variables, sacrificándose mejoras en la reducción de costes a cambio de incrementos en el bienestar. En definitiva, el problema a resolver es si la obtención de una mayor diferenciación del producto es a costa o no de un menor crecimiento.

La contrastación del modelo teórico se realiza en el Capítulo IV. La fuente de datos utilizada es la "Encuesta se Estrategias Empresariales" elaborada por la Fundación Empresa Pública que recoge, para el periodo 1990-94, información acerca de un amplio abanico de variables para una muestra representativa de empresas. En la especificación del modelo empírico se ha recurrido a la realización de algunas simplificaciones para proceder a la estimación, intentando siempre el mínimo alejamiento posible de la esencia del modelo teórico. Mediante la utilización de datos de panel donde la variable dependiente es discreta (número de innovaciones de proceso) y las independientes[2] se suponen débilmente exógenas, se comprueba cómo, en todo caso, las estimaciones

[2] La diferenciación de producto se ha medido por el número de innovaciones de producto "por línea de negocio" de cada empresa, para la rivalidad se ha construido un índice que refleja la diferenciación de las empresas rivales en relación a la media del mercado, el "tirón de la demanda" se mide por la "utilización de la capacidad productiva de la empresa" mientras que el número de empleados refleja el "tamaño" de la misma. Esta última la hemos tomado como "variable control" para contrastar la validez de nuestra proposiciones.

confirman la principal proposición del modelo teórico, cual es, la existencia de una relación cuadrática entre innovación de proceso y diferenciación vertical. Por lo tanto, se identifica la existencia de un punto a partir del cual se observa una relación de sustitución entre calidad y productividad en el seno de la empresa.

En relación al resto de variables las predicciones se cumplen o no dependiendo de la muestra escogida: el conjunto de empresas o tan sólo aquellas que presentan un cierto grado de diferenciación de su producto. Más concretamente, la medida de la rivalidad tiene el impacto esperado en nuestra variable dependiente y además es significativo con el nivel de confianza habitual si consideramos toda la muestra, pero su importancia se ve relegada por el "tamaño" cuando nos centramos en la muestra restringida. La explicación que le hemos dado a este fenómeno es que la empresa tiene en cuenta el grado de rivalidad en el mercado a la hora de invertir en innovación de proceso si no dispone realmente de una "imagen de marca" de sus productos. La razón estriba en que si la empresa está escasamente diferenciada y la rivalidad es alta, en el sentido de que las empresas del entorno están diferenciadas de forma considerable, una reducción en el coste unitario de producción (y, por tanto, en el precio) tendrá previsiblemente efectos muy limitados sobre la atracción de nuevos consumidores. Debido a que la innovación es costosa, el incentivo para destinar recursos a la misma cae con el grado de diferenciación de las empresas rivales. Por otra parte, una vez se ha conseguido una cierta "imagen de marca" en el mercado el mecanismo apuntado pierde buena parte de su impacto y, por tanto, las empresas más grandes parece que disponen de ciertas ventajas para la innovación de proceso, cobrando relevancia el argumento del "reparto de coste" de Cohen y Klepper (1996a,b). Este resultado ofrece un matiz que se debe tener presente en aquellos trabajos que pretendan estudiar la relación existente entre tamaño de la empresa e innovación.

Cuando nos referimos a la intensidad en el gasto en I+D, la estimación, además de reflejar diferencias sectoriales substanciales, sugiere que la calidad del bien no entra a formar parte de manera significativa de la función de costes de la empresa lo que, a nuestro juicio, implica que las innovaciones de producto declaradas por la empresa son, en su mayor parte, incrementales. Este resultado, en todo caso, debe tomarse con cautela, dado que la muestra que se ha dispuesto para el estudio de este aspecto concreto es muy restringida.

La investigación no estaría del todo completa si no confirmáramos una de las principales premisas establecidas y que consiste en suponer que la medida que hemos tomado como reflejo de aquella actividad innovadora de la empresa encaminada hacia la reducción de su coste unitario de producción (número de innovaciones de proceso), tiene un impacto significativo en la evolución de su productividad.

Este estudio se realiza en el Capítulo V. A partir de una función de producción del tipo Cobb-Douglas ampliada con la inclusión de un factor productivo que refleja el capital tecnológico, se contrasta nuestra hipótesis estableciendo dos supuestos que no han sido normalmente tenidos en cuenta en este tipo de trabajos. Se supone, en primer lugar, que la innovación de proceso es la variable tecnológica responsable de los avances en productividad, en tanto que la innovación de producto sólo tiene la función de mejorar la calidad del bien. En segundo lugar, en vez de considerar el montante invertido por una empresa en I+D como el principal componente de su capital tecnológico o de conocimiento, suponemos que el proceso de aprendizaje es mediante la realización exitosa del proyecto y, por tanto, nos centramos en las innovaciones obtenidas. Las estimaciones llevadas a cabo reflejan que la variable tecnológica escogida tiene un efecto significativo en la evolución de la productividad de la empresa siendo este resultado robusto bajo diversas especificaciones econométricas. En todo caso, nuestra variable se comporta de mucho mejor modo que los gastos en I+D sobre ventas (intensidad en el I+D), que es la variable que la mayor parte de la literatura había escogido hasta este momento.

En resumen, hemos demostrado que el crecimiento de la productividad de una empresa viene directamente afectado por su innovación de proceso y que, al mismo tiempo, esta variable se ve influida de forma importante y en un sentido muy concreto por el grado en que su producto está verticalmente diferenciado. Esto nos ha llevado a establecer una proposición: cuando el grado de diferenciación vertical del producto de una empresa es suficientemente elevado, dicha empresa se enfrenta a una relación de sustitución entre calidad y productividad. Probablemente, esta sería una explicación adicional de la caída en la evolución de la productividad observada desde finales de la década de los setenta en las economías occidentales. En todo caso, es ésta una conclusión arriesgada.

La investigación llevada a cabo ha tenido un propósito claro: demostrar que los estudios que han intentado explicar los determinantes de la innovación y que se han centrado en la misma de forma genérica o únicamente en uno de sus dos posibles aspectos (proceso o producto) pueden adolecer de importantes deficiencias. Esto es así, debido a que han obviado la interdependencia estratégica existente en un mercado en el sentido apuntado que, en última instancia, es la responsable de los incentivos que tiene una empresa con el fin de mejorar la calidad de su producto o reducir su coste de producción.

En definitiva, el presente trabajo ha tratado de avanzar en el estudio de la innovación con la intención de contribuir en la medida de lo posible a la apertura, en este sector, de nuevos caminos, diferenciando claramente el impacto desigual que el incremento de la calidad del producto o la reducción de su coste de producción tienen sobre los beneficios empresariales, así como la interrelación existente entre ambos tipos de mejoras.