UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL AND HUMAN SCIENCES

School of Economics

# Essays on Innovation Economics

by

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**A thesis submitted for the degree of Doctor of Philosophy**

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A mis padres Stella y C. Humberto, gracias por todo su amor, apoyo, compañía y comprensión, C. A. P. B.

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ABSTRACT

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The aim of this thesis is to provide fresh evidence on three aspects of innovation economics. The first chapter makes a clear distinction between *ideas* and *knowledge* as two different inputs in the innovation process of the firm and the internal and external sources that they come from. These inputs are analysed through three different stages of the firms' innovation process: i) the decision to start a research project, ii) the likelihood of successfully completing the R&D project and iii) the eventual impacts of innovation on firms outcomes. Using a sequential logit/probit model the impact of the inputs are evaluated. The empirical results suggest that external ideas have a positive effect only in the first two stages of the innovation process. The Marketing and Sales department plays a major role on the impact stage, as an internal source of knowledge, whereas suppliers and consumers, as external sources of knowledge, significantly influence the second and last stages of the innovation process, respectively. Firms not only use external and internal sources of knowledge & ideas. Imitation is another innovation strategy used by firms. The second chapter investigates the role of imitation and innovation in the evolution of market structure. The chapter evaluates this evolution using the action-reaction process, which occurs when the laggard firm makes an innovation using the model proposed by Vickers (1986). The chapter extends Vickers' duopoly model incorporating the effect of imitation on the action-reaction process. It also extends the model for the case when N firms are competing in the market. The theoretical predictions are taken to data, which consists of U.K innovation surveys and the Annual Respondents Database. The empirical results support the theoretical predictions that imitation has a positive effect on the action-reaction process. In addition, when exploring the three different forms of measuring competition it seems that only the Boone parametric approach has a significant impact on the action-reaction process. The final chapter focuses on the pharmaceutical industry due to its high levels of innovation. The chapter investigates the post-merger effects on innovation. In particular, it analyses i) if the rate of job separation rises around the period of mergers and ii) whether there are significant changes in the productivity of both inventors that stay and those that leave the newly formed company. Using panel fixed-effects and count data models, the results suggest a negative relationship between inventors' mobility and post-merger outcomes. On average, mergers have a negative impact on the productivity of inventors in terms of the number of patents awarded and productivity. The post-merger patent performance is negatively affected by those inventors that move and stay after the merge. Also, inventors that come from the target company and stay in the newly merger company impact productivity more negatively compared to the inventors from the acquiring firm.

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# Declaration of Authorship

I, Carlos Alberto Pineda Bermúdez, declare that the thesis entitled *Essays on Innovation Economics* and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With

the exception of such quotations, this thesis is entirely my own work;

5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself (chapter 3);
7. I, Carmine Ornaghi, certify that chapter 3 of this thesis has been co-authored with the candidate: . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

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*"The only way to a position in which our science might give positive advice on a large scale to politicians and business man, leads through quantitative work. For as long as we are unable to put our arguments into figures, the voice of our science, although occasionally it may help to dispel gross errors, will never be heard by practical men. They are, by instinct, econometricians all of them, in their distrust of anything not amenable to exact proof."*

**Joseph Schumpeter (1933)-*Econometrica*.**

# 1

# Introduction

The present thesis focuses on three different aspects of innovation economics. The first chapter investigates how internal and external inputs of knowledge help firms in developing countries (i.e., the case of Colombia) for a better performance on innovation outcomes, whereas the second chapter studies how the market structure evolves when there is a sequence of innovations and the possibility of imitation among firms (i.e., the case of the U.K). Finally, the last chapter explores the pharmaceutical industry and how the innovation outcomes of the firms (i.e., patents) and inventors mobility and performance, are influenced by managers and competition authorities decisions when proposing and clearing a merge deal, respectively.

The aim of this introduction is to give the reader a general context of the three papers that are presented in this thesis and their respective position in the literature. In addition, this introduction also intends to provide a link between all the three papers in the context of innovation. As a matter of clarification, this introduction only presents a general context of the literature of each of the papers and then each paper will contain their own specific literature.

## 1.1 Innovation: Knowledge, Ideas and Spillovers

> *"Economists have, of course, always recognized the dominant role that increasingly knowledge plays in economic processes but have, for the most part, found the whole subject of knowledge too slippery to handle."* E. Penrose (1959)-The Theory of the Growth of the Firm.

Market structure and innovation has been one of the most important areas of research in the economics of innovation. Most researchers have explored this relationship through empirical work looking for which market structure is the most suitable to encourage the innovative process. However, there is a lacuna between the market structure explored in the literature and the internal organisation of the firm as environments that determine the innovation of the firms. The first paper of my research focuses on the link between these two environments and how they interact and influence each other as determinants of innovation. The analysis is based on the Colombian Manufacturing Industry as a relevant issue for the countrys economic policy, particularly on how important is the role of this industry in the innovation performance of the country. The results of this paper would be important to managers who are searching for the best strategies and ways to compete and innovate in the market. In addition, it is also important for policy makers, that need to design policies that improve the innovative process of firms in Colombia and in some other similar countries of the region.

Innovation is an extremely important concern in Colombian's economy. Nowadays, Colombia has a lag in innovation, productivity and technology, compared with other countries in the region. For instance, the total amount of money invested in Research and Development (R&D) in Colombia is about 0.2% of the GDP, which compared with countries like Argentina, Chile and Brazil, 0.5%, 0.7% and 0.8%, respectively, is low. Given this context, in the National Surveys of Innovation in Colombia, it has been diagnosed that just a small fraction of firms invest in R&D, suggesting that they are not interested in an innovation strategy, or that firms cannot develop an adequate process or product innovation given economic and business conditions (e.g degree of competition, patents system, competition strategies, administrative organization, etc.). In addition, a report from CEPAL (Economic Commission for Latin American Countries) suggests that *"small companies innovation is still marginal. Many firms see it as something external, . . . , and not as part of a strategic vision of the company"*.

Economists have been trying to understand what are the drivers of innovation, and in particular the relationship between innovation and market structure for the past seventy years at least. Unfortunately, economists have not given enough attention to this issue compared with other areas in economics, and as Stiglitz (2010) mentions in the introduction of Schumpeter's (1943) book *"Capitalism, Socialism and Democracy"* that *"the link between industrial structure and the peace of innovation-the focus of Schumpeter's concerns-is given scant attention"*(see Schumpeter (1943), p. x.).

Since Schumpeter work, many theoretical and empirical studies in the literature have been focusing on the relation between market structure and innovation. Economist have tested the Schumpetarian hypotheses that:

- Large companies are more likely to undertake an innovation process than small firms, and

- Innovative activity is highly likely to be found in concentrated industries (See Law (2002)).

On the contrary, economists have paid little attention to the internal organisation of the firm. This matter is an important matter to consider, given that firms have different notions, strategies and behaviour both internally and externally. In the introduction of the seminal work of Edit Penrose (1959), *"The theory of the growth of the firm"*, Pitelis (2009) mentions the distinction between the firm (internal) and the market (external) as *"the essential difference between economic activity inside the firm and economic activity in the 'market' is that the former is carried on within an administrative organization, while the latter is not"* (see Penrose (1959), p. xvii).

Based on this distinction between the theory of industrial organisation and the internal organisation of the firm there is a lack of studies that links these two frameworks. Teece (1996) points out this concern: *"economic research needs to pay greater attention to organizational structure, both formal and informal, and organizational research needs to understand the importance of market structure, internal structure and the business environment"* to better understand the innovation process. Moreover, Teece also mentions that *"firm organization (not just product market structure) is an important determinant of innovation, a point made by Williamson (1975) that has largely gone unheeded by industrial organization economist"*. The importance of organization as a factor of production, was already recognized several decades ago. Marshall (1890) proposed *organization* as a factor of production apart from *capital*, *labor* and *land*. The British economist dedicated an entire chapter to business management as an aspect of organization, where the *business-man qualities* (e.g., skills, employer role, etc.), the *different types of business organizations* (e.g., joint-stock companies, co-operatives societies, private firms, etc.) and the *supply price of business ability and energy*[1], were

[1] Marshall (1890) called this price *the net earnings of management*, see p. 261.

highlighted as crucial elements for the analysis of business.

Hence, the first paper explores how internal (firm organisation) and external (market structure) factors as environments of the firm, influences the determinants of innovation in the Manufacturing Industry of Colombia. The aim of the paper is to design an empirical model that links these two environments to innovation. In other words, how the external and internal factors of the firm affect or intercept each other to determine the innovation of the firm in the case of a developing country such as is the case of Colombia.

The case of Colombia is interesting for several reasons. Mentioned before, Colombia has a very low rate of R&D compared to other Latin American countries therefore, it is interesting for the case of developing countries to investigate how firms in adverse conditions can generate innovation. Investigating the Manufacturing industry is relevant for the country's economy. Colombia's Manufacturing Industry is the second largest sector in the economy after the Financial sector in the last decade, as table 1.1 shows. Also, from the historical point of view, the manufacturing industry has driven economic growth and technological change in many economies of the world. For example, Mokyr (2009) mentioned that Industrial Revolution in England was not confined to a single industry but instead it involved important industries such as steel, electricity, chemicals, mass-produced interchangeable-parts production engineering and others (see Mokyr (2009), p. 124). The majority of these industries are all classified under the manufacturing industry according to the International Industrial Classification[2].

[2] With some others like pharmaceuticals.

Table 1.1: Colombian Economy by Sectors: Average 2000-2009

| | **Average** |
|---|---|
| **Agriculture** | 9.1% |
| **Mines** | 5.3% |
| **Manufacturing** | 14.4% |
| **Electricity, Gas and Water** | 3.0% |
| **Construction** | 4.5% |
| **Retail** | 13.0% |
| **Transport** | 6.5% |
| **Financial Sector** | 17.6% |
| **Others** | 26.6% |
| **GDP** | 100% |

These reasons justify why is important to investigate innovation in this particular industry. The poor innovative performance of the manufacturing industry has been registered in all the National Innovation Surveys of Colombia. Particularly, there is a considerable proportion of firms that have not incurred on innovations projects. From 2003 to 2010, table 1.2 reports that nearly $60\%$ of the firms did not incur in innovative activities. Moreover, those firms listed as pioneers in developing new products are classified as strictly innovative firms, represent a very low proportion in the industry. These facts report the low performance that the Colombian firms have in radical or drastic innovations.

Table 1.2: Firm Types of Innovation

| | **2003-2004** | **2005-2006** | **2007-2008** | **2009-2010** |
|---|---|---|---|---|
| *Strictly* | 2.30% | 11.80% | 4.60% | 0.60% |
| *Wide* | 24.50% | 21.90% | 33.20% | 33.80% |
| *Potential* | 21.20% | 9.20% | 5.30% | 5.10% |
| *No Innovative* | 52.00% | 57.10% | 56.85% | 60.10% |
| Total Firms | 6.172 | 6.080 | 7.683 | 8.643 |

Innovations are often discovered and developed by the private sector. Typically, entrepreneurs and managers look for different internal and external sources in order to discover, develop and implement any potential idea that yields a successful innovation (i.e, product, process or organisational innovations). With respect to the external idea sources, the private sector typically looks towards those sources of existing knowledge in users, suppliers or costumers, but not very often in scientific research (see Bank (2010) p. 8). At the same time, firms need internal capabilities in order to identify, assimilate and exploit knowledge from the environment. This is commonly known in the literature as *absorptive capacity* (see Cohen and Levinthal (1989), p. 569).

Another aim of the first paper is to combine all these inputs of knowledge to investigate the innovation process of the firm. The paper distinguishes between *ideas* and *knowledge* as different inputs for innovation[3]. Ideas are spread between individuals, sometimes they are for free access, but sometimes they belong to individuals who work for a particular institution (i.e., government, firm, household, research labs, etc.). Now to make it a feasible idea, they must need to know the steps, inputs, details and tools that allow them to reach a successful outcome, or what is better called they need the appropriate *knowledge*.

Figure 1.1 represents the innovation process of the firm. It divides the innovation process in three stages. First, the decision to innovate, followed by the completion and ending with the impact of the innovation[4]. This figure depicts how these internal and external sources of ideas and knowledge are explored across the process, to understand their importance in each of the stages. Using the Innovation National Surveys of Colombia it is possible to identify separately: *ideas* and *knowledge*. In other words, the paper contributes in the discussion of tacit and no tacit knowledge. These concepts have been discussed widely in management and recently in economics. For example, scholars like

[3]A proper definition of ideas and knowledge will be given in the introduction of the paper 1.

[4]This figure was taken and modified from the one in Greenhalgh and Rogers (2010), p. 7.

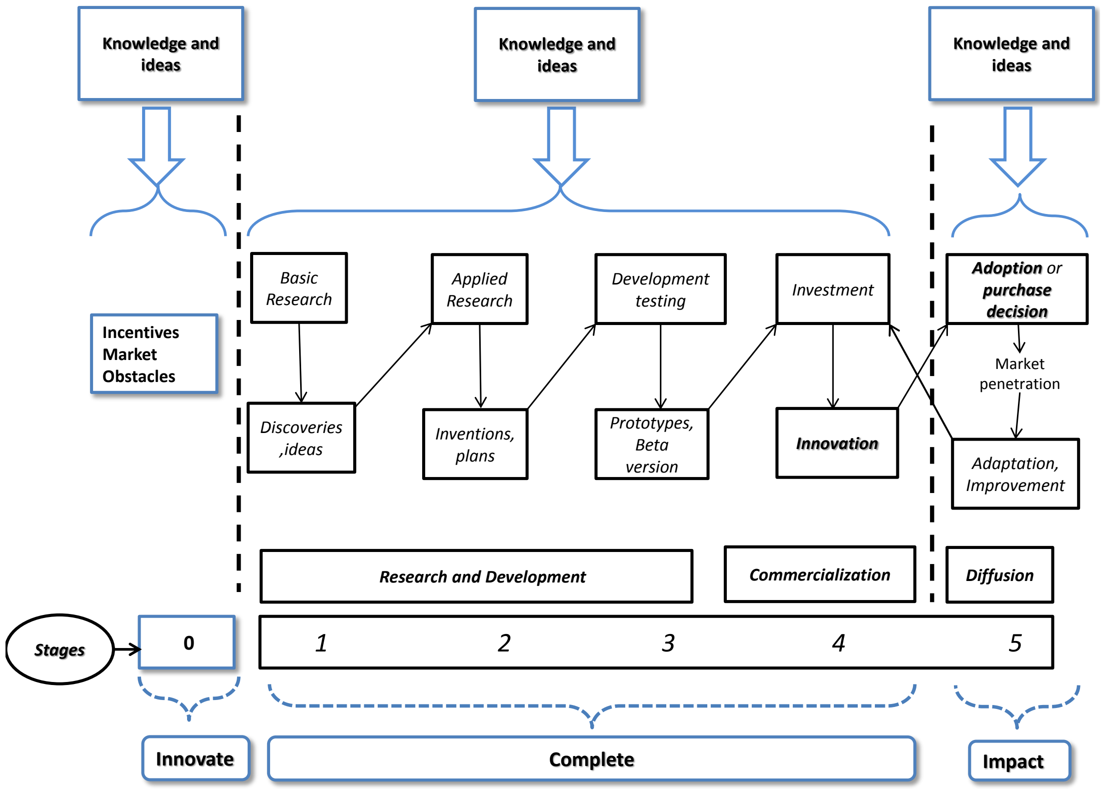



Figure 1.1: Innovation stages

Cowan et al. (2000) and Foray (2004) make an extensive discussion. The definition of Foray about codified knowledge (no tacit) is considered as some type of knowledge that is *"articulated and clarified that it can be expressed in a particular language and recorded on a particular medium. It hinges on a range of increasingly complex actions such as using a natural language to write a cooking recipe"*. In the first paper we will refer to this type of innovation input simply as *knowledge*. Regarding tacit knowledge, Cowan et al. (2000) define it as *"a knowledge that cannot be seen to be conveyed by means of codified, symbolic representations, i.e. transmitted as 'information' "*, a type of knowledge that we will simply call *ideas*. Therefore, using *ideas* and *knowledge* as two separate concepts that proxies tacit and no tacit knowledge, respectively, allows us to formulate from the empirical point of view their role in the innovation process of the firm.

To sum up, the purpose of the first paper is to investigate the importance of understanding the internal mechanism of the firm to produce innovation. In particular it focuses on how *ideas* and *knowledge* play different roles during the different stages of the innovation process of the firm (see figure 1.1). There is well established evidence in the economic and management literature that internal and external sources of *knowledge* and *ideas* are both important to foster innovation and economic growth. However, there is a lack of empirical analysis that distinguishes both, and their *internal* and *external* sources in a simultaneous analysis of the innovation outcome of the firm. This paper explores the role of ideas and knowledge sources and its relevance in three different stages of the innovation process of the firm: First, the stage where the *decision* to innovate is made; Second, the stage where the innovation is *completed* and finally, the stage where the innovation achieves certain *impact*. Using firm level data from the Innovation Survey IV of Colombian Manufacturing Industry, a sequential logit and probit models are estimated to evaluate the role of *ideas* and *knowledge* on the innovation outcome of the firm. The results suggest that the internal sources of *ideas* are crucial to increase the probability of innovation, completion and impact. The *external ideas* have a positive effect only in the first two stages of the innovation process. The *Marketing and Sales department* of the firm, plays a major role on the impact stage, as an *internal source* of *knowledge*, whereas *suppliers* and *consumers* as *external sources* of *knowledge*, are a significant and strong input in the second and last stage of the innovation process, respectively. Finally, a weak IP system on the third stage seems to have a positive impact on this part of the innovation process.

This empirical investigation helps us to understand how firms use different innovation inputs during their innovation process. There are different reasons that explain why firms are adopting innovation as the key strategy to survive and grow in a competitive market. Firms are pushed to innovate in order to maintain or increase the share in the market as well as their sales, or also to keep potential competitors out of the market creating enormous and costly barriers of entry. The competition generated in the market shapes the market structure through the different types of innovations developed by the firms. From an oligopoly structure to a monopoly framework, or a more fierce competitive market, firms are searching for different strategies to implement (i.e., product, process innovation or even imitation) in the market. Some firms become leaders in the market after large periods of investments and consecutive innovations, while some others try to catch up and overcome them. This technological competition creates and shapes the structure of the market. Under this framework, the second paper examines all these different inputs using a theoretical and empirical approach.

## 1.2 Innovation, Market Structure and Imitation

> *"In economic life competition is not a goal: it is a means of organizing economic activity to achive a goal. The economic role of competition is to discipline the various participants in economic life to provide their goods and services skilfully and cheaply"* G. Stigler (1968)-The Organization of the Industry.

Firms are constantly acquiring, learning and modifying competitors creations as one of their strategies to increase sales or reduce costs (i.e., reverse engineering); in other words, firms tend to *imitate*. Imitation has been an strategy implemented by firms in different industries such as chemical, pharmaceuticals, electronics and machinery equipments as reported in Mansfield et al. (1981). At the firm level, there are several cases of successful imitations. Examples such as Apple (Saehan Mpman vs Ipod), McDonlad's vs White Castle or Atari vs Nintendo are all business cases where imitation was taken as an invaluable strategy (see Shenkar (2010)). As innovation shapes the structure of the market as many papers on patents races and other different models have shown, imitation is another important driver in the economy that complements the evolution of the market structure.

In order to understand how innovation shapes the market structure of an industry it is possible to find in the literature a wide range of theoretical models. These models try to explain the evolution of the market structure when innovation tends to be one of the main characteristics of the industry (i.e., For instance, the Pharmaceutical Industry is characterized by high rates of patents applications.). These models can be classified in four different branches as Budd et al. (1993) proposed[5]:

[5]All this literature can be found in the paper of Budd et al. (1993). p. 563. Here I present a brief description of this structure plus some recent papers.

1. Patent Races
2. Sequence of Patent Races
3. Continuous and Stochastic rivalry
4. Learning by doing
5. Switching costs

In *patent race* models the prize (i.e., a patent) is conferred to the firm that makes the first progress in terms of technological know-how. When the prize is reached, the competition is finished. The multi-stage dimension of the game allows each firm to observe their respective position when the game starts. In these models the common result is an increasing dominance situation where the leader tends to increase the gap between its position and their followers. As opposed to patent race models, *sequences of patent race* models allow for a finite sequence of innovations. For example, the paper by Vickers (1986) proposed a duopoly model where the level of asymmetry between firms evolves over time, and the incentive to innovate depend on the past history of the game. These type of games are driven by the joint profits of the industry and their main results conclude that the action-reaction process occurs when the competition is *a là* Cournot and each innovation is not too large, whereas the increasing-dominance process occurs when the competition is Bertrand[6]. In other games, the competition is considered as continuous and not as a discrete process as the patent race models suggest, these type of models are known as *Continuous and Stochastic rivalry models*. In these type of models the laggard firm is able to reduce the gap between their position and the leaders. Within these models, Harris (1988) introduces the concept of differential games that refer to those models that try to analyse a conflict in a dynamic system where time is continuous and the strategy of the players is expressed as a function of time (dynamic planning) (see Reinganum (1981)). Examples of these types of models can be easily found in the literature. For instance, Doraszelski (2003) implements differential games when there is

[6]When the laggard firm overcomes or catch-up the leader of the industry.

accumulation of knowledge with its respective strategic implications on the patent race. The author finds that the firm that is behind in the race engages in a catch-up behavior or what is also known as action-reaction process. In general, these models find that competition tends to evolve in the direction where joint profits are higher. Finally, *learning by doing* models have been also relevant in the literature when investigating the evolution of market structure. These models explain how cost reduction is a function of output decision instead of independent expenditures like R&D. These models also include the catch-up and increasing dominance processes as the patent races models have done (see for example, Dasgupta and Stiglitz (1988)).

Another part of the literature explores the evolution of the industry. In these type of studies the evolution of the product is characterized over different phases in the market place. In an interesting paper Agarwal and Gort (1996) distinguish and depict the five stages found it by Gort and Klepper (1982) as stylized facts about the stages of development of a product in the market. The paper proposes five stages. Stage 1, refers to the situation where there are several sellers competing for consumers, followed by stage 2 where there is a high tendency of firms entry (this stage can be subdivided in an accelerating net entry of firms followed by a period of deceleration of firm entry). During stage 3, the process reaches a more stable phase, followed by stage 4, a period characterized by a negative rate of new firms entering to the market. Finally, stage 5 is the maturity phase in the market which reflects no more consistent entries. Important facts are highlighted in this study, specially during stage 2 and 4. In the former, innovations are more likely whereas in stage 4, it is found a stage of more product refinements and fixing activities. The authors also mention that during stage 4, the rise in *exit* of firms in the market can be explained by the difficulty to imitate innovations at this stage, compared to the earlier stages of rapid technological advance which lead to a higher rate of failures. This can give us an idea of how innovation and imitation, during the evolution of the market are evolving in the market. In the same line Klepper and Graddy (1990) combine some empirical facts with a theoretical model, explaining the evolution of new industries and the determinants of the market structure. Their model assume that imitation occurs after the firm has entered the market. In this model imitation is adopted immediately after entry (i.e., here there is no speed of diffusion, $\lambda$ ) and the firms are assumed to be price takers. Their results predict that the industry will be composed by those firms that reach the lowest cost after imitation plus a set of largest firms able to attain this level of cost.[7]

All these models can be considered either under the framework of patent races, or under the classification of models with entry, exit and survival of firms. However, in these papers the role of imitation has not been considered in the analysis and its effect on the market structure and the action-reaction or increasing dominance processes. Imitation has been mainly considered in models of economic growth. For instance the endogenous model proposed by Aghion et al. (2001) investigate how intense competition and imitation affect economic growth. They consider a step-by-step innovation process in which the laggard firms catch-up first with the most advanced available technology before they start searching for new advanced technologies. Their theoretical results suggest that the schumpetarian effect of more intense competition is almost compensated by the increase of incentives for firms to innovate due to the intensity of competition in the market. In addition, they suggest that with some imitation in the economy will foster the economic growth due to the fact that imitation promotes a neck-and-neck competition between firms. However, if there is too much imitation this might reduce growth, bringing the complementary roles between competition and patent policies. Some other papers have also treated imitation under the same structure that has just been mentioned

[7]There are some other models that complement this literature. For instance, on a sample of 28 U.S industries, large firms tend to do an aggressive strategy in respond to increases in each other's R&D expenditures, Meron and Caves. (1991). Khanna (1995), proposes a measure of the technological frontier of a company relative to its rivals. Those firms that are behind the technological frontier are considered in a catch-up behavior (action-reaction). In the disk drive industry, those firms that beat the industry leader seems to have greater incentive to innovate (catch-up), Lerner (1997).

(see Aghion et al. (1997)). Under this general framework of imitation, innovation and patent race models, proposing a model that incorporates imitation as another variable that explains the evolution of the market structure after an innovation has been launched is relevant and important to analyze. In some theoretical models of innovation, it is assumed that the innovation made by the innovator is immediately imitated after the innovator makes its discovery. However, it always takes some time for imitators to adopt a new innovation. For example, one of the most successful products of Apple, the well-known tablet *Ipad*, only had its first serious competitor until the end of 2012, after introducing its first Ipad model to the market on the 10th of April of 2010 (Bouldrin and Levine (2013)). This first-move advantage can consolidate the innovator's product in the market by establishing consumers preference and positioning the product in the market. Other examples are explored in the chemical, drug, electronics and machinery industries (Mansfield et al. (1981)) where the imitators appeared after few years in the market when there was an attractive generation of profits in the market. In this study, the authors found out that patents did not make the entry of firms impossible for the imitators, but they increased their entry costs. Nearly, 60% of the patented innovations were imitated within a period of four years. Afterwards, the innovators and imitators compete head-to-head in the market place influencing and determining the evolution of the market structure and the incentives to innovate for the incumbent innovator.

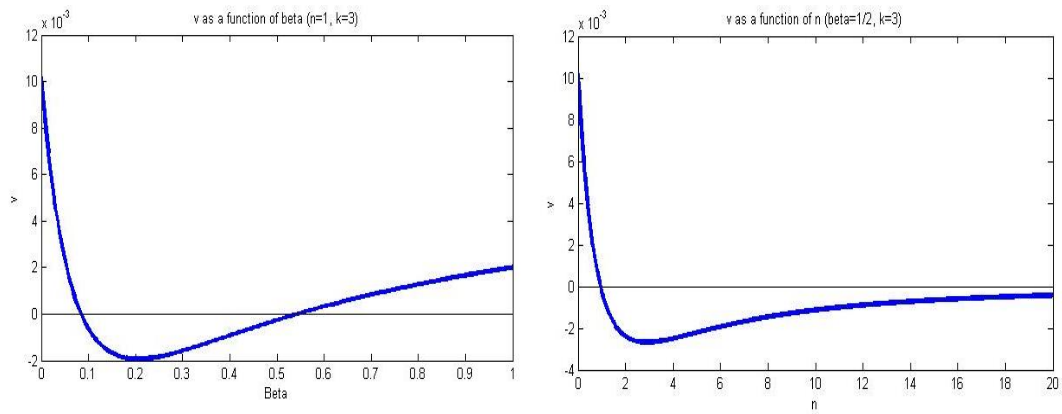
There are a few other studies that complement the literature related to imitation. Bessen and Maskin (2009) find that in an static framework patents seem to protect innovators whereas patents could hurt innovation in a dynamic setting. They also showed that imitation spurs innovation in this latter framework requiring two types on innovations called, sequential[8] and complementary[9] innovations. In addition, in this dynamic setting the innovator could be better off if there is competition that gives him incentives

[8]Sequential innovation means that each successive innovation is built on a previous innovation.
[9]Complementary innovation means that each innovator takes a different research line.

to innovate. Vives (2008) finds that competitive pressure fosters innovation depending on what measure of competition is used and what type of innovation (process or product) is taken[10]. On the contrary, in an static model, Zhou (2009) finds that competition actually dampens innovation incorporating the possibility of imitation. In this paper, the author emphasises that in a partial equilibrium model, imitation may stimulate innovation. The basic model assumes $N$ firms producing an *homogenous product* competing *a lá* Cournot. Only one firm has the ability to *innovate*, and all the other firms are identical *imitators*, where imitation is instantaneous and without any cost to acquire it. The model also assumes that marginal costs are increasing for each type of firm. In the game, the innovator chooses a level of technology represented by $k$ which is the level of innovation that is imitated by its competitors. In the second stage of the game all firms engage in Cournot competition in the product market.

[10] The drivers of process and product innovation are the market size, the degree of substitution, entry costs and technological opportunity.

Figure 1.2: Effects of Imitation and Competition on Innovation (Taken from Zhou (2009))




The model results yield that competition ($n$) dampens innovation as is shown in the second picture of figure 1.2 where it can be easily seen that as $n$ increases the effect on innovator's marginal benefit of technology never recovers to positive values[11]. On the other hand, imitation ($\beta$) spurs innovation, as is depicted in the first picture of figure 1.2. Contrary to the case of competition $n$, imitation has positive effects on the marginal benefit of the innovator's technology. With respect to the assumptions of the model, the time delay of imitation seems to be relevant in a more accurate and realistic model. The author intuits that in a dynamic framework, the marginal benefits of technology may be

[11] Own calculations to replicate the figures of Zhou (2009) using matlab.

reduced at first and then these benefits may rise over time when imitation gets strength. In a different paper Mookherjee and Ray (1991) assume that diffusion takes time[12]. The paper assumes that the innovator decision to adopt a sequence of potential innovations (process innovations), where the latest innovation adopted by the innovator, is diffused to a competitive fringe in an exogenous rate, where the competitive fridge is composed by followers who cannot innovate. Under *Bertrand* competition, the innovator optimally spaces apart the adoption dates of successive innovations[13] and under this price competition framework an increase on the rate of diffusion ($\lambda$) has ambiguous effects. For some values, $\lambda$ hastens the pace of innovation, showing that imitation stimulates it. When the authors consider *Cournot* competition they find opposite results to Bertrand. The authors finally proved that a faster diffusion of innovation increases the adoption of innovations by potential imitators. In Zhou (2009) is assumed that imitation is immediate, whereas in Mookherjee and Ray (1991) the diffusion (imitation) takes time. In this last model specification, if their diffusion were instantaneous no innovation would be adopted. Their results are based on price competition, whereas Zhou (2009) works with quantity competition.

These examples show the relevance of how innovation is being affected by imitation and competition in a static and dynamic frameworks. To explore and understand the consequences of both, innovation and imitation in a partial equilibrium framework. So, how is the market structure influenced after an innovator has launched its innovation? and How imitation plays a role in this framework? The second paper studies the role of imitation in the action-reaction process, which occurs when the laggard firm makes an innovation, using the model of Vickers (1986). Vickers' model investigates whether the current firm with low-costs is able to win the next patent race (increasing dominance

[12]Diffusion can be considered in two ways: licensing and imitation, see for example Katz and Shapiro (1987)

[13]This situation characterizes a Schumpetarian view of cycles of innovation and diffusion.

process), or whether the currently high-cost firm wins the next patent (action-reaction process). His results depend on *Bertrand* or *Cournot* competition. If there is price competition in the static sense, there is increasing dominance over time, whereas under quantity competition there is a more action-reaction process, where prices fall over time[14]. He concludes that more competition today gives less competition in the future, and vice versa. Using Vickers' framework the second paper incorporate the role of imitation in a simple Cournot duopoly model.

To summarize, this paper extends the Vickers's Cournot model concerning the evolution of market structure by incorporating the possibility of imitation. It also extends the duopoly to the case when $N$ firms are competing in the market. The theoretical predictions made by Vickers (1986) concerning the evolution of the market structure are taken to the data using an industry panel dataset built from the U.K Innovation Survey and the Annual Respondents Database. Implementing the Boone et al. (2005) parametric way of measuring competition, allow us to capture the intensity of competition in the industry and link the competition with the theoretical predictions of the action-reaction process. Using the traditional measurements of competition such as the Herfindahl-Hirschman and Lerner Indexes suggest a not significant relationship with the *action-reaction* process.

With this analysis of how firms take advantage of innovation inputs such as the ideas and the knowledge that is spread in the economic environment and how competition and imitation influences the evolution of the market structure it is also important to consider the role that competition policy has on innovation. Competition policy is an instrument that shapes and influence many high innovative industries in order to protect and incentives fair competition to benefit the consumer welfare. The importance of competition

[14] Under this competition, he explored three cases where two of them maintain the monopolist position for each firm and in the third case both firms remain active whoever wins the patent race, p.10.

policy on innovation was highlighted in a speech to the international competition policy in Oxford in 2001 by John Vickers who pointed out how crucial the role of competition policy is for the general welfare of consumers and the dynamic of innovation ( see Vickers (2001)). Particularly, Vickers highlighted that competition has two important aims. One, to promote better offers for costumers through *product market competition* and two, that the competition leads to new developments or new/better products. In the latter, Vickers (2001) refers to *competition to innovate*. Vickers refers to how important is competition to promote innovation, as follows: *"tolerating anti-competitive behavior by innovators seems likely to be anti-innovation"* situation. So is it competition policy playing its role in *"creating and maintaining conditions favourable to innovation"* (see Vickers (2001), p. 3.) in the pharmaceutical industry? The last paper, explores the post-merger effects on innovation outcomes and inventors mobility and performance in the pharmaceutical industry, to somehow explore how the decisions of competition authorities in clearing the deals between pharmaceutical companies has affected and influenced the performance of the new merged companies and inventors.

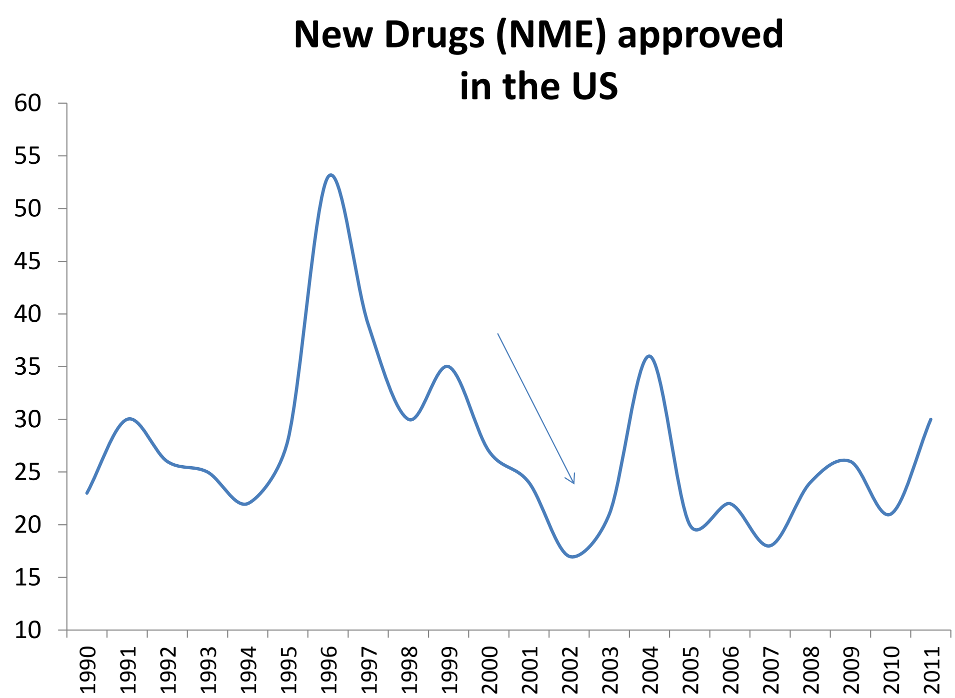
## 1.3 Innovation and Competition Policy: The case of Pharmaceutical Industry

> *"Permitting horizontal mergers between large pharmaceutical companies appears to have limited the desirable pursuit of independent parallel paths in pharmaceutical development. And it is likely contributed to the decline in the rate of pharmaceutical innovation."* W.S. Comanor and F.M Scherer Comanor and Scherer (2011)-Mergers and Innovation in the Pharmaceutical Market.

Recently the decline of innovation in the pharmaceutical industry is a matter of concern among scholars. Empirical facts show that the level of new drug approvals have declined since mid nineties in the U.S as is shown in figure 1.3. For example, this level is not the same as the one registered fifty years ago. In fact, in 2008 this level only reached 21 new drugs approved for marketing in the U.S which is below the average of the pharmaceutical industry (see Munos (2009), p. 959.) registered in the nineties were the new drugs approved reached on average 31 new drugs per year (see LaMattina (2011)).

There are some potential explanations for this decline in the industry. On the one hand, the increase in the cost of developing a new drug due to increases in clinical trial costs and more regulatory restrictions (see Pammolli and Riccaboni (2011). Furthermore, the costs for developing new drugs has increased in the last thirty years. In the early seventies, the total amount of R&D spent by the pharmaceutical industry was around \$ 5 billion dollars compared to the \$ 30 billion reported by 2002 (See Comanor (2007), p. 67.). Comanor argued that this increase in the R&D costs can be explained by the change of a more science-based mode. Counter to this another argument for this decline can be attributed to the increase concentration by recent mergers and acquisitions

Figure 1.3: Drugs Approved in the U.S




(M&A) may have affected the rate of innovation in the industry by limiting independent parallel paths[15] (Comanor and Scherer (2011), p. 34). This finding is also supported by Munos (2009) who suggests that M&A has not been an effective way to overcome the innovation deficit in the pharmaceutical industry.

The use of M&A in the pharmaceutical industry has had different purposes. These purposes can be separated into two groups. Grabowski and Kyle (2008) (GK) refer to the first group as the *adaptive or defensive motives* that include those firms that react

[15] Comanor and Scherer (2013) define parallel paths as an R&D investment strategy in different initiatives that explore a variety of technical paths (p. 107).

to any industry-wide shock. In this group we can also find those firms that face the problem of patent expiration and therefore encourage a merger. The second group also described by GK, as *proactive or offensive motives*, reflects firms that are looking to increase market share and market power by implementing a M&A. Within this group, firms might be also tempted to increase their size to reach economies of scale and scope, for example in increasing the number of therapeutic areas. Also, the technological synergies created through the acquisition of the R&D of the target company, the reduction of R&D costs and the new presence in a therapeutic category are other reasons for M&A in the pharmaceutical industry.

Above all these purposes, there are some potential effects that are caused by mergers. An important effect on the new merged firm is the effect on its innovation outcome. Some positive effects are expected after the merger and they can be explained by the technological similarities between the acquirer and the acquired firms. Another set of positive effects can be registered in different forms. Ornaghi (2009a) points out some of the positive effects as: First, the reduction of R&D costs by avoiding duplications of research projects. Second, the creation of knowledge synergies between the acquirer and the target firm and as a third explanation, the internalization of the knowledge flows of the acquired firm can stimulate the R&D of the new firm. However, the author also mentions some potential negatives effects that may affect the performance of the new firm. One effect is the potential reduction of inventors due to the adjustments on the new R&D staff of the new merged firm that can affect the general 'know-how' of the pharmaceutical company. As a second potential effect, is that there are integration problems that emerge in the new firm due to the business cultural divergences. This might help to explain the post-merger performance of the company.

Under this framework, the pharmaceutical industry has been one of the industries where mergers have been a pattern during the last three decades. The first wave is usually attributed between 1989 and 1990, followed by another period of mergers between 1994 and 1996. After this wave of mergers, the beginning of the new century registered the highest market values of deals ever recorded in the Industry. These economic facts encouraged concerns among academics. So, how mergers are affecting the performance of the industry in terms of innovation outcomes? In an article by Morgan (2001) the effects of mergers on innovation within the pharmaceutical industry can be represented in three particular merger cases. In the first merger considered in her analysis between Glaxo and Wellcome, she points out that the technological similarities between these companies was very low. In fact, as an example, she mentions the most important drug possessed by Glaxo was for atimigraine treatments and the most representative drug of Wellcome was for HIV/AIDs therapies, that reflects the low level of similarities between the companies. In this case, the clearing merger processes evaluated by the European and U.S. competition authorities focused on these two drugs particular markets. Basically, their concerns were on the potential effects of the merger in the development of atimigraine treatments. Their main concerns were related to all the competition effects. In particular, the competition *"in the R&D market would be eliminated, this might affect Glaxo's ability and incentive to unilaterally reduce output in the relevant R&D market would be enhanced and the number of R&D tracks for the non injectable drug would be likely to decrease"* (see Morgan (2001), p. 186). In the second case analysed in the article, between Upjohn and Pharmacia companies, the Federal Trade Commission in the U.S. was worried about the potential effects of reducing competition on the solid tumor treatments. This reduction of competition might affect the number of research projects in the area. Finally, the author explores the case of Ciba and Sandoz, who created the new pharmaceutical company Novartis. In this merger, similar predictions of a decline in innovation for several markets were perceived. For example, the gene therapy product market case was one of the main concerns by the competition authorities. In all these merger cases, the commissions have suggested different options to protect competition and to request to the companies involved in the merged to satisfy some conditions. For instance, in the case of Novartis, the commission requested to Novartis *"to grant gene therapy researchers non exclusive licenses at low royalties to certain essential gene therapy technologies"* (see Morgan (2001), p. 188.).

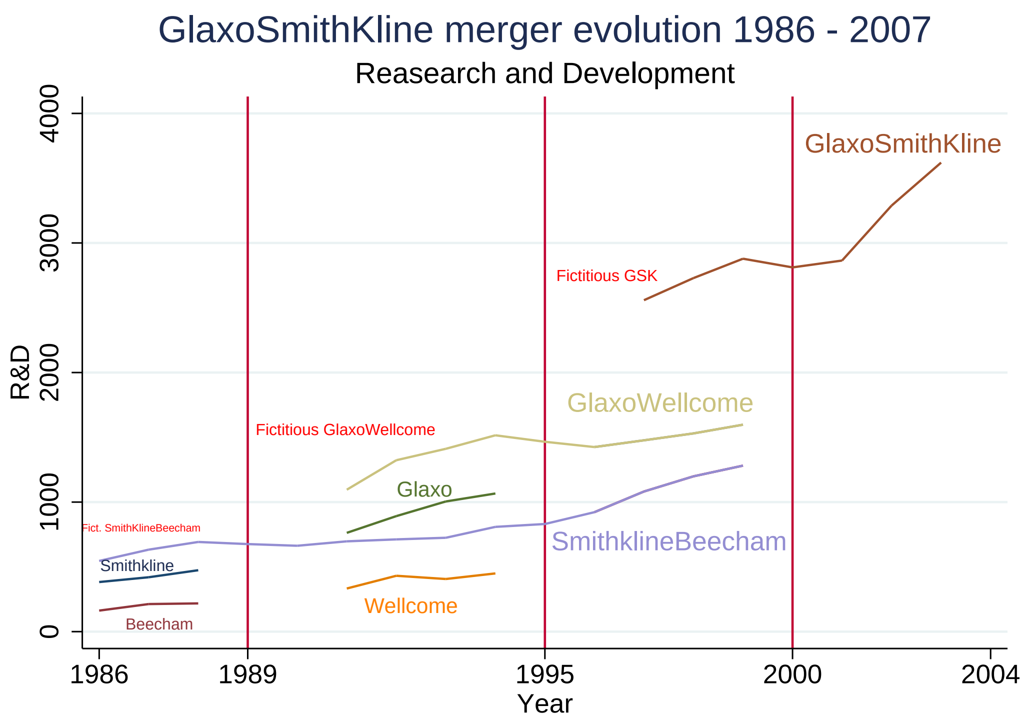
All these examples of mergers, show us how pertinent it is to investigate the post-merger effects on the industry in order to evaluate the role that competition authorities have played in shaping the post innovation outcomes of the newly merged pharmaceutical companies. This paper might also contribute to understand the decline on the innovation performance in the pharmaceutical industry that has been recorded in the last 30 years. Moreover, in the last volume of the *Handbook of Industrial Organization*, Whinston (2007) emphasizes the wide heterogeneity in merger outcomes and the lack of empirical studies that allow us to understand better the dynamic efficiencies after the merge. He highlights the importance of the topic through different papers that have investigated this effect in different industries. Particularly, studies like Ravenscraft and Scherer (1987) show the decline in post-merger profitability of acquired lines of business compared to the better position that the companies had before the merge. Some others studies have investigated labor productivity, total factor productivity in sectors such as food, banking and paper industries, but it does not report any analysis on the pharmaceutical industry.

According to Scherer (2010), the pharmaceutical industry is one of the most important laboratories to investigate innovation. It is one of the industries with the highest record of innovations, where all new discoveries of inventors tend to be patented. The the technological process in the industry is one of the longest, risky and uncertain innovation processes among industries. The industry is also under a rigorous control from regulatory authorities. In many countries these regulations are based on price controls where a price is established and paid by the national health system to the pharmaceutical producer, or as is well-known, the *reimbursement price*. Some other countries like

South Korea, Mexico, Spain and the United Kingdom regulate the profits that are made by the pharmaceutical companies. To do this, the government establishes a rate of return that takes into account the operating costs, promotion expenditures and R&D spendings (see Kyle (2007), p. 90). The high returns in the pharmaceutical industry can induce some regulation of profits. This corroborative evidence is recognised by Scherer (1993) who points out that the high profit returns of the pharmaceutical companies compared to other industries. The United Kingdom promotes a good example of profit regulation. In 2014 the profit regulation established that any company *"may be permitted to retain up to 50% additional profits before making additional payments to the government for excessive profits. In turn, no company will be permitted any price increase to address lack of profitability unless its profits have fallen 50% of allowable profit"* (see ABPI (2014), p. 8).

The pharmaceutical companies make great efforts to invest huge amounts of R&D in order to keep a high competitive innovative level in providing life-extending drugs, reducing the amount of diseases and contributing to a better consumer welfare. This desire of pharmaceutical firms to increase their number of drugs in different therapeutical areas have promoted the use of different strategies by the companies as is the case of M&As. For example, the case of mergers as was mentioned before has been a characteristic that reflects the dynamic competition of the industry in the last thirty years. Reflection on the merger waves of the pharmaceutical industry, it is important to mention some facts related to this strategic behavior. One of the challenges to investigate post-merger effects in the pharmaceutical industry is the fact of multiple mergers for some pharmaceutical companies. For example, the case of GlaxoSmithKline depicted in figure 1.4 reflects the evolution of the company and its different R&D levels of investments, and also reflects the complexity in dealing with the data and the analysis. In order, to control for the potential issue of multiple mergers, the analysis established a pre and post merger period of time between mergers of at least three years.

Figure 1.4: Multiple Mergers




This allowed us to track the potential effects of mergers and to evaluate the performance of all the different deals that have shaped the industry. Moreover, not only the effects at the firm level are important to understand, also the effects at the inventors level are crucial in terms of their mobility and the performance in patents productivity after the merge. In this way the third paper explores all the effects that mergers can cause at the inventors level in order to have a better understanding in the innovation process of the pharmaceutical industry. To sum up, this final paper/chapter is particular interested in investigating the effect of mergers on the innovation productivity of inventors of the acquiring and target companies and to what extent differences in the rate of job separations of scientists in the aftermath of a merger can explain the heterogeneity in the performance of newly formed companies. The study uses detailed data on inventors from the European Patent Office (EPO) from 1978 to 2008, and accounting data from Compustat for 1986 to 2008. The results suggest that on average, mergers have a negative impact on the productivity of the inventors from both the acquiring and target company and that they have an even more disruptive effect on the productivity of scientists who leave the company.

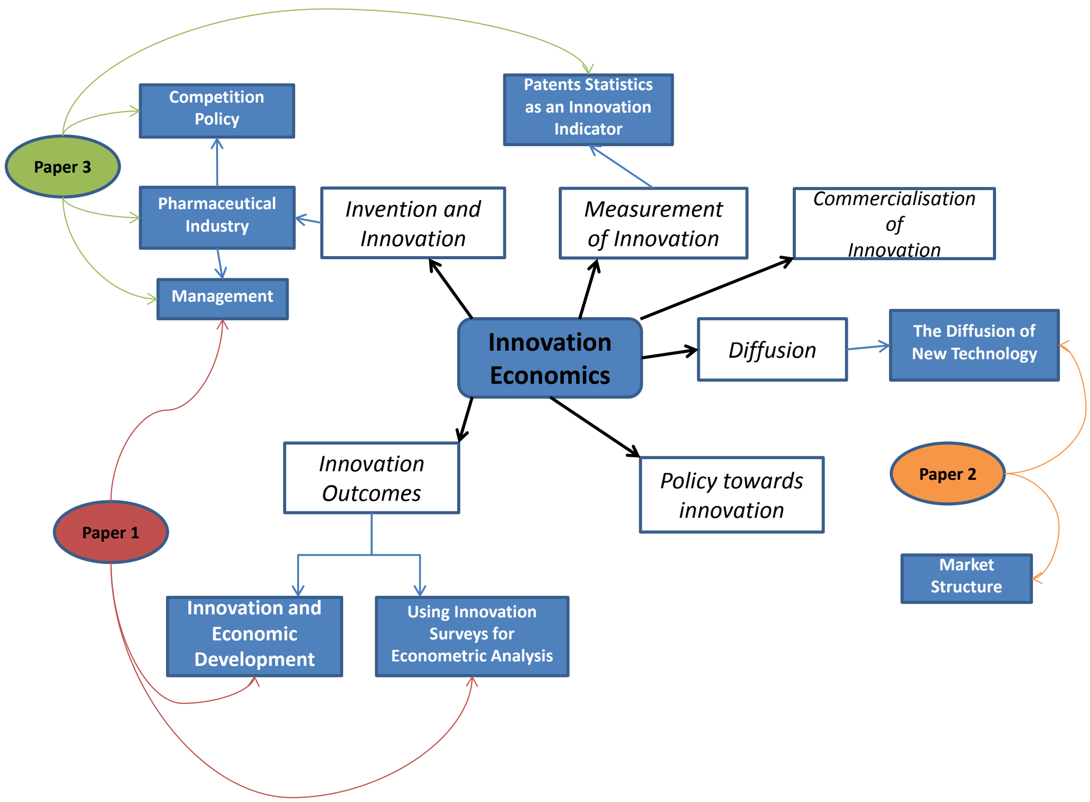
Finally, as a joint work with Carmine Ornaghi in the final chapter of this thesis, my work and contribution to the paper consists in the collection and cleaning of the data. Also, I construct the database structure of the multiple sources of data we need to analysed in this paper. I also analyses the data providing different ideas during the research. Moreover, I also write up the literature review, the description of the data, the hypothesis formulations, the empirical specifications implemented in the analyses and the results of the paper.

## 1.4 Position of this thesis in the Literature

In the introduction of the Handbook of Economics of Innovation the main topic mentioned by the editors is the dynamism of the innovative process, followed by innovation policy and another wide topic called the digital revolution which refers to innovations information and computing technology. With this general classification, the Handbook is classified by six general groups. Within these groups that are described below, figure 1.5 places these three papers on the literature according to the areas where their contribution is more adequate within innovation economics.

This figure is based on the classification proposed by the editors of the Handbook where the six different main topics are: 1) Invention and Innovation, 2) Measurement of

Figure 1.5: Position of the papers in Innovation Economics




Innovation, 3) Commercialisation of Innovation, 4) Diffusion, 5) Policy towards innovation and 6) Innovation outcomes, which are represented by the white boxes. Each of these white boxes contain different topics where the papers can be placed. The black arrows connect each of these topics with innovation economics, whereas the blue arrows connects the subtopics that each of these boxes have. The *invention and innovation* elements of this figure contains topics such as learning by doing, collective invention and inventor networks, geography of innovation, property rights and invention and pharmaceutical innovation. The *innovation of outcomes* is close to areas such as the energy, technical change in agriculture and economic development. The area of *diffusion* consists of international trade, foreign direct investment and technology spillovers and diffusion of technology topics. Finally, the last area in which the three papers can be place is the *measurement of innovation*, where topics like growth accounting, measuring the returns of R&D or patents as an innovation indicator are discussed.

According to this classification, the first paper (in red) contributes to the literature in topics related to development and the use of innovation surveys for econometric analysis. In addition, the paper is also closely linked to management sciences as the red arrows point out. This is another branch that is not considered in the handbook. The second paper, (in orange) can be placed between the diffusion of technology and the market structure literature from industrial organisation. Finally, paper three (in green) is localised on the invention and innovation branch of innovation economics. The green arrows represent all the different areas where the paper is linked with innovation economics. Two separate areas such as competition policy and management are also treated by this paper. With this classification we can observe the position and relevant area of contribution for all the papers that are presented in this thesis.

The following three sections contain and explain the main contributions for each paper followed by a general conclusion of the whole thesis. At the end of the thesis are all the appendixes for each paper and the complete list of references used in this research.

# 2

# Internal and External Sources of Knowledge & Ideas: An empirical analysis of the innovation process of the firm

## 2.1 Introduction

The aim of this paper is to produce fresh evidence on the impact of knowledge and ideas on three different stages of firms' innovation process: i) the decision to start a research project, ii) the likelihood of successfully completing the R&D project and iii) the eventual impact of innovation on firms outcomes.

There are several studies in macroeconomics that have shown the importance of innovation in economic growth (see for example Romer (1990) and Grossman and Helpman

(1991)). Similarly there is overwhelming evidence in the IO and management literature that innovation is fundamental for firm survival and success (see for example, Kim (1997)). Nevertheless, only 30% of firms in the U.S manufacturing industry were innovative between 2008 and 2010[1]. Among the group of firms that decide to innovate, several companies do not complete the innovation process. For example, Cozijnsen et al. (2000) indicate that around 20-30% of innovation projects ended in failure in the U.S. in 1996 and more than 39% of innovation projects failed completely or partially from a sample of Dutch firms. Asplund and Sandin (1999) emphasizing that if a new entrant fails with its new product it faces a low probability of surviving, showing how important it is that an innovation project fulfills the expected outcome. Finally, examples of innovations that did not produce an economic impact in terms of expanding market size, improving the quality of the product or reducing the production costs, are easily found in management literature (See Palmberg (2006)).

Several authors have discussed the importance of distinguishing knowledge & ideas as two different inputs of innovation. Romer (1998) emphasises the misleading approach to equate *ideas* with *knowledge* and to treat them as private goods, given that an idea can be used by many people at the same time, but knowledge can not. An idea can be considered as a private good when it is owned and embodied by an individual who will only share it if there is, for example, an economic incentive (or if he is working on an specific R&D project). Romer concludes that an idea is neither a public good nor a private good nor a mixture of both[2].

[1]White House Report, 2014, *Making in America: U.S Manufacturing Entrepreneurship and Innovation*, The Executive Office of the President.

[2]For example, in the Pharmaceutical Industry an investigation by Gambardella and reported in Comanor (2007), p.57, mentions the importance of biological discoveries in the industry might be a public good, but *"although a public good, science is not a free good. Internal scientific capabilities are critical for taking advantage of the public good"*. This is a good example of how a public good is not a free good.

Cowan et al. (2000) refer to codified knowledge as knowledge that is *"recorded in some codebook...as a storage depository, as a reference point and possibly as an authority"*. This knowledge can be interpreted by people who are able to read the code. For example, within the internal structure of the firm, staff with university degrees related to marketing and statistics are more likely to be able to interpret all the information and codes related to the marketing area of the business. That is the knowledge that is embodied in the members of this particular department/area of the firm and that is related to the specific functions of that area of the company. On the contrary, Cowan et al. also define tacit knowledge as *"a component of human knowledge...distinct from the knowledge explicit in conscious cognitive process"* or *"a knowledge that cannot be seen to be conveyed by means of codified, symbolic representations, i.e. transmitted as 'information' "* (see p. 212.). Hereafter, I will refer to explicit or codified knowledge simply as *knowledge* while I will use as *ideas* to refer to tacit knowledge.

Baldwin and Hanel (2003) (p.75) in a study of Canadian manufacturing firms, make a clear distinction between ideas and knowledge. In particular, they consider the case of reverse engineering as a way to absorb ideas that spills out from other firms. Firms can also establish joint projects with other companies which involve a direct exchange of knowledge. In other words, a firm can form links to access knowledge directly from its competitors, suppliers and consumers along with a method for implementing the knowledge, whereas the example of reverse engineering only provides the innovative idea without considering technical issues of implementation and the effort required of the firm to implement that idea.

Similarly, Foray (2004) (p. 5) states that codified knowledge is *"articulated and clarified that it can be expressed in a particular language and recorded on a particular medium. It hinges on a range of increasingly complex actions such as using a natural language to write a cooking recipe, applying industrial design techniques to* *draft a scale drawing of a piece of machinery..., and so on"*. Greenhalgh and Rogers (2010) have defined *knowledge*, as the pool of scientific evidence and human expertise useful for production and innovation. Moreover, when this knowledge is stored in individuals it can be interpreted as human capital (see Greenhalgh and Rogers (2010) p. 6).[3]

To complement this distinction between knowledge and ideas, Leiponen (2005) (p. 306) notes that "*having an innovative idea is only one part of the successful development of a new product or process. To develop the idea into a well-functioning technology that can be profitably manufactured and marketed the firm needs technical, marketing, and integrative competencies*". So, the distinction between *ideas*, as a fundamental part of the innovative process, and *knowledge* that is required to develop that innovative idea is crucial for better understanding the innovation process of the firm. As ideas and knowledge are both relevant to the process, and as they both have an impact in developing economies, it seems reasonable to analyse them simultaneously in a framework that evaluates their impact on the innovation process.

This paper *contributes* to the literature above by studying the role of external and internal sources of knowledge and ideas in three different stages of the innovation process: 1) why a firm *decides* to innovate, 2) what determine the successful completion of the R&D project and 3) what factors affect the impact of innovation on the firms performance (e.g. costs and revenues). To the best of my knowledge no other paper has used such a rich empirical specification to understand the role of these inputs in the innovation process of the firm.

The empirical analysis is based on data for Colombian manufacturing firms in the period 2007-2008. Firms that decide to innovate are around 43%. From those firms

[3]For instance, human capital is measured in Heger (2004) as the ratio $humancapital = \frac{skills}{allemployees}$.

that decide and complete their innovation, nearly 25% did not achieve the innovation proposed, which represent a significant proportion of the manufacturing industry of Colombia (see table 2.1). Based on this fact, a simple question emerges: What determinants explain the choice of the firm between innovating or not? (*the innovation* stage) and How does this choice changes across the different stages of the innovation process? (*the completion* and *impact* stages). To answer these questions the empirical model will include the innovation inputs discussed previously, ideas and knowledge, along with other variables that are generally considered in the innovation literature, such as the size of the firm, market concentration or competitive pressure/degree of monopoly power. With this framework, this paper also brings together economic and management factors within the same analytical specification.

Table 2.1: % Firms that achieved the impact expected 2007-2008.

| | **Success** | **Failure** |
|---|---|---|
| *Innovative Firms %* | 75.19% | 24.81% |
| Total Firms | 2494 | 823 |

To estimate the multi-stage framework, we will use a sequential logit and probit models approach that offers a good *methodology* for treating this approach[4]. From the innovation point of view, authors such as Du et al. (2007) and Monjon and Waelbroeck (2003a,b) have developed an empirical approach using the sequential nature of the questions asked in innovation surveys, that explains the probability that a firm decides to innovate[5]. Du et al. (2007), use a sequential model that captures the sequentiality of

[4]There are several applications of different areas in economics. For example, the article of Kahn and Morimune (1979) uses a sequential logit model to explain the number of spells that a worker had in 1966, to investigate the effects of Trade Unions have on employment stability. Another application is the article by Hu et al. (2001) that estimates a multistage logit model to show how the structure of the disability determination process of the Social Security Administration in the U.S behaved from 1989 to 1993.

[5]This means that, in order to proceed in the questionnaire to the innovation sections of the survey, the firm has to answer affirmatively to whether or not it innovates, before describing the determinants that influence the innovation process, and so on.

innovation surveys in a panel of Irish manufacturing firms. The authors use a sequential probit model, where in the first stage the firm decides to innovate, and in the second, the firm decides the type of innovation to implement (i.e. product, process or both). This model is tested against a one-stage multinomial model and the authors find that the sequential model outperforms the multinomial approach. Monjon and Waelbroeck (2003a,b) define a model where firm choose between whether to innovate in *process* innovation or not, and a separate sequential model where the first estimate is the probability that the firm innovates in *product*, followed by a choice whether the innovation is incremental or radical. In a similar way Veugelers and Cassiman (1999), use a sequential logit model where the first step explains the determinants of the firm to innovate, followed by the decision on to make, to buy it or use both types as possible strategies in developing new technologies.

The results of this paper have some interesting implications in terms of policy making and management recommendations. Evaluating and identifying the degree of importance of internal and external sources of *knowledge* and *ideas*, and discovering at which stages these sources are most relevant during the innovation process would uncover how important cooperation is for innovative firms (see d'Aspremont and Jacquemin (1988) and Machinea et al. (2008), p. 125). For example, if universities or competitors are significant sources of knowledge and ideas for innovation during the first stage, when the firm decides to innovate, that could suggest that these economic agents should have a high level of interaction with the firm that proposes innovative projects to some potential innovative firms. Therefore, the links between sources of innovation and firms could be strengthened in order to increase the probability that a firm undertakes an innovation project. The results of this paper suggest that the marketing ideas seems to have a strong significant effect compared to the codified knowledge of the marketing department during the last stage of the innovation process. In addition, the ideas coming from the managers of the firm are crucial during the whole innovation process, with a strong and significant effect along all the development of the R&D project.

The remainder of the paper is organized as follows. Section 2, formulates the hypothesis and section 3, describes the data while section 4 explains the sequential logit and probit models used in the analysis. Section 5, shows the main empirical results and section 6 concludes.

## 2.2 Knowledge and Ideas in the Innovation Process

Fagerberg et al. (2010) extensively analyse the importance of innovation in developing countries by focusing on topics related to national capabilities, international sources and firm-level aspects of innovation[6]. The authors review several firm-level studies that explore the determinants of innovation. They conclude that firms with well-developed technological capabilities are more likely to innovate. These capabilities can be divided into two sources depending on where they stem from: internal and external sources where ideas and knowledge come from[7].

Several authors have distinguished between internal and external sources of knowledge and ideas. Leiponen (2005)) argues that the interaction between the internal and external sources of knowledge of the firm is one of the pillars for successful innova-

[6]While most of the available studies in innovation have focused on developed economies, innovation is becoming an increasingly important area in developing economies. For example, the World Bank published a guide called *Innovation Policy: A guide for Developing Countries* (See Bank (2010)) which shows the relevance of the topic. Crespi and Zuniga (2012) also found for a set of Latin American countries, that those firms that invest in knowledge are more able to develop technological advances, and those that complete their innovation have greater labor productivity, where the analysis follows the methodology of Crépon et al. (1998) applied to six Latin American countries, Argentina, Chile, Colombia, Costa Rica, Panamá and Uruguay. Reports on Latin America like Machinea et al. (2008) also highlight how innovation is now a key consideration in government policy.

[7]These capabilities refer to internal R&D, design, engineering, quality standards, adoption of ICT, marketing, management, and skills. See Fagerberg et al. (2010), p. 851-856.

tion. Svetina and Prodan (2008) find that the effects of the interaction of these two sources during the innovative process could have different implications for firms of different sizes. They mention that in large firms, knowledge and information are transferred mainly by the interaction of the different internal departments (R&D, marketing, production departments, etc.) whereas in small and medium sized firms, knowledge transfer are mainly from outside. Ideas also play a mayor role within the innovation process. For example, in management the importance of internal and external ideas is embodied in a recent paradigm called open innovation *"that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology."* (see Chesbrough et al. (2008), p.1). Leiponen and Helfat (2010) confirm how important are the different sources of knowledge and how by accessing to a great number of them the firm increases the probability of gaining knowledge that will lead to innovation.

Finally, there are some references that highlight the importance of some specific departments, as sources of knowledge & ideas, during the innovation process of the firm. In particular, Albach (1993) (p. 198) stays that the most important partners for the R&D department for the success of the innovation are the production and the sales departments. In addition, Odagiri and Goto (1993) highlights the importance between the production and R&D departments on innovation in the case of the Japanese firms. For example, a close communication between the production and R&D departments is crucial for developing a new process or product given that the staff of the production department tend to participate since the early stages of the innovation process until the final development of the innovation (see Odagiri and Goto (1993), p. 108).

Therefore, in the first stage when the firm decides whether to innovate or not is influenced by different sources of knowledge & ideas. During this stage a set of inputs can influence the decision of the firm to undertake an innovative project. The among literature suggest to formulate the following hypothesis for the first stage:

- **H1-1:** Internal and external sources of ideas increase the probability of starting an innovation as a source of new innovative ideas.
- **H1-2:** The *Production* and *R&D* knowledge have a strong effect when the firm starts an innovation project given their role in the capacities and abilities to undertake and develop successfully the project.

During the second stage of the innovation process of the firm there are several sources of knowledge & ideas that are more relevant than others. Malerba (1992) identified that firms' learning is linked to different sources of knowledge that may be internal or external to the firm. As internal sources he highlights the activities carried out in the production, R&D and marketing departments among others where internal knowledge can be generated and located. For external sources, Malerba suggests the set of firms within the same industry, suppliers, or advances in science and technology perceived by the firm among others (see Malerba (1992), p. 847). However, these studies do not specify in detail the internal sources of knowledge. In fact, several studies view a firm's internal knowledge as a general measure of its skills, training or in-house R&D (see Caloghirou et al. (2004), Du et al. (2007), Svetina and Prodan (2008), Vega-Jurado et al. (2009)), but do not identify where this knowledge is generated within the firm (i.e. which departments).

To complete an innovation, suppliers seems to have an important role with the innovative firm. In von Hippel (1988) the relationship between suppliers and the R&D project is important during the innovation process given that this relationship supplies *"components or materials required in the innovation's manufacture of use"* (p. 36), in other words suppliers have an crucial role when the innovation is being manufactured or completed. Other studies have found as an important source of knowledge for innovation within the supply chain. For example, Tether (2002) mentions that suppliers in the automobile and electronics industries in Japan were very important in the innovation process of the firms and also that they complement all the R&D efforts (p. 951-52). In another study for the Spanish manufacturing firms, Marchi (2012) highlights how suppliers are also important to develop a new product or process. However, among this empirical literature there is not a clear distinction about where is located the importance of suppliers in the innovation process, apart from von Hippel (1988) that makes a clear theoretical distinction. Finally, the manufacturing/production department also plays a crucial role during the completion of the innovation. For instance, Sundbo (1997) mentions that the implementation of the innovation takes place in the production department as a commercial product or as an organisational change (p. 444).

Hence, we can summarize in the second stage, the innovation inputs of knowledge and ideas are transformed into tangible outcomes[8]. Particularly important in this stage is the role that some specific sources of *knowledge* and *ideas*. Hence, there are two important hypotheses:

- **H2-1:** The *knowledge* proceeding from the *suppliers* is positively associated with the probability of completing the innovation because they contribute into the production process of the R&D project.
- **H2-2:** *Production* knowledge is positively correlated when the firm completes its innovation project.

Finally, the last stage of the innovation process is related to the impact that the innovation has for the firm as a part of the innovation process. Several articles suggest the importance of some innovation inputs for the successful of the innovation. Leiponen and Helfat (2010) finds out that a broader horizon of different sources of knowledge are

[8]For example, when the firm obtains a *process* or *product* innovation.

associated with successful innovations. In another paper, Leiponen and Helfat (2011) finds the importance of multilocation of the R&D activity and its significant positive correlation with different external sources of knowledge. She mentions that firms with different sources of knowledge can access more information (i.e., universities, research institutions, customers, competitors, and suppliers.) that improve the likelihood of innovation success. However, these studies are not clear enough to determine what is the role of these inputs during the last stage of the innovation process. However, there are some theoretical studies that suggest that the impact of innovation is strongly linked with the marketing and clients sources of knowledge. For example, Teece (1986) highlights the importance of complementary assets in the innovation process. In particular, Teece mentions the relevant role of marketing for the successful commercialization of an innovation as a fundamental asset. Moreover, Baldwin and Hanel (2003) explain how innovators need to have marking capabilities to penetrate new markets that are essential to the innovation process. In addition, clients or consumers are also a key element during the last stage of the innovation process given all the feedback they can provide to improve the innovation that allows firms to expand the market share or improve the quality of the products (see for example, Jeppesen and Molin (2003)). Clients provide an important source of knowledge that allow firms to learn and improve their innovation projects.

The impact or successful of the innovation can be expressed in terms of improvements in quality, cost reductions or to expand or maintain the market share of the firm. However these studies do not specifically stays which are the more significant and relevant sources of knowledge for a successful innovation outcome during the last stage of the innovation process. Hence, we can formulate the following hypothesis that contains the most relevant innovation inputs used during the last stage of the innovation process:

- **H3-1:** The *marketing department* and the *clients* of the firm increase the probability that the expected impact is achieved after the innovation is completed.

Based on the previous arguments we investigate how these inputs are influencing the innovation process of the firm and the way we measure them in the following sections.

## 2.3 Data and Variables

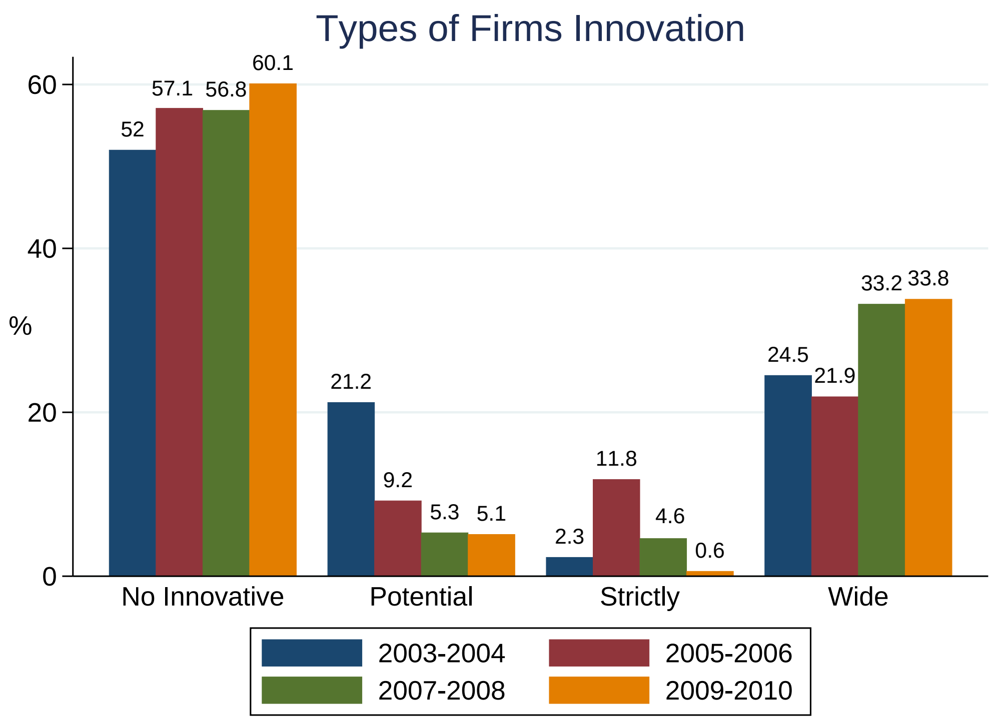
The data used in this paper are retrieved from *Encuesta de Desarrollo e Innovación Tecnológica, 2007-2008* from the National Statistics Department of Colombia (*DANE*). The analysis covers the period 2007-2008 with firms from the Colombian Manufacturing Industry directory. Previous years could not be merged given that the previous surveys could not be merged because many of the questions were not the same and were changed over time in order to produce a more stable and standard questionnaire. One advantage of using this survey is that it excludes those firms that changed their line of business, stopped operating, changed location code or that did not respond the survey. At the beginning there were 8654 firms, but after the cleaning process 7683 firms were left.

### 2.3.1 Innovation, Completion and Impact

This subsection defines our dependent variables used during the three different stages of the innovation process of the firm. The definition of innovation adopted in this paper follows a broader perspective, where the term itself is not just about technological innovations such as new processes or products, it also includes non-technical innovations such as innovation in logistics, distribution and marketing, a definition that fits better in developing countries (See Fagerberg et al. (2010), p. 835)[9]. The Oslo manual (OECD, 2005, p. 46) defines an innovation as "*the implementation of a new or signif-*

[9] Holmstrom and Tirole (1989) also emphasize the relevance of non-technical innovations, *"In tandem with technological innovations, innovations in firm organization (as well as other institutions) have enhanced welfare greatly"*, p. 63.

Figure 2.1: Innovative firms classification




*icantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations".* This definition agrees with the one expressed by Schumpeter in his 1934 book and also with the approach that Fagerberg et al. (2010) highlight for developing economies[10].

With this definition of innovation, the first dependent variable of the first stage of the innovation process of the firm is defined by a binary outcome variable as:

[10]This innovation definition is widely used in some applications for developing countries in several chapters of Szirmai et al. (2011).

$$y_1 = \begin{cases} 1, & \text{If the firm decides to innovate} \\ 0, & \text{otherwise} \end{cases} \tag{2.3.1}$$

where the subscript $1$ represents, *stage 1* of the innovation process. To define the dependent binary outcome variable in the *stage 2* of completion of the innovation we use the information related to the different categories of the innovative firms. Figure 2.1 shows the classification of the firms in four different innovative categories from 2003 to 2010. In the first category, the *non-innovative* firms represented nearly $60\%$ of the firms in the manufacturing industry. Those firms listed as pioneers are ones that developed new or improved products to sell them in foreign markets, or developed a new process are defined under the category of *strictly innovative* firms, a low proportion fell into this classification[11]. In the last two innovation surveys nearly $33.5\%$ of the firms in the industry are considered *widely innovative* firms defined as those firms that have innovated in at least one of the following forms: new or improved goods, processes, organisational techniques or marketing strategies. Finally, the category, *potentially innovative* firms are defined as those firms that have not finished or abandoned an innovation project, which represented on average $10.2\%$ of the firms in the industry. These firms are considered as firms that abandon the R&D project. Therefore, the completion stage, or *stage 2*, is defined by firms under the strictly and widely categories, whereas those firms that have not completed the R&D project are under the potentially category. A formal way the completion stage is defined as:

$$y_2 = \begin{cases} 1, & \text{If the firm completes the innovation (Strictly or Widely)} \\ 0, & \text{otherwise}(Potentially) \end{cases} \tag{2.3.2}$$

[11]The low proportion of the strictly innovative firms shows the low performance of Colombian firms in what might be considered radical or drastic innovation.

expression 2.3.2 represents those firms that have already decided to start an R&D project and have completed the innovation. Finally, the innovation survey asks to those firms that innovate to indicate the degree of importance of the impact of the innovation. The importance is measured in three different levels, high, medium or no effect. If the firm answers yes to the high or medium levels, it is considered as a firm that makes an impact from its R&D project. The impact is measured as improvements in quality, production cost reductions or maintain/expand the market share of the firm. Hence, *stage 3* is composed by firms that decided and completed their innovation and identifies those firms that reach an impact from the innovation made it by the firm. The binary outcome variable of the last stage is defined as:

$$y_3 = \begin{cases} 1, & \text{If the innovation has an impact} \\ 0, & \text{otherwise} \end{cases} \tag{2.3.3}$$

If any of these impact outcomes are reached in *stage 3*, the innovation of the firm is considered to has an impact otherwise the outcome of the innovation is not gained.

### 2.3.2 Sources of Knowledge

This subsection focuses on the main sources of *knowledge* and *ideas* both internal and external of the firms used during the three different stages of the innovation process of the firm and that represent our core set of covarieties.

#### External

Following previous studies (i.e., Malerba (1992) and others), this paper measures external sources of knowledge as looking at co-operation with three different external sources: research institutions (i.e., universities), suppliers and clients. We use a set of dummies taking value 1 if a firm reports a co-operation to any of the external sources of knowledge mentioned, otherwise it takes a value of 0. Through co-operation the channels of knowledge flows between the firm and the external sources are established in a formal way. Co-operation transfers no tacit and specific knowledge to firms from external sources of knowledge (Caloghirou et al. (2004), p. 32). It is also sometimes a way to share costs and uncertainty between the different sources implemented by the firm (Vega-Jurado et al. (2009)).

Table 2.2: Percentage of firms with links to external sources of knowledge by firm size and source

| | | *Small* | *Medium* | *Large* |
|---|---|---|---|---|
| **Universities** | → | 2.45% | 7.67% | 17.70% |
| **Suppliers** | → | 7.22% | 17.05% | 30.73% |
| **Other Firms** | → | 3.16% | 8.86% | 20.99% |
| **Clients** | → | 6.13% | 13.18% | 22.91% |

Table 2.2 reveals a general pattern of how Colombian firms have more knowledge-sharing external links with their suppliers and clients across all sizes, compared to connections with universities and other firms as external sources of knowledge. However, table 2.2 illustrates that *large* firms are more capable of setting up more links with these external sources compared to the *small* firms[12].

### Internal

Related literature traditionally considers in-house R&D, training and skills as important sources of *internal* knowledge[13]. In the empirical specification it is important to

[12]The size of the firm is defined by the total number of employees. Small firms refers to a workforce no more than 50 employees, whereas a medium size has between 51 and 200 employees. Large firms have more than 201 employees.

[13]This is close to the well-known concept proposed by Cohen and Levinthal (1989) of absorptive capacity defined as the firm's ability to identify, assimilate, and exploit knowledge from the external environment.

identify knowledge located in each area of the firm so that the contribution of where each department of the firm contributes to the innovation process can be assessed. Internal sources of knowledge is measured as the ratio between the number of workers with undergraduate or postgraduate degrees and the total workforce of the firm for three different departments: production (*Production Knowledge*), marketing and sales (*Marketing Knowledge*) and R&D (*R&D Knowledge*). The variable is measured following the approximation in Heger (2004). For example, for the case of the R&D department, its knowledge is represented as:

$$R\&D\_Knowledge = \frac{\sum_{i=1}^{N^{R\&D}} N_i^{R\&D}}{N_i^{tot}} \tag{2.3.4}$$

where $N_i^{R\&D}$ is the number of employees with a university degree (undergraduate or postgraduate) in the R&D Department of firm $i$ and $N_i^{tot}$ is the size of the workforce of the firm. A brief glance at the data shows that the knowledge of the firms is most concentrated in the production department, followed by the marketing and sales, and a low proportion in the R&D department which mainly belongs to a small fraction of large firms (see table 2.6). The knowledge of the production and marketing departments is measured as expression 2.3.4.

### 2.3.3 Sources of Ideas

#### External

The firm also perceives ideas generated outside. Within the main external sources of ideas we use *suppliers*, *clients*, *internet*, *intellectual property* information systems, *consultants*, *books* and *catalogues*. To measure the *external* ideas of the firm, we define a dummy variable that takes value of 1, if the firm uses at least one of the sources

Table 2.3: Internal and External Sources of Ideas by firm size

| | **External** | **Ideas** | |
|---|---|---|---|
| | **No Use** | **Use** | |
| ***Small*** | 75.23% | 24.77% | ***100%*** |
| ***Medium*** | 53.86% | 46.14% | ***100%*** |
| ***Large*** | 40.33% | 59.67% | ***100%*** |
| | **Internal** | **Ideas** | |
| | **No use** | **Use** | |
| ***Small*** | 69.00% | 31.00% | ***100%*** |
| ***Medium*** | 43.18% | 56.82% | ***100%*** |
| ***Large*** | 27.16% | 72.84% | ***100%*** |

mentioned before which implies that the firm is regressing to the external economic and institutional environment in order to acquirer innovative ideas, otherwise it takes a value of 0. Table 2.3 shows that *Large* firms tend to use external sources less (59.67%) than internal sources, whereas for *small* firms the difference is smaller, from 31% to 24.77%.

### Internal

A set of potential *ideas* can be generated by the firm in order to start a new innovation process that provides the firm with the ability to complete the innovation and also achieve the expected impact. According to the survey, it is possible to identify an important number of internal sources of ideas located in the internal organization of the firm in areas such as the Managers & Directors, Production, Marketing & Sales, and the R&D departments'. Basically, a firm is asked if any of the previous internal sources is used as the origin of ideas to innovate. A firm is measured as having internal ideas if it uses at least one of the previous internal sources mentioned before as a dummy variable that takes value of 1, otherwise it takes a value of 0 if the firm has not obtained the idea from these sources.

The most frequent *internal sources* of innovative ideas for those firms that decide to innovate are *Managers* and *Directors* (33% of the firms), followed by the *Production Department* (30.35%) and *Marketing and Sales* Department (25.54%). The *R&D Department* only registered 13.26%, which is similar to the findings of Baldwin and Hanel (2003). Such firms are considered to rely on internal sources to generate ideas. By firm size, 72.84% of *large* firms used internal sources to generate innovative ideas, a fact that could be reflect the internal strength that large firms posses. This figure contrasts the 31% of small firms that utilised these sources as an engine for innovative ideas as table 2.3 shows.

Table 2.4: Innovation by size

| | ***Not innovative*** | ***Innovative*** | **Total** |
|---|---|---|---|
| ***Small*** | 72% | 28% | **100%** |
| ***Medium*** | 47% | 53% | **100%** |
| ***Large*** | 29% | 71% | **100%** |

### 2.3.4 Size, Market Structure, Barriers and Technological Opportunity

Finally, the other set of explanatory variables that are used in the model are the most commonly known determinants of innovation from the Schumpetarian tradition as Cohen and Levin (1989) and Acs and Audretsch (1987) point out. Considering the main variables, Schumpeter argues that large companies are more likely to undertake an innovation project than small firms. By size, only 28% of small firms were involved in innovative activities, whereas 71% of the large firms innovated in the period 2007-2008 supporting the Schumpetarian argument that large firms have greater capacities to start innovation projects[14](see table 2.4). The *size* of the firm as an explanatory variable is measured as the number of employees in the firm and it is expected to have a positive effect on the probability of innovating. In addition, a square of the size variable is included to check for non-linearity.

Another important determinant of the innovative activity mentioned by Schumpeter is the market structure or the degree of competition/concentration, where it is argued that innovative activity is more likely to be found in concentrated industries. In this sense, the Schumpetarian hypothesis of imperfect competition and its effects on innovation are also controlled for the model. Given the availability of certain economic variables in the survey like turnover, a good approximation of concentration is given in Geroski (1990), where a way to proxy the degree of monopoly power is using the relative number of small firms. However, in this paper, concentration is measured as the sum of all the total workforce of large firms, $N_l$ divided by the total workforce in the industry, $N_I$. This can be seen in the following expression:

$$Concentration = \frac{\sum_{l=1}^{L} N_l}{N_I} \tag{2.3.5}$$

In order to control for technological opportunity in manufacturing industries we follow Scherer (1965) who proposes to classify industries according to the technological field. It is easier or less costly for a firm to innovate according to the industry this firm is classify (see Cohen and Levin (1989)). The OECD global technological intensity classification of manufacturing industries in Hatzichronoglou (1997) classifies industries according to their technological level. This variable is measured according to Hatzichronoglou who distinguishes between four categories: high, medium-high,

[14]Nevertheless, there is another view that small firms can be more innovative as they face lower levels of bureaucracy than can slow down innovation projects. See for example the article in *The Economist*, Big and Clever: Why large firms are often more inventive than small ones published 17th of December, 2011.

medium-low and low technological industries. Using the industrial classification (SIC) it is possible to classify a firm under any of the four categories mentioned. To proxy the technological opportunity concept, we construct four dummy variables with value of 1 if the firm is classified under any of the four categories mentioned before. Implementing this classification allows the Colombia Manufacturing Industry to be ordered by the level of innovation and also to proxy the technological opportunity of the industries. As a result, the *Chemical* industry was the most active industry for innovation, classified under the high technological category, where 49.4% of chemical firms were actively involved in innovation activities (see table 2.5). Using this classification allows the technological opportunities that a firm faces to be identified according to its industrial classification (SIC).

Table 2.5: Innovation by Industry

| **Industry** | **No innovation** | **Innovation** | **Technological Level** |
|---|---|---|---|
| *Chemical Manufacturing* | 50.6% | 49.4% | High |
| *Cardboard and Paper Manufacturing* | 55.9% | 44.1% | Low |
| *Electronic and Machinery Manufacturing* | 56.0% | 44.0% | Medium-High |
| *Food and Beverages Products* | 58.4% | 41.6% | Low |
| *Rubber and Plastic Products* | 58.6% | 41.4% | Medium-Low |
| *Medical and Optical Products* | 59.4% | 40.6% | High |
| *Equipment and Machinery Manufacturing* | 61.3% | 38.7% | Medium-High |

Within this categorisation the next most innovative industry (i.e. high-technological) was the *Medical and Optical Products* industry followed by the medium technological *Electronic and Machinery* industry. However, it is possible to notice that there is significant activity by low technological firms in the *Cardboard and Paper*, *Food and Beverages* and *Rubber and Plastic Products* industries. It is not surprising that Colombia is more focused on innovations related to these types of industries, leaving aside drastic innovations that are more common in High-technological industries[15]. This clas-

[15]This is due to the fact that Colombia is a developing economy, so it is more specialised in lower value

sification of industries shows the relevance of considering the concept of innovation in a broader perspective for developing countries. Using a broader concept of innovation as Fagerberg et al. (2010) and von Tunzelmann (2004), who argue that the efforts that industries make to innovate in a technical and not-technical perspective need to be considered given their significant role for the economy as is the Colombian manufacturing industry case.

Finally, we also control for some firm restrictions or barriers to innovate such as the the lack of co-operation with other firms, the lack of a strong Intellectual Property (IP) system and how easy is to imitate the innovation made by the company by its competitors. These variables are a set of dummies that takes value 1 if the firm perceives any of these restrictions otherwise it takes a value of 0. Summary statistics of all the variables described in this section and used in the empirical model are presented in table 2.6. A full description of all the variables used in the empirical analysis is presented in the appendix of chapter one.

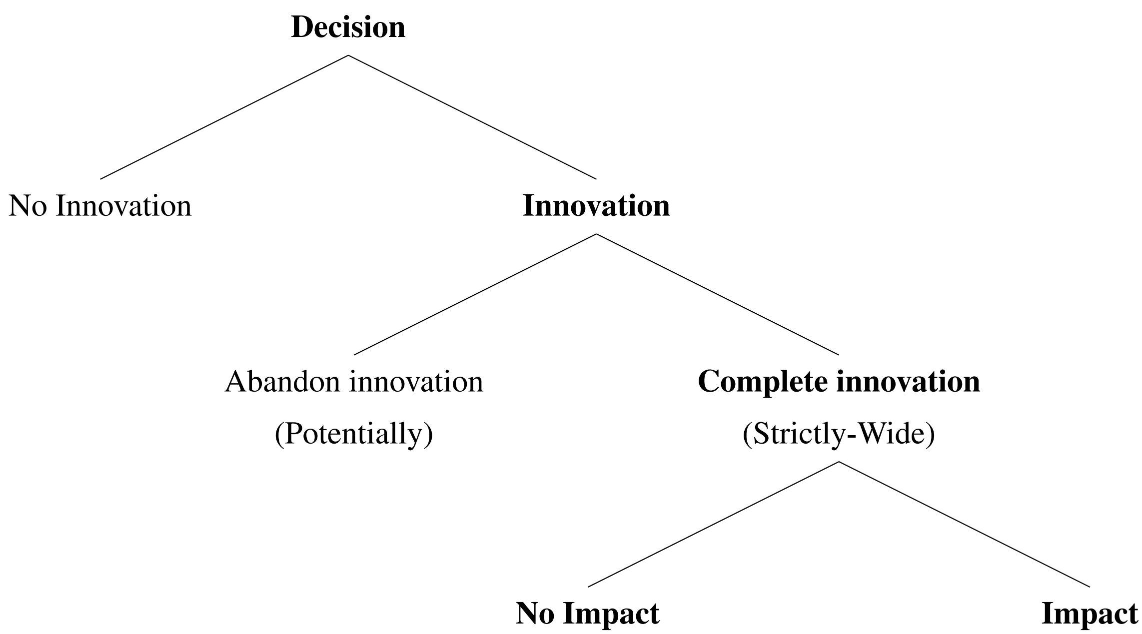
industries.

Table 2.6: Descriptive statistics

| Variable | Mean | Std. Dev. | Min. | Max. | N |
|---|---|---|---|---|---|
| ***Stages*** | | | | | |
| Innovation Decision | 0.431 | 0.495 | 0 | 1 | 7.674 |
| Complete | 0.876 | 0.329 | 0 | 1 | 3.311 |
| Impact | 0.858 | 0.349 | 0 | 1 | 2.902 |
| ***External Knowledge*** | | | | | |
| Research Institutions. | 0.051 | 0.219 | 0 | 1 | 7.674 |
| Clients | 0.093 | 0.291 | 0 | 1 | 7.674 |
| Suppliers | 0.117 | 0.321 | 0 | 1 | 7.674 |
| ***Internal Knowledge*** | | | | | |
| Training | 0.07 | 0.255 | 0 | 1 | 7.674 |
| Production Knowledge | 0.864 | 0.149 | 0 | 1 | 7.674 |
| Marketing Knowledge | 0.02 | 0.056 | 0 | 0.839 | 7.674 |
| R&D Knowledge | 0.003 | 0.016 | 0 | 0.4 | 7.674 |
| ***External and Internal Ideas*** | | | | | |
| External | 0.329 | 0.47 | 0 | 1 | 7.674 |
| Internal | 0.408 | 0.492 | 0 | 1 | 7.674 |
| ***Firm Restrictions*** | | | | | |
| Lack Co-operation | 0.398 | 0.49 | 0 | 1 | 7.674 |
| Easy imitation | 0.438 | 0.496 | 0 | 1 | 7.674 |
| Lack IP System | 0.35 | 0.477 | 0 | 1 | 7.674 |
| Size | 88.372 | 226.842 | 1 | 4660 | 7.674 |
| Concentration | 0.579 | 0.116 | 0.272 | 0.950 | 7.674 |

## 2.4 Hypothesis and Empirical Specifications

In this section I describe the empirical framework used to investigate the effects of internal and external sources of *ideas* and *knowledge* on the three stages of the innovative process involves. These stages are depicted in the following tree:




Tree 1: Innovation stages

It is possible to express the probabilities of all the outcomes for each of the previous stages by following Maddala (1983) and Amemiya (1985)[16]. Formally, the empirical model and its sequentiality is expressed in the following way:

The empirical framework can be estimated using a sequential logit/probit. A sequential logit/probit is defined as a separate logistic/probabilistic regression (see Buis

[16]There is also a complete survey of qualitative response models in Amemiya (1981) where sequential models are discussed.

(2011)) for each *step* or *decision* on the sub-sample that is 'at risk' of making that decision[17]. Based on this definition, those firms that decide to innovate will follow different steps in order to successfully complete the innovation process.

In the *first stage*, when the firm decides to innovate, the probability is determined by the discrete choice between choosing to start some kind of innovation or none at all. This probability is represented as:

*Innovative stage*

$$Prob_1[y_1 = 1|\mathbf{X}_1] = F(\alpha^{'}\mathbf{X}_1) \tag{2.4.1}$$

$$Prob_1[y_1 = 0|\mathbf{X}_1] = (1 - F(\alpha^{'}\mathbf{X_1})) \tag{2.4.2}$$

For the *second stage*, when the firm can complete its innovation the probabilities of finishing or abandoning the innovation are:

*Complete stage*

$$Prob_2[y_2 = 1|\mathbf{X}_2, y_1 = 1] = F(\alpha^{'}\mathbf{X}_1)F(\beta^{'}\mathbf{X}_2) \tag{2.4.3}$$

$$Prob_2[y_2 = 0|\mathbf{X}_2, y_1 = 1] = F(\alpha^{'}\mathbf{X}_1)(1 - F(\beta^{'}\mathbf{X}_2)) \tag{2.4.4}$$

Finally, in the *third stage*, the probability that the innovation has the impact expected is given by:

*Impact stage*

$$Prob_3[y_3 = 1|\mathbf{X}_3, y_1 = 1, y_2 = 1] = F(\alpha^{'}\mathbf{X}_1)F(\beta^{'}\mathbf{X}_2)F(\gamma^{'}\mathbf{X}_3) \tag{2.4.5}$$

$$Prob_3[y_3 = 0|\mathbf{X}_3, y_1 = 1, y_2 = 1] = F(\alpha^{'}\mathbf{X}_1)F(\beta^{'}\mathbf{X}_2)(1 - F(\gamma^{'}\mathbf{X}_3)) \tag{2.4.6}$$

[17] The sequential logit model is considered as a special case of the nested model by Ophem and Schram (1997). In addition, Nagakura and Kobayashi (2009) made an empirical test between a sequential and a nested logit model where the sequential logit model is a limiting case of the nested logit model.

Where $y_1, y_2$ and $y_3$ denote the three different probabilities that are estimated in each stage. A set of explanatory variables, $\mathbf{X}_1$, $\mathbf{X}_2$ and $\mathbf{X}_3$, are used in each stage as described in section 2 (see table 2.6). The vector of parameters to be estimated are represented by $\alpha$, $\beta$ and $\gamma$. Assuming a logistic cumulative distribution function for $F(\cdot)$, in the first stage the probability that the firm decides to innovate is given by:

$$Prob_1[y_1 = 1|\mathbf{X}_1] = \frac{e^{\alpha^{'}\mathbf{X}_1}}{1 + e^{\alpha^{'}\mathbf{X}_1}}$$

The second stage the probability that a firm completes the innovation is determined by:

$$Prob_2[y_2 = 1|\mathbf{X}_2, y_1 = 1] = \frac{e^{\alpha^{'}\mathbf{X}_1}}{1 + e^{\alpha^{'}\mathbf{X}_1}}\frac{e^{\beta^{'}\mathbf{X}_2}}{1 + e^{\beta^{'}\mathbf{X}_2}}$$

The model is estimated by maximum likelihood. In the first stage the log-likelihood function is:

$$LnL = \sum_{i=1}\{y_{1i}lnF(\alpha^{'}\mathbf{X}_1) + (1 - y_{1i})ln(1 - F(\alpha^{'}\mathbf{X}_1))\}$$

It is assumed that the probabilities $y_1, y_2$ and $y_3$ are conceptually distinct and statistically independent from each other as is pointed out by Maddala (1983) and Liao (1994). An important advantage of sequential models is that the selection process is explicitly taken into account given the structure of the innovation survey. This selection process is represented by the sequentiality of the three different stages proposed in the model[18]. In order to check for robustness, and to extend to another econometric specification the paper implements a sequential probit model that has also been used in other empirical exercises such as Monjon and Waelbroeck (2003b). The decision in the first stage of the

[18]This sequential feature of the model allows estimation biases to be avoided as is pointed out in Monjon and Waelbroeck (2003b)(p. 99).

model is represented by using the following conditional probability:

$$Prob_1[y_1 = 1|\mathbf{X}_1] = \int_{-\infty}^{\mathbf{X}_1'\alpha} \phi(w)dw = \Phi(\mathbf{X}_1'\alpha) \tag{2.4.7}$$

Where $\Phi$ is the standard normal distribution and $\phi(w) = \left(\frac{1}{\sqrt{2\pi}}\right)e^{\frac{-w^2}{2}}$ represents the standard normal density distribution. $\mathbf{X}_1$, $\mathbf{X}_2$ and $\mathbf{X}_3$ are the sets of covariates that are used in each of the three stages to evaluate the innovation process of the firm. The coefficients are estimated using the maximum likelihood method and the logit model presented above.

## 2.5 Empirical Results

Table 2.7 summarises the main statistical and empirical characteristics of all the stages estimated in the sequential logit and probit models.[19] The model correctly predicts a high proportion of outcomes, with a weak signal of multicollinearity given by the low number of iterations that each stage has to take to converge and estimate the probabilities. In general, the $\chi_2(df)$ is statistically significant for all three stages. For the sake of clarity, the impact of ideas and knowledge are presented separately but they have been estimated jointly as explained before. Appendix of chapter 1, reports a list of tests which assess specification error, the goodness of fit, multicollinearity and outliers, which were carried out for the analysis of the sequential logit model.

[19]To make comparable the coefficients between the logit and probit models, it can be used the rule of thumb described in Wooldridge (2001) by dividing the logit estimates by 4 and the probit estimates by 2.5. See p. 469.

Table 2.7: General Diagnostic of the sequential logit and probit estimations

| Sequential Logit | **Pseudo-R2** | **Log-likelihood value** | **Correctly predicted** | **Iterations** | $\chi^2(df)$ | **Obs.** |
|---|---|---|---|---|---|---|
| **Stage 1** | 0.4525 | -2872.5007 | 86.43% | 5 | 2758.96(19)*** | 7674 |
| **Stage 2** | 0.2375 | -943.94088 | 88.61% | 5 | 517.88(19)*** | 3311 |
| **Stage 3** | 0.0620 | -1112.0867 | 85.80% | 4 | 134.81(19)*** | 2902 |
| Sequential Probit | | | | | | |
| **Stage 1** | 0.4527 | -2871.3611 | 86.43% | 5 | 3377.61(19)*** | 7674 |
| **Stage 2** | 0.2369 | -944.71045 | 88.46% | 5 | 539.31(19)*** | 3311 |
| **Stage 3** | 0.0624 | -1111.5982 | 85.80% | 4 | 141.09(19)*** | 2902 |

### 2.5.1 Ideas and Knowledge

#### Ideas

According to the results in table 2.8, external and internal sources of ideas are considered by the firm to be sources of generating innovative ideas, confirming hypothesis **H1-1**. Based on the results, in the second stage, the relevance of internal and external ideas is their persistent, strong and significant effect. Those firms that keep their innovative ideas until the second stage are more likely to complete their innovation. Along the same lines, only internal sources are still significant and considered in the *impact* stage by the firm. In the last stage, the effect of external ideas is vanished in the sense of achieving the impact expected in improvements of the quality of the product, or cost reductions in the production process or increases in the market share of the firm. Based on the results in table 2.8, the firm tends to rely on *internal* sources of *ideas* in order to raise its probability of *impact*. The effect of ideas on the third stage could be explained by the limited capabilities that these types of firms have when they operate in a developing country, such as Colombia, in order to achieve the desired impact. This could be a signal of how important the concept proposed by Cohen and Levinthal (1989) of *absorptive capacity* is. This is, having a weak capacity to absorb and process ideas from external sources that can affect the probability of successfully completing an innovation project, given the extra costs that these firms would have to incur in order to develop the external innovative idea. Hence, the internal ideas seems to be more reliable in the last stage of the firm process, generating a significant impact on the innovation process.

Table 2.8: Sequential Logit and Probit Estimations

| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***Sources of Ideas*** | | | | | | | |
| External | 2.061*** | 0.920*** | 0.366 | | 1.225*** | 0.569*** | 0.196 |
| | (0.17) | (0.26) | (0.36) | | (0.10) | (0.15) | (0.20) |
| Internal | 3.413*** | 2.807*** | 0.375** | | 2.017*** | 1.555*** | 0.212** |
| | (0.11) | (0.21) | (0.17) | | (0.06) | (0.10) | (0.10) |
| Interaction | -2.233*** | -1.191*** | -0.061 | | -1.312*** | -0.696*** | -0.018 |
| | (0.20) | (0.34) | (0.38) | | (0.12) | (0.18) | (0.21) |
| ***Firms*** | 7674 | 3311 | 2902 | | 7674 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors listed beneath coefficients.

The importance of ideas in the innovation process of the firm can also be supported from a management point of view. Utterback (1971) argues that the firm incurs in three stages to achieve the technological innovation proposed. The stages proposed by Utterback (1971) are: the idea's generation (i.e. deciding to innovate), solution (i.e. completing the innovation) and the implementation stages (i.e. achieving an impact with the innovation). Therefore, the idea generation stage will improve the capacities of the firm. Along these lines, we can say that the sources of ideas play a crucial role during the three different stages analysed in the model[20].

[20]Under Utterback (1971) definition of innovation. In this paper this definition is also extended to new marketing methods or new organisational methods.

An interesting result relies on the interaction between the sources of internal and external ideas. According to the results, the interaction between the two sources has a significant, stable and negative impact on two of the three stages of the innovation process for the logit and probit models. In particular, it affects the probability that the firm decides to innovate and complete the innovation. The interesting part of this result lies in the fact that the firm lacks the capabilities necessary for implementing the ideas that come from outside the boundaries firm and the internal sources of ideas that the firm generates in-house. Again, this could also be explained by the lack of a strong absorptive capacity that would provide the firm with the necessary skills for utilising internally and externally generated ideas.

### Knowledge

It is important to remember that the results are jointly estimated as was mentioned in the introduction of this section. The results in table 2.9 show the main sources of external and internal *knowledge* of the firm. Under the three-stages framework established it is possible to identify the stage where each particular source plays its most significant role in the innovation process. These results confirm some of the hypotheses explored in section 3. Regarding internal sources of knowledge, it seems more likely that firms in the Colombian manufacturing industry utilise all the knowledge embodied in the R&D department when deciding whether or not to innovate (**H1-2**). Surprisingly, the production knowledge does not play a significant role in the first stage. This might suggest that firms are relaying more on this knowledge during the completion stage. These results answers which specific type of knowledge is implemented by the firm in the first stage therefore hypothesis **H1-2** is rejected. Interestingly, other departments, such as marketing, are not expected to play a role during the first stage as their main effect is expected to be on the last stage where the firm seeks for the impact of the innovation. In the second stage, when the firms may complete the innovation the significance of these internal sources of knowledge fades as is reported in the second column of table 2.9. The results suggest instead that firms require strong *training* processes in order to complete their innovation projects. Surprisingly, internal knowledge accumulated in the departments of the firms does not play a significant role in the second stage in the logit specification. However, under the probit results the knowledge embodied in the production department has a weak significant effect. Therefore, hypothesis **H2-2** is rejected because the results are not robust under the different empirical specifications.

Table 2.9: Sequential Logit and Probit Estimations (continuation)

| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***External Knowledge*** | | | | | | | |
| Research Inst. | 0.164 | -0.494* | 0.067 | | 0.08 | -0.213* | 0.045 |
| | (0.23) | (0.26) | (0.24) | | (0.12) | (0.13) | (0.12) |
| Clients | 0.486*** | 0.145 | 0.782*** | | 0.258*** | 0.083 | 0.389*** |
| | (0.17) | (0.24) | (0.21) | | (0.09) | -0.11 | (0.1) |
| Suppliers | 0.658*** | 0.370* | 0.147 | | 0.345*** | 0.166* | 0.069 |
| | (0.15) | (0.21) | (0.16) | | (0.08) | (0.1) | (0.08) |
| ***Internal Knowledge*** | | | | | | | |
| Training | 2.025*** | 0.822*** | 0.157 | | 1.085*** | 0.366*** | 0.084 |
| | (0.23) | (0.28) | (0.18) | | (0.12) | (0.13) | (0.09) |
| Marketing Knowledge | 0.62 | 1.481 | 3.750*** | | 0.366 | 1.075 | 2.001*** |
| | (0.79) | (1.61) | (1.45) | | (0.42) | (0.85) | (0.76) |
| Production Knowledge | -0.06 | 0.786 | 0.022 | | -0.033 | 0.540* | -0.011 |
| | (0.28) | (0.59) | (0.53) | | (0.15) | (0.31) | (0.29) |
| R&D Knowledge | 6.078** | 7.076 | 4.28 | | 3.472** | 3.343 | 1.914 |
| | (2.45) | (6.37) | (4.22) | | (1.43) | (2.72) | (2.08) |
| ***Firms*** | 7674 | 3311 | 2902 | | 7674 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.
Robust Standard Errors listed beneath coefficients.

An interesting result in the last stage of table 2.9 using either the probit or logit estimates confirms what Teece (1986) called the complementary capabilities or assets that the firm must possess to successfully commercialise its innovation. Teece (1986) mentions services such as competitive manufacturing, after-sales care and marketing as the most relevant to the last stage of the model. The probability of a successful impact during the innovation process of the firm increases by around 0.4 with a 1% increase in the marketing knowledge of the firm when considering the marginal effects either with logit or probit specifications. This result provides empirical support to the hypothesis suggested by Teece (1986) related to the marketing capacities. In bet it confirms empirically that using the *knowledge* in the *Marketing and Sales department* increases the likelihood that the firm successfully achieves the expected impact of its innovation project, confirming hypothesis **H3-1**.

Many studies have mentioned the power that external sources of knowledge have over the innovation of the firm. In the model it is possible to consider the external sources of knowledge as channels that transmit knowledge to the firm. The model identifies exactly where each of these sources has a relevant effect on the innovation process. Considering the external sources of knowledge, the results confirm that there is a high probability that the firm decides to innovate if a co-operation channel exists between *clients* and *suppliers* that provides knowledge to the firm. So, during the completion stage the firm tends to use the knowledge provided by *suppliers* which allows to confirm hypothesis **H2-1**. The positive effect of such external knowledge on the completion of the innovation can be explained by its influence on the innovation process of the firm, which is based on the *experience* that suppliers can provided to the innovative firm, as is argued by Monjon and Waelbroeck (2003b). Nevertheless, an interesting result emerges from the knowledge provided by research institutions such as universities and research centers. This flow of knowledge affects the probability of completing the innovation. The implication is that the internal capabilities of the firm are not used to assimilate the technical knowledge provided by universities or other research institutions. This might be due to a lack of abilities to process external knowledge that affects the probability of completing the innovation.

For those firms that complete their innovation, the last stage of the analysis concerns the impact of the innovation. During the last stage, the *consumers* or *clients* knowledge is the only external source of knowledge that has a positive and significant effect, its effect is stronger than during the first stage. The probability of a successful impact increases by around 0.07, measured by marginal effects, either with the probit or logit specifications for those firms that acquire knowledge through their clients. This might be explained by the invaluable nature of the information supplied by the *consumers* into the process through suggestions that improve the innovation outcomes. Therefore, a strong process of collaboration with consumers could provide opportunities to the firm in discovering, developing and improving the innovation to increase the probability that the innovation project achieves the impact expected by the company. This result is in line with the theoretical predictions suggested by von Hippel (1988), confirming hypothesis **H3-1**.

### 2.5.2 Firm Characteristics and Restrictions

Finally, in this subsection we control for some additional restriction variables for the firm such as the role of the Intellectual Property (IP) system, lack of co-operation from other firms and how easy a firm can imitate an innovation. We also present other hypotheses to explored. Table 2.10 shows the control variables related to *firm characteristics*. The size of the firm has a positive and significant effect on the innovation decision. However, this positive effect across these two stages decreases as is commonly found in the literature.

Table 2.10: Sequential Logit and Probit Estimations (continuation)

| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***Firm Characteristics*** | | | | | | | |
| Size | 0.002*** | 0.001 | 0.00 | | 0.001*** | 0.00 | 0.00 |
| | (0.00) | (0.00) | (0.00) | | (0.00) | (0.00) | (0.00) |
| $Size^2$ | -0.000*** | 0.00 | 0.00 | | -0.000*** | 0.00 | 0.00 |
| | (0.00) | (0.00) | (0.00) | | (0.00) | (0.00) | (0.00) |
| ***Firm Restrictions*** | | | | | | | |
| Lack Co-operation | -0.043 | 0.006 | 0.049 | | -0.02 | -0.01 | 0.028 |
| | (0.10) | (0.15) | (0.14) | | (0.06) | (0.08) | (0.07) |
| Easy imitation | 0.478*** | 0.209 | 0.280** | | 0.264*** | 0.098 | 0.155** |
| | (0.11) | (0.16) | (0.14) | | (0.06) | (0.08) | (0.07) |
| Lack IP System | -0.176 | -0.127 | 0.501*** | | -0.099* | -0.058 | 0.271*** |
| | (0.11) | (0.16) | (0.16) | | (0.06) | (0.09) | (0.08) |
| ***Industry Characteristics*** | | | | | | | |
| Concentration | 0.658** | 0.023 | 0.345 | | 0.357** | 0.005 | 0.233 |
| | (0.3) | (0.58) | (0.52) | | (0.17) | (0.31) | (0.28) |
| Medium low Tech | 0.169* | -0.165 | 0.252* | | 0.094** | -0.095 | 0.149* |
| | (0.09) | (0.16) | (0.15) | | (0.05) | (0.09) | (0.08) |
| Medium High Tech | 0.02 | -0.121 | 0.156 | | 0.013 | -0.078 | 0.081 |
| | (0.12) | (0.21) | (0.19) | | (0.06) | (0.11) | (0.1) |
| Hight Tech | 0.089 | -0.288 | -0.103 | | 0.047 | -0.137 | -0.048 |
| | (0.13) | (0.2) | (0.2) | | (0.07) | (0.11) | (0.11) |
| constant | -2.630*** | -0.678 | 0.424 | | -1.520*** | -0.439 | 0.295 |
| | (0.32) | (0.68) | (0.59) | | (0.17) | (0.36) | (0.33) |
| ***Firms*** | 7674 | 3311 | 2902 | | 7674 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.
Standard errors listed beneath coefficients.

In the third stage the size of the firm is no longer relevant. *Firm restrictions* are also another set of characteristics considered in the analysis. Within this restriction, the lack of co-operation between firms apparently does not play an important role in the innovation decision of the Colombian manufacturing firms over the period considered. Nonetheless, the model captures the negative effect expected during this stage. On the one hand, there are two important variables that are statistically significant, such as the ease of imitation by other firms which has a positive effect on the firms decision to innovate. This result might explain the incentive that the firm has when it perceives that its innovation is being imitated and adopted by another company, to innovate further. In a theoretical model Zhou (2009) sets up a static model for homogenous products finding that imitation spurs innovation. This is a prediction that supports, from the theoretical point of view, the positive effect that imitation has during the first stage of the innovation process.

On the other hand, the fact that there is a lack of a strong IP system in the first stage seems to have a negative impact on the probability that a firm gets involved in an innovation project. In the *impact* stage it seems that a weak IP system has a positive effect on the probability of producing an *impact*. This result from the third stage could be explained in two ways. First, it could be explained by the high costs that the firm has to incur in order to innovate. For example, in Colombia the application cost of a patent is around US$290, compared to countries such as Argentina and Brazil where the cost are US$95 and US$100, respectively. Also, to maintain the patent the firm has to incur additional costs. These facts can disincentivise the firm from acquiring an IP right, an issue that can be more pronounced when the firm faces financial problems. So, having a weak IP system generates a positive effect on the impact stage given that it is more likely that after achieving an impact it is easier to promote the product quickly in the market (i.e. product innovation), avoiding all the transaction costs, or the firm may prefer to keep secret any process that reduces production costs (i.e. process innovation). Second, not having a negative effect on the perception of a weak IP system it can be explained by those firms that feel better off at keeping its innovation as a trade secret. This result may be specific to developing countries, as is the case with the Colombian manufacturing industry, where there is maybe distrust in the IP system as an effective means of protecting IP rights.

Finally, the degree of concentration in the industry is statistically significant and has a positive effect in the first stage of the model. This variable reflects that it is more likely that a firm innovates when there is not enough competition in the market, reinforcing the Schumpetarian approach that imperfect competition encourages innovation. This result is also explained by the same model that includes the effect of imitation found in Zhou (2009) where it is also argued that competition dampens innovation. In general, using either logit or probit empirical specifications the results seem to reflect a consistent story. In search of some robust results, the next section proposes alternative forms of measuring the internal knowledge of the firm for knowledge and ideas.

### 2.5.3 Robustness checks

This section checks different measures of internal sources of knowledge and ideas given the relevance they have within the innovations process of the firm. With respect to the internal source of ideas we explore the ideas from the R&D, production and marketing departments plus those ideas that are coming from Managers and Directors. Regarding the internal sources of knowledge, we classify them by three different types, general engineering, maths & statistics, and biotechnology.

#### Opening Internal Sources of Ideas

Apart from the two empirical specifications implemented in the previous results, some other measures of knowledge of the internal ideas and internal knowledge of the firm are also relevant to check for robustness of the results. To check these results, the set of internal ideas of the firm is classified by three different important sources according to the departments of the firm. Particularly, the ideas that come from the R&D, production and marketing departments plus the ideas that are created by the leaders and managers of the firm (Managers Ideas).

Table 2.11: Sequential Logit and Probit Estimations (Internal Sources of Ideas)

| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***Sources of Ideas*** | | | | | | | |
| External | 0.844*** | 0.392*** | 0.05 | | 0.506*** | 0.205*** | 0.028 |
| | (0.10) | (0.13) | (0.13) | | (0.06) | (0.07) | (0.07) |
| **Internal** | | | | | | | |
| R&D ideas | 0.818*** | 0.724*** | 0.366** | | 0.416*** | 0.336*** | 0.197** |
| | (0.18) | (0.22) | (0.16) | | (0.09) | (0.10) | (0.08) |
| Production ideas | 1.157*** | 0.964*** | 0.248* | | 0.659*** | 0.493*** | 0.147** |
| | (0.10) | (0.13) | (0.13) | | (0.06) | (0.07) | (0.07) |
| Marketing Ideas | 0.095 | 0.127 | 0.474*** | | 0.032 | 0.03 | 0.260*** |
| | (0.13) | (0.16) | (0.14) | | (0.07) | (0.08) | (0.07) |
| Manager ideas | 1.721*** | 1.319*** | 0.311** | | 0.992*** | 0.694*** | 0.174** |
| | (0.09) | (0.12) | (0.12) | | (0.05) | (0.06) | (0.07) |
| ***Firms*** | 7671 | 3311 | 2902 | | 7671 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors listed beneath coefficients.

The results including these variable are shown in table 2.11 using the logit and probit specification. For sake of clarity the impact of ideas, knowledge and the firm characteristics are presented separately but again they have been estimated jointly, as in the previous section. Exploring in detail the internal source of ideas provides us with a close impression of the role of managers in the innovation process of the firm. According to the results, their ideas are strongly consistent and significant across all the stages of the innovation process. The tacit knowledge embodied in the managers, directors and C.E.O executives and the R&D department of the firm play a crucial role for the company. The executives are key to the firm due to their ability in fostering a willingness to innovate. Their role is fundamental to combine and lead innovative ideas that can be achieved by the firm. In fact, Hill et al. (2014) highlight the potential tension between different creative people and the importance of managers in handling this tension by creating *"an environment supportive enough that people are willing to share their genius, but confrontational enough to improve ideas and spark new thinking"* (p. 97.). So, not only is the leadership of managers fundamental but also their ability to collect, understand and improve the ideas of all the elements, departments and staff that are involved in the innovation process which helps managers to create innovative and achievable ideas achievable for the firm. In line with the importance of managers, the role of marketing *ideas* and its strong relevance during the impact stage of the innovation process is also essential for the success of the innovation.

Table 2.12: Sequential Logit and Probit Estimations (Internal Sources of Ideas, continuation)

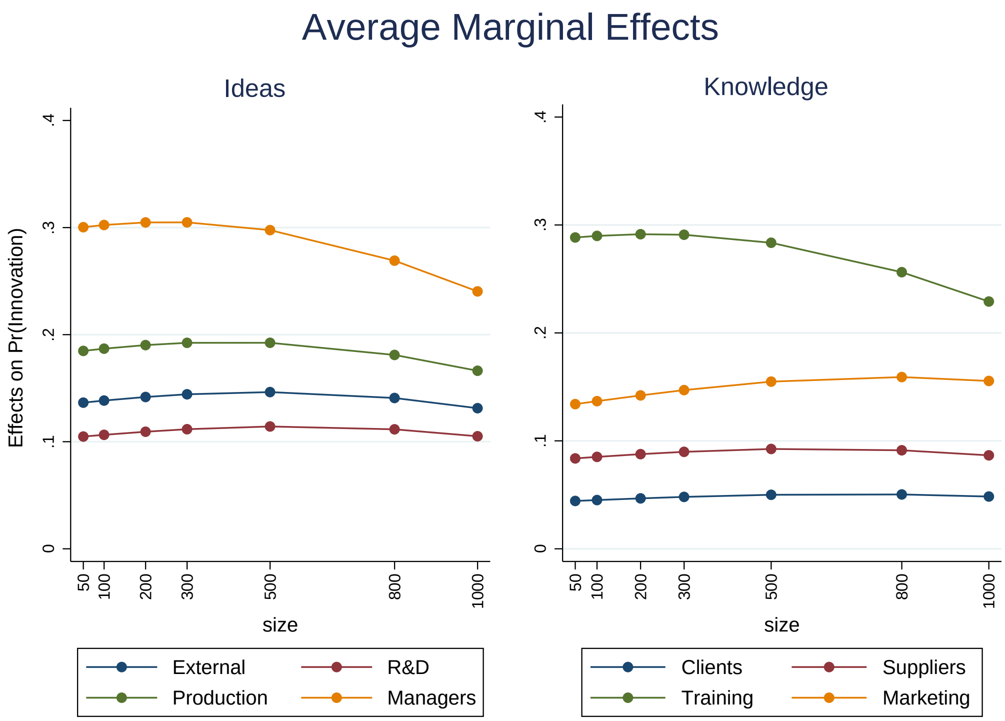
| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***External Knowledge*** | | | | | | | |
| Research Institutions | 0.03 | -0.667** | -0.015 | | -0.017 | -0.320** | 0.002 |
| | (0.27) | (0.27) | (0.24) | | (0.14) | (0.14) | (0.12) |
| Clients | 0.353* | -0.046 | 0.646*** | | 0.185* | -0.009 | 0.319*** |
| | (0.20) | (0.24) | (0.21) | | (0.10) | (0.120) | (0.10) |
| Suppliers | 0.606*** | 0.276 | 0.066 | | 0.338*** | 0.115 | 0.024 |
| | (0.17) | (0.21) | (0.16) | | (0.09) | (0.11) | (0.08) |
| ***Internal Knowledge*** | | | | | | | |
| Training | 1.946*** | 0.696** | 0.092 | | 1.087*** | 0.309** | 0.055 |
| | (0.23) | (0.28) | (0.18) | | (0.14) | (0.13) | (0.09) |
| Marketing Knowledge | 0.967 | 1.669 | 3.135** | | 0.585 | 1.348* | 1.677** |
| | (0.72) | (1.42) | (1.36) | | (0.41) | (0.77) | (0.72) |
| Production Knowledge | 0.005 | 0.75 | 0.075 | | -0.01 | 0.544* | 0.000 |
| | (0.25) | (0.55) | (0.52) | | (0.14) | (0.30) | (0.29) |
| R&D Knowledge | 4.786** | 6.426 | 2.47 | | 2.806** | 3.563 | 1.157 |
| | (2.21) | (5.49) | (3.78) | | (1.40) | (2.44) | (1.92) |
| ***Firms*** | 7671 | 3311 | 2902 | | 7671 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors listed beneath coefficients.

In addition to the results in tables 2.11 and 2.12 the average marginal effects of internal and external sources of ideas & knowledge for the first stage of the innovation

Figure 2.2: Marginal Effects




process are depicted in figure 2.2. The marginal effects of these sources are plotted against firm size. The left graph in figure 2.2 reflects the significant marginal effects in stage one. In this graph, the larger the size of the firm the lower is the marginal effect of ideas generated by the managers compared to the other sources of internal and external ideas. So not only is the role of managers fundamental to the innovation process as was mentioned before, but also their role in the innovation depends on the size of the firm.

With a larger and more complex organisation, managers might find it difficult to co-ordinate and process all the information of each department of the firm and also some information generated internally might be lost during the process of creating innovative ideas[21]. With respect to the other sources of ideas generated in the production and R&D departments, and external ideas, the respective marginal effects seem more stable as firm size changes. Regarding the sources of knowledge, the effect of getting more training is reduced with the size of the firm, whereas the marginal effect of marketing knowledge increases the probability of starting an innovation project the larger is the size of the firm. The external sources of knowledge, suppliers and clients, have a lower marginal effect on innovation and a more stable path along the different possible firm sizes of the firm. So, among all the sources of ideas and knowledge, managers ideas and training are crucial in the starting stage of an innovation project.

Considering these sources and stages, the ideas coming from the production department of the firm are significant during the completion stage of the process. The results suggest that the probability of completing the innovation, increases with the tacit knowledge of the firm and the codified knowledge of the company embodied in the departments seems not statistically significant under the logit specification and only a weakly significance at the 10% level under the probit model. In regard to the external sources of ideas, their effect during the innovation process of the firm is still consistent and strong as with the results in the last section. Regarding the other part of the model that contains the internal and external sources of knowledge, the results are still consistent and strong as the previous empirical specifications reported in table 2.9. Table 2.12 shows the results that maintain the principal conclusions of internal and external sources of codified knowledge. The other part of the results with regard to firm and industry characteristics are specified in table A.10 and the general diagnostic of the logit and probit specifications are presented in the appendix, chapter 1.

[21] This might also be explained by the different forms of internal organization of large firms. For example, there are different forms such as the M-Form or the functional separation that affect the monitoring and performance of the company. See Williamson (1967) or Carlton and Perloff (2005)

### Internal type of Knowledge

Another part of the robustness checks includes the different types of internal knowledge of the firm. Internal knowledge is classified into three different types.

Table 2.13: Sequential Logit and Probit Estimations (Robustness)

| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***External Knowledge*** | | | | | | | |
| Research Inst. | 0.177 | -0.477* | 0.109 | | 0.089 | -0.208 | 0.065 |
| | (0.23) | (0.26) | (0.24) | | (0.12) | (0.13) | (0.12) |
| Clients | 0.484*** | 0.172 | 0.784*** | | 0.256*** | 0.101 | 0.390*** |
| | (0.17) | (0.24) | (0.21) | | (0.09) | (0.11) | (0.1) |
| Suppliers | 0.653*** | 0.375* | 0.155 | | 0.342*** | 0.165 | 0.077 |
| | (0.15) | (0.21) | (0.16) | | (0.08) | (0.1) | (0.08) |
| ***Sources of Ideas*** | | | | | | | |
| External | 2.066*** | 0.942*** | 0.39 | | 1.228*** | 0.580*** | 0.212 |
| | (0.17) | (0.26) | (0.36) | | (0.1) | (0.15) | (0.2) |
| Internal | 3.419*** | 2.827*** | 0.407** | | 2.021*** | 1.573*** | 0.230** |
| | (0.11) | (0.2) | (0.18) | | (0.06) | (0.1) | (0.1) |
| Interaction | -2.227*** | -1.197*** | -0.088 | | -1.309*** | -0.706*** | -0.036 |
| | (0.2) | (0.34) | (0.38) | | (0.12) | (0.18) | (0.21) |
| ***Internal Knowledge*** | | | | | | | |
| Training | 2.034*** | 0.869*** | 0.19 | | 1.090*** | 0.385*** | 0.101 |
| | (0.22) | (0.28) | (0.17) | | (0.12) | (0.13) | (0.09) |
| Engineering | 0.940** | -1.248 | 0.528 | | 0.536** | -0.737* | 0.3 |
| | (0.38) | (0.81) | (0.7) | | (0.22) | (0.41) | (0.38) |
| Maths & Statistics | -0.055 | -0.755 | 2.399** | | -0.014 | -0.489 | 1.327** |
| | (0.52) | (0.74) | (1.03) | | (0.27) | (0.4) | -0.54 |
| Biotechnology & Natural Science | 0.23 | 16.516* | 15.751 | | 0.062 | 10.144* | 7.158 |
| | (2.08) | (9.88) | (11.64) | | (1.21) | (5.48) | (5.16) |
| ***Firms*** | 7674 | 3311 | 2902 | | 7674 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.
Robust Standard Errors listed beneath coefficients.

The first type of knowledge called *engineering*, includes the most important types of engineering such as electronics, telecommunications, civil, metallurgical, food, and others. The second measure of internal knowledge, classified as *Maths & Statistics*, includes all the knowledge related to mathematics, statistics and physics. Finally, *Biotechnology & Natural Sciences* includes the areas biology, microbiology, geology and biotechnology. These three types of internal knowledge are included in the model to evaluate their impact on the same three stages already analysed.

Table 2.13 includes the results for the internal and external sources of ideas and knowledge that the firm has. By types of knowledge, *engineering* is a crucial input for starting an innovation project. It is interesting that in the third stage under the probit specification, it has a negative effect on the probability of completing the innovation. This might be due to the fact that this variable includes different types of engineering that might not be necessary for the completion stage. For example, architecture and urbanism are included under this category and these fields may not be relevant to the competition stage.

It is interesting that *Biotechnology & Natural Sciences* is an important type of knowledge during the completion stage of the two empirical specifications in table 2.13. This might suggest that areas related to biotechnology are important to the firm for finishing the innovation. This is not surprising given that many industrial activities within the manufacturing industry use biotechnological knowledge. For instance, industries like pharmaceuticals, food & agriculture, chemical products, textiles, biofuels and others use this specific type of knowledge intensively[22]. The last measure of internal knowledge contains all the activities related to mathematics and statistics. Interestingly, the abilities represented in calculations and statistical research are likely to increase the probability of achieving the desired impact.

[22]See for example, EuropaBio.com

Table 2.14: Sequential Logit and Probit Estimations (Robustness)

| Sequential Logit | | | | Sequential Probit | | | |
|---|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | | Innovation | Completion | Impact |
| ***Firm Characteristics*** | | | | | | | |
| size | 0.002*** | 0.001 | 0.000 | | 0.001*** | 0.000 | 0.000 |
| | (0.00) | (0.00) | (0.00) | | (0.00) | (0.00) | (0.00) |
| $size^2$ | -0.000*** | 0.000 | 0.000 | | -0.000*** | 0.000 | 0.000 |
| | (0.00) | (0.00) | (0.00) | | (0.00) | (0.00) | (0.00) |
| ***Industry Characteristics*** | | | | | | | |
| Lack Cooperation | -0.045 | 0.018 | 0.036 | | -0.021 | -0.005 | 0.015 |
| | (0.1) | (0.15) | (0.14) | | (0.06) | (0.08) | (0.07) |
| Easy imitation | 0.478*** | 0.196 | 0.275** | | 0.264*** | 0.088 | 0.153** |
| | (0.11) | (0.16) | (0.14) | | (0.06) | (0.08) | (0.08) |
| Lack IP System | -0.175 | -0.119 | 0.487*** | | -0.099* | -0.054 | 0.265*** |
| | (0.11) | (0.16) | (0.16) | | (0.06) | (0.09) | (0.08) |
| Concentration | 0.667** | -0.048 | 0.268 | | 0.361** | -0.043 | 0.193 |
| | (0.30) | (0.58) | (0.52) | | (0.17) | (0.31) | (0.28) |
| Medium low Tech | 0.148* | -0.147 | 0.234 | | 0.082* | -0.083 | 0.135* |
| | (0.09) | (0.16) | (0.15) | | (0.05) | (0.09) | (0.08) |
| Medium high Tech | -0.005 | -0.056 | 0.172 | | -0.002 | -0.043 | 0.085 |
| | (0.12) | (0.22) | (0.19) | | (0.06) | (0.11) | (0.1) |
| Hight Tech | 0.152 | -0.205 | -0.044 | | 0.081 | -0.087 | -0.024 |
| | (0.13) | (0.2) | (0.19) | | (0.07) | (0.1) | (0.1) |
| constant | -2.702*** | 0.112 | 0.453 | | -1.560*** | 0.104 | 0.29 |
| | (0.2) | (0.38) | (0.36) | | (0.11) | (0.2) | (0.2) |
| ***Firms*** | 7674 | 3311 | 2902 | | 7674 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.
Robust Standard Errors listed beneath coefficients.

This result might be related to the strong, significant effect of the marketing knowledge presented in the previous sections. Statistics are an extremely important input for staff working in the marketing department to forecast potential markets movements, outcomes and sales. The advertising of the innovation seems to be fundamental to the success of the research project started in stage one. Hence, the use of statistics in market research is an important component of success. Different statistical methods are implemented such as direct simulation, standard statistical models, consumer purchase behaviour among others.[23]

Regarding the other part of the model, the impact of the variables discussed above is unchanged after implementing this new empirical specification that contains the new forms of measuring internal knowledge. With this change in the empirical specification, all the other coefficients related to external knowledge, such as clients and suppliers, are almost unchanged with respect to the previous results in the two specifications. The general diagnostic of this model validates the results obtained in the extended version proposed in this section as table 2.15 shows.

Table 2.15: General Diagnostic of the sequential logit and probit estimations

| Sequential Logit | **Pseudo-R2** | **Log-likelihood value** | **Correctly predicted** | **Iterations** | $\chi^2(df)$ | **Obs.** |
|---|---|---|---|---|---|---|
| **Stage 1** | 0.4523 | -2873.9468 | 86.37% | 5 | 2757.46(19)*** | 7674 |
| **Stage 2** | 0.2385 | -942.74712 | 88.55% | 5 | 521.24(19)*** | 3311 |
| **Stage 3** | 0.0611 | -1113.0553 | 85.80% | 4 | 132.66(19)*** | 2902 |
| Sequential Probit | | | | | | |
| **Stage 1** | 0.4524 | -2872.9641 | 86.45% | 5 | 3372.91(19)*** | 7674 |
| **Stage 2** | 0.2379 | -943.48127 | 88.43% | 5 | 541.72(19)*** | 3311 |
| **Stage 3** | 0.0615 | -1112.6338 | 85.80% | 4 | 137.65(19)*** | 2902 |

[23] See for example Steenkamp (2000) for a literature review on topics related to statistics and marketing.

## 2.6 Conclusion

This paper investigates the impact of different measures of internal and external sources of knowledge & ideas on the different stages of the innovation process of the firm. This paper is the first attempt to distinguish between *ideas* and *knowledge* as different inputs in the innovation. These particular inputs can be considered as formal (knowledge) and informal (ideas) inputs for innovation. Having an idea is not enough to develop an innovation. Firms also need to complement this input with knowledge from external and internal sources during the various steps in the process of innovation, from decision to completion until the last stage where the innovation is expected to have an impact. These inputs increase the probability that a firm achieves its expected outcome and also incrementally increase the success rate of innovation projects undertaken.

The main results can be summarised as follow. First, from the management side, it is important to identify at which stage each input contributes most to the innovation process. We found that the *Marketing and Sales Department* as an internal source of knowledge has a positive and strong impact when the company reaches the last stage of the innovation process (as predicted by Teece (1986)) and also when the firm decides to start an innovation project. The *external* knowledge source of *suppliers* has a significant effect when the firm *completes* its innovation and *consumers* in the last stage where the firm tries to achieve the *impact* expected, as is argued by von Hippel (1988). Regardless of the knowledge sources, all *external* sources of ideas are irrelevant at the last stage of the process, whereas *internal* sources of ideas are significant during the whole innovation process.

Second, when exploring the types of internal sources of ideas, the results show how crucial the role of managers and directors is to the firm during the whole innovation process. In particular, their ability to generate tacit knowledge is fundamental for increasing the probability of success of the innovation. In addition, by types of knowledge, engineering plays an important role when the firm decides to innovate. Interestingly, the knowledge related to biotechnology has an important effect during the completion stage of the innovation process. Along the same lines, the impact stage is characterised by the abilities of the firm related to maths and statistics, as an important type of knowledge that increases the probability of success.

Third, from the economic point of view, small and large firms innovation processes seem only to differ during the first stage of the innovation process. This result suggest that future research that provides a better understanding of the design of public innovation policies and protection of property rights in the manufacturing industry would be useful. The findings also suggest that public and private institutions do not play an important role in shaping manufacturing innovation processes. This a further area for future research would be a better understanding of how to design public education programmes to reevaluate their contribution to economic growth. Inputs such as knowledge and ideas play a significant role, but external sources of knowledge should be encouraged by public institutions, forums and business fairs and the local business authorities such as chambers of commerce to help firms promote and develop a strong network of knowledge sources. In addition, the relevance of the internal sources of ideas for companies are key to the firm that innovate's.

In future research, it would be useful to construct a panel data to cover more time periods in order to see how these inputs influence the innovation process in a more dynamic framework. Moreover, it would be very interesting to merge the innovation surveys with some other data such as the manufacturing industry and international trade surveys in order to extend the economic analysis to productivity performance and also to have a better measure of variables such as the degree of concentration which could be measured in a more convenient form. In addition, with this information we can also extend the analysis to investigate the contribution of innovation to aggregate productivity growth. Finally, it would be also interesting to incorporate other cases as industries and countries to compare different dynamics of these innovation inputs and outcomes.

# 3

# Competition, Innovation and The Evolution of Market Structure: An empirical investigation of the Action-Reaction process in the U.K.

## 3.1 Introduction

The evolution of market structure has been at the centre stage of the economic innovation literature over the past four decades. This evolution is driven by a dynamic process of technological competition where product or process innovation lead a firm to a superior position in the market over its competitors. Two possible outcomes can be produced under this dynamic competition framework. One outcome where the firm can consolidate its position in the market is generally defined as an *Increasing Dominance* process. The other outcome where the laggard can catch up or overtake the leader is known as an *Action−Reaction* process (see Beath et al. (1990))[1].

The distinction between *increasing dominance* and *action-reaction* processes were introduced in Vickers (1986), (hereafter, VK). VK constructs a patent race model with a sequence of non-drastic *process innovations* where patents are won by the highest bidder in a deterministic auction. The theoretical predictions in VK concludes that the nature of behavior in the market product is fundamental on how the market structure of the industry evolves. Particularly, he found that high competition in the market (Bertrand competition) is more likely to lead to an *increasing dominance* process over time, whereas under less intense competition (Cournot competition) the *action-reaction* process is more likely to arise. This latter outcome depends on the initial disparity cost between efficient and inefficient firms and the impact/superiority of the new technology/innovation are not too large.

The aim of this paper is to *contribute* to the literature of the evolution of market structure in two ways. *First*, the theoretical predictions of VK for the *action-reaction* process based on a linear Cournot model are extended incorporating the possibility that the firm can imitate the innovation developed by the innovative firm and also to extends the model in the case of $N$ firms when there is one innovator and $n$ imitators[2]. The *second* contribution of the paper provides the first empirical analysis of the predictions of these types of models in the evolution of market structure incorporating the effect of *imitation*. We use UK data to test the original predictions of VK as well as the effects of imitation. This paper is the first to attempt an empirical evaluation of VK model including the effect that imitation has on the action-reaction process[3].

[1]This concept could also represent the Schumpetarian approach of creative destruction.

[2]Imitation can be done by the laggard or inefficient firm. Also the leader or dominant firm can imitate in the case where the inefficient firm innovates.

[3]Geroski (1990) explored how innovation decentralised and reduced the market concentration for 73 industries in the U.K between 1970 and 1979. This work explored how innovation affected the evolution

Different extensions of these dynamic processes can be found in the literature. Contributions such as Beath et al. (1987) focused on sequential *product innovations* to analyse the evolution of the industry as opposed to VK. They establish a vertical differentiated duopoly model, where the innovations are improvements in the quality of the product. Each firm produces one product and the technological competition is modelled by a series of auctions where the firm competes to win the quality patent. Beath et al. (1987), find that there are different results between *product* and *process* innovations in the evolution of the market structure. While VK finds that fierce competition yields an increasing dominance situation, the authors show that in a *product* innovation framework, Bertrand competition could favour an *action-reaction*[4] or *increasing dominance* processes. The *action-reaction* process is likely when the technical change is sufficiently rapid so the identity of the high quality firm or the product leadership changes[5]. The increasing or persistent dominance process occurs when the technical progress is extremely slow, so the high quality firm wins all the patent auctions.

Another extension in the same line of VK is the work of Delbono (1989) who explores how the market structure evolves when the technological history of the firm is considered in the evolution of the market structure; in other words, when the payoff depends on the total number of patents of the firm. In a market characterized by continuous technological progress and lumpy adoption costs, Riordan and Salant (1994) define a model of strategic technology adoption. They found similar results for the case of *increasing dominance* processes as VK, but under different circumstances where the technological adoptions by the firm do not limit the adoption of its rivals and also where the technological adoptions endogenize the nature and dates of *new* technologies. Rein-

of the market structure as a result in the reduction of concentration in the market.

[4]In product innovation, low-cost firms, are of high-quality, whereas high-cost firms are of low-quality.

[5]This means that the best response of the firm to the improvements in quality, is not feasible under the current capabilities of either firm prior to the auction.

ganum (1985) sets up a model where one firm is the current incumbent and the rest are all challengers. In her model the sequence of innovations are drastic and only one of the players benefit from a monopoly profit until a better innovation is achieved. This model derives the Schumpetarian process of *creative destruction*, where a firm temporary enjoys monopoly power but is overthrown by a more inventive challenger. The rewards from each innovation are assumed to be appropriable, if the firm wins the race, becoming the leader until the next innovation occurs. Given that these theoretical predictions depend on the nature of competition and type of innovation it is important to provide empirical evidence on that.

In addition to the literature above several works study the relevance of imitation on innovation. There are two general views extensively discussed. One by Gilbert (2011) in favour of patents as a method to solve the problem of imitation and free riding and the other against as explained by Bouldrin and Levine (2013). With these two positions, a set of theoretical models from the economic growth (Aghion et al. (1997)) and industrial organization (Zhou (2009)) point of view have shown that imitation could foster innovation on innovative firms. To reinforce this view Bessen and Maskin (2009) find that patents seem to protect innovators in an static framework, but they could hurt innovation in a dynamic setting, where imitation can spur innovation.

Imitation is an important element in the technological competition. Mansfield et al. (1981) showed that patents did not make entry impossible for the imitators and nearly, 60% of the patented innovations were imitated within 4 years by those firms that adopted imitation as an strategy to compete in the industry[6]. This suggest that imitation can play

[6]The data for this study was taken from the *"chemical, drug, electronics and machinery industries concerning the cost and time of imitation (legally) of 48 product innovations"*, see Mansfield et al. (1981), p. 907. They collected the data in these four industries were all the firms agreed to co-operate. The majority of the interviews were made with major officials of each firm to assure that the data were reliable and accurate.

an important role in explaining the action-reaction process[7].

Besides these theoretical predictions, and retaking the importance of the type of competition in the market, the empirical model incorporates the level of competition as one of the crucial elements determining the action-reaction process. Direct observation about the type of strategies that firms use such as prices or quantities are not observable. This paper uses three different ways to measure competition. The first measure uses the Herfindahl-Hirschman index that captures the degree of concentration in the industry. Then we explore the Lerner index as one of the most traditional measure of competition in a particular industry[8]. Finally, we compute the competition measures proposed by Boone et al. (2005) and Boone (2008) as a new form of measuring competition based on strong and robust theoretical foundations[9]. These two papers by Boone use the parametric and non-parametric methodologies of measuring competition, respectively. In this paper we will apply the parametric approach[10]. To the best of my knowledge, this paper is the first to use this new way of measurement competition to evaluate its impact in the action-reaction process.

The empirical analysis is based on the U.K data. The U.K has been one of the top ten most innovative economies and where in 2013 was ranked third after Switzerland and Sweden and since 2007 the U.K has been ranked in the top ten dynamic innovative

[7] See for example, Shenkar (2010) who argues that a good imitator usually produces something better at a lower cost. They do not need to incur sunk investment, for example, as the innovator does. However, to become a successful imitator, they require skills, capabilities, and strategic planning, something that is missing in those imitators that fail in adopting an innovation. Such examples are Apple, McDonlad's, Wal-Mart, Visa, among others, whom he called *imovators*, referring to firms that know how to mix imitation and innovation. Another relevant example is the automobile industry in South Korea, as an experience that showed how imitation helped to spur innovation (Kim (1997)).

[8] For example, Aghion et al. (2005), Aghion et al. (2002), Negassi and Hung (2013) and Correa and Ornaghi (2014) are applications of the Lerner index.

[9] See for example, Boone (2000).

[10] The no parametric approach uses the Data Envelopment Analysis (DEA).

economies in the world[11] [12]. This result reflects how the U.K economy is actively innovating and how its industries are pursuing new technological improvements. Therefore, testing VK predictions to the U.K seems a reasonable choice to explore. An unbalanced panel data set is built with 161 industries for the periods 2002-2004, 2004-2006 and 2006-2008. The data used to construct the panel comes from two different sources. First, the information concerning the innovation aspects of the firms and industries are retrieved from the U.K Innovation Survey. Second, to complement this data we use the U.K Annual Respondents Database that contains firm level data on costs and profits. The panel is constructed at the industry level merging the information of these two data sources at 3-digit Standard Industrial Classification (SIC) and taking the different industry averages for the covarieties used in the empirical model. The *methodology* implemented to evaluate the theoretical predictions in the empirical model is based on a linear fixed effect panel data model. Given that competition and innovation may affect each other, we use lags of competition to control for the potential endogeneity problem between these two variables.

The empirical results confirm the theoretical predictions that imitation has a positive effect on the action-reaction process. In addition, when exploring the three different forms of measuring competition it seems that only the Boone parametric approach has a significant impact on the action-reaction process whereas the traditional measures did not present a significant relationship.

The remainder of the paper is organized as follows. Section 2 presents the theoretical general framework of the paper accompanied with the proof that incorporates the effect

[11]This result is based on the Global Innovation Index. See for example, Dutta and Lanvin (2013). The index is based in two sub-indices. One, collects the innovation inputs such as institutions, human capital and research, infrastructure, market and business sophistication. The other, the innovation output, is conformed by all the knowledge, technology and creative outputs (i.e. intangible assets, patents, etc.).

[12]The first year the Global Innovation Index was published.

of imitation using a linear Cournot model. Section 3 introduces the data and the way the variables have been constructed. Section 4 presents the main results and section 5 concludes.

## 3.2 Theoretical Model

This section explains briefly the general framework of the two-firm patent race model of VK based on Beath et al. (1990). The model is extended in two ways. First, it is assumed that the firm has the ability to imitate. Second, competition takes place among $N$ firms.

### 3.2.1 General Model

VK investigates how a sequence of innovations affects the evolution of market structure. In particular, his paper explores whether the currently low cost firm wins the next patent race, or whether the currently high cost firm gets the innovation. Each race is played as a simple auction game where in any period in time $t$, the firm which values the patent most highly is awarded with the innovation. This innovation is perceived as a *process* innovation where the winning firm lowers its cost to some value, for example $c_3$. The game is memoryless and the patent races are assumed to be deterministic, so there is no uncertainty about the innovation. The profit function of the firm is decreasing in its own cost and increasing in its rival level cost.

The model assumes a simple duopoly with asymmetries in costs. Two different types of firms are identified as high ($h$) and low ($l$) cost firms. The level costs for each firm are given by some previous patents or innovations that each firm already holds and the disparity cost between $h$ and $l$ is represented as[13]:

$$c_1 > c_2 \tag{3.2.1}$$

Where $c_1$ is the cost of $h$ and $c_2$ the cost of $l$. With the introduction of a new technology or innovation, which is awarded to the highest bidder between $h$ and $l$, the winner will get a reduction in cost, represented as $c_3$. Therefore, the new asymmetry between firms becomes, for example:

$$c_3 < c_2 \tag{3.2.2}$$

in this case $h$ is the firm that gets the patent and establishes a lower cost compared to its initial rival $l$ firm. The outcome of inequality 3.2.2 can be explained by the *competitive threat* principle that states the conditions when is more likely that the $h$ firm wins the patent race or viceversa, when $l$ gets the new technology. This principle considers two possibilities:

First, if the low cost firm wins the race, its profit will be:

$$\pi(c_3, c_1) \tag{3.2.3}$$

Where $c_3$ represents the cost level of $l$ firm and $c_1$ is the level cost of $h$ firm. In the same way as before, if the high cost firm wins the innovation, its profit will be given by:

$$\pi(c_2, c_3) \tag{3.2.4}$$

Where $c_2$ is the cost of the $l$ firm and $c_3$ the new level cost of the previously $h$ firm. Hence, with these definitions the competitive threat principle can be constructed as:

[13] For a detail explanation see Beath et al. (1990).

$$l_{incentive} = \pi(c_3, c_1) - \pi(c_2, c_3) \quad (3.2.5)$$

which indicates the incentive of firm $l$ to win the patent, whereas the following equation, $h_{incentive}$, represents the incentive of $h$ firm for adopting the new technology, expressed as the difference between the profits when $h$ firm gets the innovation (i.e. $c_3$) and when it does not innovate (i.e. $c_1$) and its rival does:

$$h_{incentive} = \pi(c_3, c_2) - \pi(c_1, c_3) \quad (3.2.6)$$

With these results is possible to calculate the aggregate profits of the industry using equations 3.2.5 and 3.2.6. We can analyse when the $h$ firm has more incentive to innovate than $l$ firm ($h_{incentive} > l_{incentive}$):

$$\pi(c_3, c_2) - \pi(c_1, c_3) > \pi(c_3, c_1) - \pi(c_2, c_3)$$

$$\underbrace{\pi(c_3, c_2) + \pi(c_2, c_3)}_{\sigma_h(c_3,c_2)} > \underbrace{\pi(c_3, c_1) + \pi(c_1, c_3)}_{\sigma_l(c_3,c_1)}$$

$$\sigma_h(c_3, c_2) > \sigma_l(c_3, c_1) \quad (3.2.7)$$

Where $\sigma_h$ represents the aggregate profits of the industry when $h$ firm wins the patent and $\sigma_l$ represent the aggregate profits of the industry when the $l$ firm innovates. Particularly, expression 3.2.7 reflects the outcome of the *action-reaction* process when the high cost firm achieve the innovation over the $l$ firm when there is a single innovation.

Instead of a single innovation, VK considers a sequence of single auctions that affect the evolution of the industry. These sequences of innovations are taking place at times

$\tau = 1, \ldots, T$. Each of these auctions introduce a successive *process* innovation that is represented as a sequence of lower costs as $c_{\tau+2} < c_{\tau+1}$. In the same line as it was explained for the case of the single patent race, we have that in auction $\tau$, the previous patent holder has a cost $c_{\tau+1}$ and its rival has a cost $c_k$, where $k = 1, \ldots, \tau$. To determine the outcome in auction $\tau$, let $V(c_{\tau+2}, c_j)$ be the present value at $\tau$ of all current and future profits, minus any successful bids that the firm predicts may happen in future auctions. Hence, the firm that has won the patent at $\tau$ will have a cost of $c_{\tau+2}$ and its rival will hold a patent $c_j$, where $j = 1, ..., t+1$. In the last auction at $T$ we will have a present value of $V(c_{T+2}, c_j) = \pi(c_{T+2}, c_j)$. Following the same logic of equations 3.2.1 to 3.2.7 in the case of a single auction, the maximum bid of the $h$ firm will be given by $V(c_{\tau+2}, c_{\tau+1}) - V(c_k, c_{\tau+2})$.

Finally, what VK proved were the conditions to express the action-reaction process. Particularly, if for all $\tau = 1, \ldots, T$ and for all $k = 1, \ldots, \tau$, the aggregate profits of the industry assure that:

$$\sigma(c_{\tau+2}, c_{\tau+1}) > \sigma(c_{\tau+2}, c_k) \tag{3.2.8}$$

Hence, expression 3.2.8 yields in every auction an action-reaction process. VK explores the result of equation 3.2.8 using a Cournot duopoly model where the original $h$ firm has a greater incentive to innovate than the $l$ firm, if the initial disparity cost denoted by, $b$, and the superiority of the new technology denoted by, $d$ are not too large. Otherwise, the lower cost firm has the greater incentive. The action-reaction process is given by equation 3.2.9 which is reached after solving for the duopoly model with heterogeneous firms in VK model. Therefore the action-reaction process in VK for the duopoly Cournot case is given by:

$$2B > 5b + 8d \tag{3.2.9}$$

In the following subsections, we incorporate the possibility of imitation to study its effects in the evolution of the market structure. Also, the model also extends the VK model explored for the case with one innovator (1) and $n$ imitators, $N = 1 + n$.

### 3.2.2 Extension I: Generating the Action-Reaction process under Cournot competition with imitation

This subsection applies the previous results of the action-reaction process using the Cournot model when there is *process* innovation. A homogenous product market with $N$ firms is assumed. Suppose that each firm sets $q_i$ and the total output is given by $Q = q_1 + q_2 + ... + q_n$. The demand function is $P(Q) = a - mQ$ and $a, m > 0$. The heterogenous cost functions of the firms are expressed by $C_i(q_i) = c_i q_i$ and $0 \leq c_i < a$. The firm maximises $\pi_i = (a - m(q_i + q_{-i}))q_i - c_i q_i$, and its equilibrium profit is given by $\pi_i = \frac{[a - Nc_i + C_{-i}]^2}{m(N+1)^2}$, where $C_{-i} = \sum_{j \neq i} c_j$, and $N$ is the total number of firms. Now, considering the duopoly case where $N = 2$ and $m = 1$, the equilibrium profit becomes:

$$\pi_i = \frac{[a + c_j - 2c_i]^2}{9} \tag{3.2.10}$$

Now, suppose that the $l$ firm represented with the lowest cost level $c_2$ has a cost level of $c$, and the $h$ firm with a high cost of $c_1$ has a cost level of $c + b$, where $b > 0$. The firm that innovates will get a reduction in cost of $c_3$ will get a cost reduction of $c - d$, which means that if $h$ firm wins the patent its current cost $c + b$ will be converted in $c - d$ and the same applies for the $l$ firm that will convert is cost from $c$ to $c - d$ through the implementation of the new technology, $d$.

Suppose the $h$ firm wins the patent race while the $l$ firm loses, will lead us to the action-reaction process. Now assume that the $l$ firm has the capacity to imitate a proportion of the innovation $d$ by some degree of imitation represented by $\beta$, where $\beta \in [0, 1]$.

Also, assume the case when the monopoly price is high enough than each of the two level costs, so whoever gets the innovation ensures that both firms will remain in the market.

### Calculating the aggregate profits of the industry $\sigma_l$ and $\sigma_h$

Firstly, consider the case when the $l$ firm wins the patent race and the $h$ firm has the capacity to imitate, the profits of the two firms are shown by equation 3.2.10 and adding the assumptions about costs and imitations the profits of the innovator and imitator are represented as follows:

$$\pi^l_{innovator} = \frac{[a + (c + b - \beta d) - 2(c - d)]^2}{9}; \quad \pi^h_{imitator} = \frac{[a + (c - d) - 2(c + b - \beta d)]^2}{9} \tag{3.2.11}$$

Where $\pi^l_{innovator}$ is the profit of the low cost innovative firm and $\pi^h_{imitator}$ is the profit of the high cost imitative firm[14]. Summing the equations in 3.2.11, the aggregate profits of the industry when the $l$ firm gets the innovation are:

$$\sigma_l = \frac{[B + b + (2 - \beta)d]^2 + [B - 2b + (2\beta - 1)d)]^2}{9} \tag{3.2.12}$$

Where $B = a - c$. The other possible scenario is when the $h$ firm obtains the new technology and the $l$ firm has the possibility to imitate the innovation. The profits when the $h$ firm wins the patent race and the $l$ firm imitates are, respectively:

[14]Here it is assumed that the firm is able to imitate immediately the innovation is launched by the $l$ firm. In a more realistic scenario, it would be very interesting to see how imitation takes time in order to adopt the innovation as was pointed out in Mookherjee and Ray (1991).

$$\pi^{h}_{innovator} = \frac{[a + (c - \beta d) - 2(c - d)]^2}{9}; \quad \pi^{l}_{imitator} = \frac{[a + (c - d) - 2(c - \beta d)]^2}{9} \tag{3.2.13}$$

In order to achieve the aggregate profits of the industry when the $h$ firm wins, we procedure as in equation 3.2.12. Therefore, after some calculations the expression yielded is:

$$\sigma_h = \frac{[B + (2 - \beta)d]^2 + [B + (2\beta - 1)d)]^2}{9} \tag{3.2.14}$$

Comparing aggregate profits, 3.2.12 and 3.2.14, we can check when $\sigma_h$ is greater than $\sigma_l$ and apply the competitive principle to determine the action-reaction process when:

$$\sigma_h > \sigma_l$$

The last expression yields the following result when there is a duopoly composed by two types of firms $h$ and $l$ with the possibility to imitate[15]:

$$2B > \underbrace{5b}_{\text{Initial disparity cost}} + \underbrace{8d}_{\text{Superiority of the new technology}} - \underbrace{10\beta d}_{\text{Proportion of innovation being imitated}} \tag{3.2.15}$$

Comparing the result of VK expressed in equation 3.2.9 with the new expression in 3.2.15 it is possible to see that with imitation is more likely to reach the *action-reaction* process as an outcome of the technological competition between the $h$ firm and the $l$ firm. In other words, the more imitation in the industry the more likely the action-

[15]See appendix A chapter 2 for all the calculations of this section.

reaction process is.

In a simple example values of parameters are set to equation 3.2.15, where $a = 60$ and $c = 10$, then $B = 50$. Assuming low values of $b = 1$ and $d = 1$, for example, we can easily see always the case of $\sigma_h > \sigma_l$ regardless what the degree of imitation $\beta$ is $(0 \leq \beta \leq 1)$. Under this scenario, irrespective of parameters values, the VK results holds. However, if we take large values of $d$ and $b$ there are two scenarios to consider, depending on the level that imitation takes.

- If the degree of imitation is high, $\beta = 1$, the $h$ firm has greater incentive to innovate. Therefore, the action-reaction process is, $\sigma_h > \sigma_l$.
- If the degree of imitation is low, for example, $\beta = 0.1$, the $l$ firm has a greater incentive to win the patent race. Hence, we have $\sigma_l > \sigma_h$.

So if the new technology offers a significant improvement and the degree of imitation is not high, the firm with low cost will have more incentive to innovate given that the aggregate industry profits are higher ($\sigma_l > \sigma_h$). However, if the degree of imitation is high, the $h$ firm will have a greater incentive to win the patent. In other words, the $l$ firm will only design a significant *process innovation* if imitation is not strong, otherwise will not have the incentive to be involved in this type of innovation. On the other hand, the $h$ firm will have more incentive to adopt technological improvements under high levels of imitation from the $l$ firm. Table 3.1 summarises these results:

Table 3.1: Results

| | Low imitation ($\beta = 0.1$) | High imitation ($\beta = 1$) |
|---|---|---|
| Large $d$ and $b$ | $\sigma_L > \sigma_H$ | $\sigma_H > \sigma_L$ |
| No large $d$ and $b$ | $\sigma_H > \sigma_L$ | $\sigma_H > \sigma_L$ |
| If $d > b$ | $\sigma_L > \sigma_H$ | $\sigma_H > \sigma_L$ |
| If $b > d$ | $\sigma_H > \sigma_L$ | $\sigma_H > \sigma_L$ |

$\sigma_l > \sigma_h$, Increasing Dominance process.

$\sigma_h > \sigma_l$, Action-Reaction process.

The next subsection, extends the current scenario but considers the case when the number of imitators are $n$ and there is only one innovator.

### 3.2.3 Extension II: Considering the case with N firms

The simplest case to consider with $N$ firms can be composed with one innovator and $n$ number of imitators, therefore the total number of firms will be given by $N = 1 + n$. If we assume that the firm with the lowest cost $l$ innovates, and the total number of imitators are given by all the rest of the firms considered as high cost $h$ firms, we can construct the simple case with $N$ firms in the industry.

As in the case where $N = 2$, here we proceed in the same line to calculate the aggregate profits of the industry when the $l$ firm innovates and the rest of the firms are $h$ imitators. Therefore the profits are given by:

$$\pi^l_{innovator} = \frac{[a - N(c-d) + (N-1)(c+b-\beta d)]^2}{(N+1)^2}; \quad \pi^h_{imitator} = \frac{[a - N(c+b-\beta d) + (c-d)]^2}{(N+1)^2} \tag{3.2.16}$$

Where, $\pi^{l}_{innovator}$ is the profit of one *innovator*, and $\pi^{h}_{imitator}$ is the profit of one of the $h$ imitator firms. Aggregate profits of the industry when $l$ gets the innovation and there are $n$ numbers of $h$ imitators is:

$$\sigma_l = \frac{[a - N(c-d) + (N-1)(c+b-\beta d)]^2 + [a - N(c+b-\beta d) + (c-d)]^2}{(N+1)^2} \tag{3.2.17}$$

In the opposite case when the patent is gained by the $h$ firm and the rest of the firms are $l$ imitators, we have the following profit functions:

$$\pi^{h}_{innovator} = \frac{[a - N(c-d) + (N-1)(c-\beta d)]^2}{(N+1)^2}; \quad \pi^{l}_{imitators} = \frac{[a - N(c-\beta d) + (c-d)]^2}{(N+1)^2} \tag{3.2.18}$$

The aggregate profits of the industry when $h$ gets the new innovation is:

$$\sigma_h = \frac{[a - N(c-d) + (N-1)(c-\beta d)]^2 + [a - N(c-\beta d) + (c-d)]^2}{(N+1)^2} \tag{3.2.19}$$

Comparing both aggregated profits, we find that the action-reaction process outcome will be derived under the specific profits functions solving the following expression 3.2.20:

$$\sigma_h > \sigma_l \tag{3.2.20}$$

Simplifying the expressions represented within equation 3.2.20, the general equation for the *action-reaction* process when there are $N = 1+n$ number of firms in the industry is[16]:

$$2B > (1 - 2N + 2N^2)b + 2N(N-2)c + 2N^2 d - (1 - 2N + 2N^2)2\beta d \quad (3.2.21)$$

If we substitute $N = 2$ equation 3.2.15 arises. The process of *action-reaction* occurs when the *high cost firm* wins the patent race. This happens when the joint profits of the firms are higher when the costs of the $h$ firm are lower. The *increasing dominance* process occurs when the $l$ firm wins all the patent races. According to VK, this seems to occur in Bertrand competition[17]. If $N \rightarrow \infty$, it is likely to have the *increasing dominance* process. This is consistent with the conclusion of VK who states that *"less competitiveness today leads to more competition in the future"* (p. 11). In other words, if there is Cournot competition today, an *action-reaction* process is more likely. However, if the number of players increases the *increasing dominance* process could be present. These theoretical results suggest how important is to include the level of competition in an empirical specification of the action-reaction process.

### 3.2.4 Theoretical Results

#### Initial Disparity Costs, Superiority of the Innovation and Imitation

Table 3.2 summarises all the theoretical predictions explored during this section. In particular, extensions I and II of the Cournot linear model and the possibility of imitation that derives some theoretical predictions. The main variables exploited in the model are *initial disparity cost* (**b**), *impact/superiority of the new technology* (**d**) and *imitation* (***βd***) that will be measured and tested in the next following sections.

[16] For all the calculations of this part see appendix, chapter 2.
[17] A necessary condition for this situation is that the $h$ firm earns zero profits.

With respect to **b**, a positive but not too large effect is predicted by equation 3.2.15, as well as for the effect of the variable **d**, with specific magnitude impacts of 5 and 8, respectively (see equation 3.2.15). These results go in the same line as VK's model predictions. In other words, the model suggests that a small disparity cost between $l$ and $h$ make more likely that the less efficient firm will innovate. This result could be explained by the fact that smaller gaps in costs between $h$ and $l$ would facilitate that the $h$ firm overcomes the $l$ firm to get the innovation. Another result suggests that if the superiority of the new technology is not too large it is more likely the action-reaction process. This result could be explained by the benefits in terms of profits that is gained by the $h$ firm with the innovation. If the benefit from **d** is not too large, the incentive for the $l$ firm to obtain the innovation is not high because this will not provide a significant effect on his profits. Hence, the $h$ firm will have more incentive to innovate. In this context, the empirical predictions of these variables are not too large positive effects on the action-reaction process. In the next section, the theoretical predictions of **b** and **d** will be linked to the data. As a note of clarification, the same notation will be used to measure the variables to be consistent between the theoretical and the empirical parts.

Table 3.2: Predictions

| | **Process innovation** | | |
|---|---|---|---|
| **Effects on Action-Reaction** | | | |
| ***Definition*** | ***Variable*** | ***Theoretical Prediction*** | ***Empirical Prediction*** |
| Competition | **HHI** | + | + |
| | **PCM** | + | + |
| | **Boone** | + | + |
| Initial disparity cost | **b** | + | + |
| Impact of new technology | **d** | + | + |
| Imitation | $\beta d$ | - | +/- |

Another important part of the theoretical results is the effect of imitation ($\beta d$). The result expressed in equation 3.2.15 suggests that the more negative is the effect of $\beta d$, the more likely is the action-reaction process. This could be explained by the benefit that the $l$ firm can gain through the imitation of the innovation developed by the $h$ firm. In this case, the $l$ firm will have more incentive to imitate and also to allow the $h$ firm to innovate given that through his innovation the $l$ firm can benefit more in terms of profit than if the $l$ firm would have made the innovation. In this context, the empirical results of this variable will depend on the way it is measured. For example, we will use the lack of protection of the innovation. The firm is asked if she has protected or not its innovation using patents or industry designs. The way the variable is measured is through a dummy variable that takes a value of 1 if the firm has not protected its innovation, otherwise it takes a value of 0. Then, our imitation variable will capture the proportion of firms not using protection for their innovations. Hence, a positive effect of this proxy will capture imitation. The less a firm protects its innovation the easiest is for other firm to imitate.

**Competition**

In addition, this table also shows the expected empirical predictions of competition as another important explanatory variable in the empirical model. Based on VK who predicts that under Cournot competition is more likely to met the *action-reaction* process and as it is also mentioned in Budd et al. (1993) where *"action-reaction process-i.e the current laggard winning the next race-which occurs when the market competition is Cournot and each innovation is not too large, and for increasing dominance-the leader winning all races-which occurs when product market competition is Bertrand" (p. 565).*, this theoretical results also suggest to include the effect of competition in the action-reaction process. The positive expected signs about the competition variables are discussed in the following sections where it is explained how different forms of competition are measured. In particular, the paper uses the Herfindahl-Hirschman Index, the Price Cost Margin (PCM) and the Boone's measure.

## 3.3 Data and Variables

This paper uses firm level data from the U.K Innovation Survey (UKIS) that covers all the information related to the innovations aspects of the firms, and also uses the data provided in Annual Respondents Database (ARD). The period considered in the UKIS goes from 2002 to 2008 for a panel database provided by the U.K Data Service (UKDS). This survey is conducted every two years and it covers the three previous years. For example, one survey covers the three year period 2002 to 2004. The data from the ARD, also published by UKDS, covers the period 2002 to 2008. This survey is conducted for several number of industries at the 3 digit Standard Industrial Classification (SIC) level and contains all the relevant information about the different types of costs and sales that the firm produces. The two data sources are merged at the industry level to construct the panel database implemented in the analysis. Appendix A, chapter 2 explains the cleaning process undertaken to build the final dataset. The next subsections describe how the variables were taken from each survey and how they were constructed for the empirical analysis.

### 3.3.1 Measuring Action-Reaction processes at the industry level

We first explore how the UKIS is used to construct a measure of the *action-reaction* process that constitutes the dependent variable in the empirical model. Assume that there are ten firms in industry A as shown in table 3.3. For periods $\tau = [2002-2004], [2004-2006]$ and $[2006-2008]$, each firm reports, whether it has implemented an innovation in product, process, or both. The data do not allow us to identify which firm is competing against who as the patent race model suggests. Therefore, it is assumed that if the firm answers *yes* to any type of innovation this could imply that the firm is involved within a patent or innovation race against any other firm who also tries to reach the innovation. In addition, whoever gets an innovation even in the case that the firm does not apply for a patent, the firm is still reducing its cost if they achieve a *process* innovation or a quality improvement through a *product* innovation. Under this assumption we can construct the proportion of firms that are under the *action-reaction* process distinguishing between *process* and *product* innovation. In particular, the *action-reaction* process can be defined as the situation where those firms that have innovated for example in the period [2002-2004] but have not innovated in the subsequent period of the survey [2004-2006][18]. In the same line, those firms that have innovated successively in all the periods can be considered as actively innovative firms, which describes the outcome of *increasing dominance* process. For example, $firm\ 6$ depicts the case of a firm that has been actively innovating in process innovations, as well as $firm\ 9$.

Table 3.3: Dependent variable: Action-Reaction(AR) and Increasing Dominance(ID)

| Industry A | Innovation $Yes = 1, No = 0$ | | | Process Innovation | | | Innovation $Yes = 1, No = 0$ |
|---|---|---|---|---|---|---|---|
| | **$\tau$=[2002-2004]** | | | **$\tau$=[2004-2006]** | | | **$\tau$=[2006-2008]** |
| **Firm 1** | 0 | $\rightarrow$ | **AR** | 1 | $\rightarrow$ | **ID** | 1 |
| **Firm 2** | 0 | $\rightarrow$ | **AR** | 1 | $\rightarrow$ | **ID** | 1 |
| **Firm 3** | 1 | $\rightarrow$ | **ID** | 1 | $\rightarrow$ | **AR** | 0 |
| **Firm 4** | 1 | $\rightarrow$ | **AR** | 0 | $\rightarrow$ | **ID** | 0 |
| **Firm 5** | 1 | $\rightarrow$ | **AR** | 0 | $\rightarrow$ | **AR** | 1 |
| **Firm 6** | 1 | $\rightarrow$ | **ID** | 1 | $\rightarrow$ | **ID** | 1 |
| **Firm 7** | 0 | $\rightarrow$ | **AR** | 1 | $\rightarrow$ | **AR** | 0 |
| **Firm 8** | 0 | $\rightarrow$ | **ID** | 0 | $\rightarrow$ | **ID** | 0 |
| **Firm 9** | 1 | $\rightarrow$ | **ID** | 1 | $\rightarrow$ | **ID** | 1 |
| **Firm 10** | 0 | $\rightarrow$ | **ID** | 0 | $\rightarrow$ | **AR** | 1 |
| Panel Period | | | | $\tau$=1 | | | $\tau$=2 |
| Percentage of AR and ID in Industry A | | | AR 50%<br>ID 50% | | | AR 40%<br>ID 60% | |

In table 3.3 it is possible to calculate the proportion of firms in industry $A$ under *action-reaction* and *increasing dominance* process. For example, for the panel period $\tau = 1$, the industry $A$ has $50\%$ of the firms under the *action-reaction* process, whereas

[18]The question in the survey is: *Have you introduce a product or process innovation?*, where firm answers *yes*$= 1$ to the question if they have introduced product or process innovation or *no*$= 0$ otherwise.

the rest remainder under the *increasing dominance* process. Hence, given the information at the firm level, this methodology is applied for each industry $j$ at the 3-SIC digit level to construct the percentage of *action-reaction* and *increasing dominance* processes, for all the innovations related to product and process innovations for each of the two panel periods ($\tau = 1$ and $\tau = 2$) shown in table 3.3 as our dependent variable.

### 3.3.2 Measuring Competition

This section explores three different forms of how to measure competition: The Herfindahl-Hirschman Index (HHI), the Lerner Index or the Price Cost Margin (PCM) and the Boone's parametric measure competition applied to the 161 industries considered in the analysis.

#### HHI and Price Cost Margin measurements

The HHI measure of concentration is the first way to capture the different levels of competition in each industry. The $HHI$ is given as the squared of all the market shares, $s_i$ that belong to the same industry $j$. Let us consider the market share of firm $i$ as, $s_i = \frac{Y_{it}}{\sum_{i \in N_{jt}} Y_{it}}$, where $Y_{it} = p_{it}Q_{it}$ is the revenue of the firm, then the HHI is given by[19]:

$$HHI = \sum_{i \in N_{jt}} s_i^2 \tag{3.3.1}$$

The $HHI$ index is measured in a scale that goes from 0 to 10.000, where 0 means a low level of concentration in the industry which can be related to a high competitive industry, whereas a level of 10.000 means a high concentrated industry or a more close monopolistic structure. Therefore what is expected is a positive effect from $HHI$ on

[19]In this paper the revenue is represented by the turnover of the firm.

the $AR_{j\tau}^{process}$ process.

The other measure of competition, the Price Cost Margin (PCM) or Lerner Index is defined as the ratio between the difference of price ($p$) and the marginal cost ($MgC$) divided by the price, $p$. Yet, the $MgC$ is not observable, so a good approximation implemented in empirical applications is the total variable cost of the firm, $TVC_i$, which can be measured from ARD database. $TVC_i$ is composed by the labor costs of the firm and other inputs used during the production process such as the costs of materials, energy, water and water disposal[20]. Accordingly, the $PCM$ measure of competition is[21]:

$$PCM_i = \frac{p - MgC}{p} \equiv \frac{pQ - (MgC)Q}{pQ} \equiv \frac{Y_{it} - TVC_{it}}{Y_{it}} \tag{3.3.2}$$

After calculating the $PCM$ as a measure for all firms and then talking the simple average per industry $j$ and years we have:

$$PCM_{jt} = \frac{1}{N_{jt}} \sum_{i \in j} \frac{Y_{it} - TVC_{it}}{Y_{it}} \tag{3.3.3}$$

Where $N$ is the total number of firms in industry $j$ in year $t$. $PCM$ ranges from

[20]Boone (2008) suggests to measure $TVC_i$ as the way described in this paper, see p. 1254.

[21]Additionally, another empirical proxy to measure $LI$ can be represented as:

$$PCM = \frac{p - MgC}{p} \equiv \frac{GVA}{Y_{it}}$$

Where the Gross Value Added (GVA) can be used as a proxy for profits, $\pi_{it}$. This measure is deflated using the Producer Price Index (PPI). Moreover, with the asymmetries between firms another approximation of the $PCM$, becomes the weighted average of each firm's margin, where each weight is given by the market share of the firm as $PCM = \sum_{i=1}^{N} s_{it} \frac{P-MgC}{P}$. Finally, in Nickell (1996) and Aghion et al. (2005) the $PCM$ is considered as $PCM_{it} = \frac{\text{operating profits} - \text{financial cost}}{\text{sales}}$ and competition is defined as $c_{jt} = 1 - \frac{1}{N_{jt}} \sum_{i \in j} li_{it}$.

$0$ to $1$, where a value close to $1$ implies greater market power, whereas a level close to 0 implies a more competitive market or low levels of market power. It is expected that for the case of *action-reaction* process the competition could be less intense that on a contrary case, where an intense level of competition can produce an *increasing dominance* process[22].

### Boone parametric measurement of competition

The principal idea of the concept proposed by Boone (2008) is that when competition becomes fierce in a particular industry, firms that are more inefficient are likely to be punished more harshly in terms of profits. In the paper of Boone et al. (2005) the author argues that an increase in competition increases the profit of the most efficient firms relative to the less efficient firm[23]. To complement this idea, Boone suggests to estimate the relationship between the relative profits and $MgC_i$. Given that $MgC_i$ cannot be observed, a way to capture the efficiency of the firm, is defining the average variable cost as $AVC_i = TVC_i/Y_i$ for a firm $i \in j$ industry for all the years between 2002 and

[22] An empirical paper by Negassi and Hung (2013), proposes that if the competition coefficient is not statistically significant the competition is weak (*Cournot* competition). If the coefficient is statistically significant, competition is fierce, then price tends towards the marginal cost so we could interpret the result as close (*Bertrand* competition). They used the $PCM$ as a measure of competition.

[23] Boone (2008) proposes a measure of competition using the Relative Profit Difference $RPD$ measure. Calculating the profits $\pi_{it}$ and efficiency or productivity $n_{it}$. Normalizing profits and efficiency, ordered such that $n_{it}$ is decreasing in $i$, we have:

For efficiency:

$$\frac{n_{it} - n_{N_t t}}{n_{1t} - n_{N_t t}}$$

and the RPD:

$$\frac{\pi_{it} - \pi_{N_t t}}{\pi_{1t} - \pi_{N_t t}}$$

If the area under the curve is smaller in $t+1$ than in $t$, the competition has become more intense in year $t+1$ (e.g., Bertrand). This measure is the non-parametric approximation of competition proposed by Boone (2008). There are some applications such as the study of Schiersch and Schmidt-Ehmcke (2010) for the German manufacturing firms.

2008[24]. Then the empirical specification of the relative profit measure is given by:

$$ln(Y_i - TVC_i) = \alpha + \beta AVC_i + e_i$$

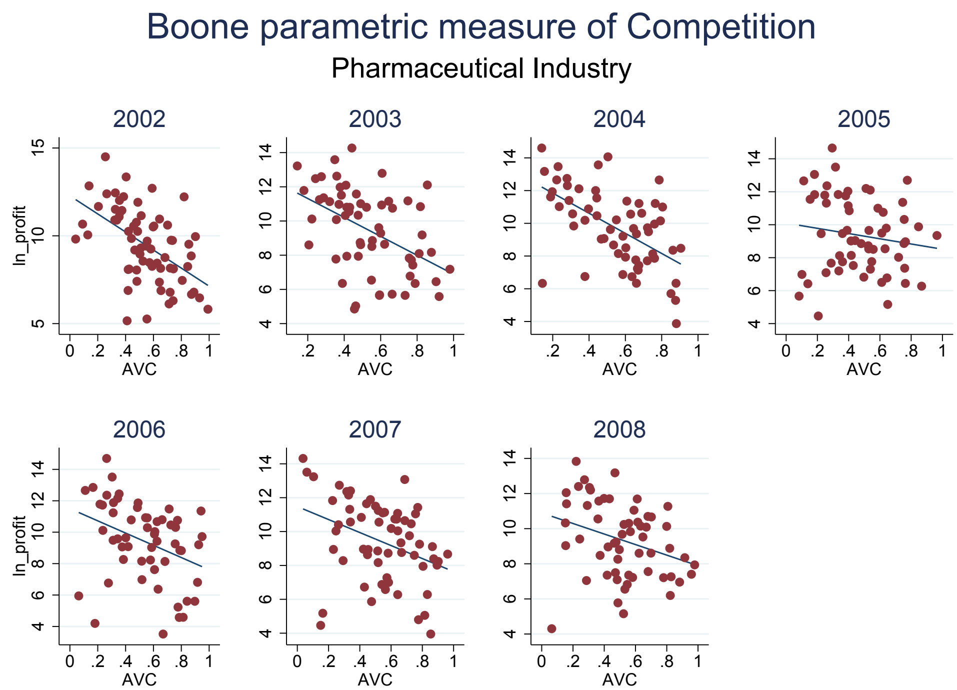
$$ln(\pi_i) = \alpha + \beta AVC_i + e_i \tag{3.3.4}$$

The $\beta$ coefficient captures the relative profits measure for each of the 161 $j$'s industries for each year between 2002 and 2008. If the slope becomes more negative across time it is a signal of increasing in competition during the period. Therefore, a set of regressions were conducted using equation 3.3.4 for all the $161$ industries at 3-SIC between 2002 and 2008. The estimations for each of these $\beta$'s in each $j$ and year represent the Boone parametric measure of competition implemented in the empirical model of section 4. The set of graphs in figure 3.1 is an example of one of the $161$ industries considered in the analysis. In this example the Pharmaceutical industry levels of competition are illustrated using the relative profits measure. All the regressions are carried out in cross-sectional dataset using the robust standard errors in order to estimate the $\beta$ that captures Boone's competition.

To illustrate how competition has evolved between 2004 and 2005 in the figure 3.1, we can see how the slope in the year 2004 is more negative than the one depicted in 2005. This illustration indicates how competition is less intensive in the Pharmaceutical industry from 2004 to 2005. After 2005 the level of competition has been more fierce in the industry as the slopes become again to the same pattern registered between 2002 and 2004, as we can see in figure 3.1.

[24] In other words this is measured as the ratio between costs and revenues as is pointed out by Boone et al. (2013), p. 53.

Figure 3.1: Boone Competition




To sum up, *Boone* parametric method of measuring competition goes in the same line as the $PCM$. ***Boone's*** measurement is the coefficient estimated in equation 3.3.4 where the estimated coefficient is usually negative and where competition increases the profits of the most efficient firms relative to the inefficient ones. As the coefficient becomes more negative[25] a more intensive competition is perceived, result that might be close to Bertrand competition. On the contrary, if the coefficient becomes less negative, it reflects a less competitive market which is more likely to represent some degree of Cournot competition[26]. These two measures of competition (PCM and Boone) are

[25] Figure 3.1 is a good example of how the degree of competition is changing in the Pharmaceutical Industry.

[26] It is known that Bertrand equilibria is more competitive than Cournot equilibria. For a detail explanation and references, see Vives (2008) p. 433.

expected to have a positive effect on $AR^{process}_{j\tau}$. The reason is because any increase in $PCM$ and $Boone$ reflect less competition in the market which can be associated with Cournot competition. This means that a positive effect of any of the competition measures can be read as an incentive of the most inefficient firms (i.e, high cost firm, $h$) to innovate and overcome the most efficient firms (i.e, low cost firm, $l$) in the market, which is in line with the theoretical predictions of the *action-reaction* process.

### 3.3.3 Measuring Initial Disparity Costs, Impact of Innovation and Imitation

**Initial Disparity Costs (b)**

This section describes the rest of the variables considered in the theoretical model of equation 3.2.15[27]. The *initial disparity costs* between firms which is represented in equation 3.2.15 as $\boldsymbol{b}$ is measured as follows. First of all we distinguish between low $l$ and high $h$ cost firms in each industry $j$ for all the years between 2002 and 2008. To calculate this variable, the measure takes a threshold that separates between $h$ and $l$ cost firms using the $median$ of the ratio $\frac{TVC_i}{Output_i}$, where $Output_i = \frac{turnover_i}{deflator}100$ in each industry[28]. In this way, the firms under this threshold are classified as low cost firms, $l$ and the ones above as high cost firms, $h$. Finally, taking the simple average for each group, the high cost firms group will be represented as the average $\frac{1}{N_{H_{jt}}}\sum_{i\in j} H_{jt}$ and the group of low cost firms as $\frac{1}{N_{L_{jt}}}\sum_{i\in j} L_{jt}$. Thus, the final measure of *disparity cost* will be the difference between these two groups as follows:

[27] As a note of clarification, the next subsection titles incorporate in parenthesis the theoretical variable explored in the previous section in order to provide as clear as possible the way is measured in the data. For example, this subsection is referred to the theoretical variable represented by $b$.

[28] The deflators used for all industries are taken from the Office of National Statistics for the U.K. For agricultural industries the Agricultural Price Indices (API) is used, for manufacturing industries the Producer Price Indices (PPI). For the service industries the Service Producer Price Indices (SPPI). Finally, for the retail trade industries the Consumer Price Index (CPI) is applied.

$$\boldsymbol{b} \equiv DispCost_{jt} = \frac{1}{N_{H_{jt}}} \sum_{i \in j} H_{jt} - \frac{1}{N_{L_{jt}}} \sum_{i \in j} L_{jt} \tag{3.3.5}$$

### Impact/Superiority of the Innovation (d)

To provide a good approximation of the impact of innovation the paper implements two complement measurements. The *impact of new technology* captures the effect represented in equation 3.2.15 as $\boldsymbol{d}$. One of the advantages of the UKIS survey is that this effect can be observed directly by capturing the impact of both *product* and *process* innovation. The effect can be splitted into two parts, in order to capture the innovation effect in the market and in the firm. The survey has different forms to measure the effect. First, the UKIS asks, *How important were each of the following effects of your product and/or process innovations introduced?*, when it entered into new markets or when it increased the market share. This measure is used as a proxy of the innovation in the market that captures the impact/superiority of the new technology and is represented as *impact market size*. Second, as a complement to the previous measure and to be consistent with the *process* innovation analysis, the survey also possesses the particular case of the impact of the innovation related to *costs reduction*. It is identified as the reduction in costs due to improvements in the production process of the firm and is represented as *impact costs reduction*[29]. These questions are answered using Likert scale values that goes from $0$ =Not relevant, $1$ =Low, $2$ =Medium and $3$ =High. Taking the simple mean for each of the previous questions for each industry give us the approximate measure of the impact of $\boldsymbol{d}$, expressed and measure as:

[29]Also, the survey can identify the impact of innovation due to improvements in quality of goods or services.

$$ImpactMarketSize_{jt} = \frac{1}{N_{jt}} \sum_{i \in j} ImpactMarket_{ijt}$$

$$ImpactCostsReduction_{jt} = \frac{1}{N_{jt}} \sum_{i \in j} ImpactCostsReduction_{ijt} \qquad (3.3.6)$$

**Imitation ($\beta$d)**

In the theoretical model the effect of imitation is captured by the term $\boldsymbol{\beta d}$, which measures the proportion of the cost reduction that each imitating firm can appropriate from the innovation of another firm. In order to capture the effect of imitation, we proxied the proportion of firms that have not used any type of protection of process in each industry, to capture the lack of Intellectual Property System by the firms. In the survey firms are asked, if the firm has protected or not their process innovation using patents or registering an industry design. These two variables are highly related to firms that have incurred in process innovations. Hence, the proportion of innovation being imitated is taken as the simple average of all firms in a particular industry $j$ in year $t$, as:

$$Imitation(1) = \boldsymbol{\beta d}_{jt} = \frac{1}{N_{jt}} \sum_{i \in j} IndustryDesign_{it}$$
$$Imitation(2) = \boldsymbol{\beta d}_{jt} = \frac{1}{N_{jt}} \sum_{i \in j} Patents_{it} \qquad (3.3.7)$$

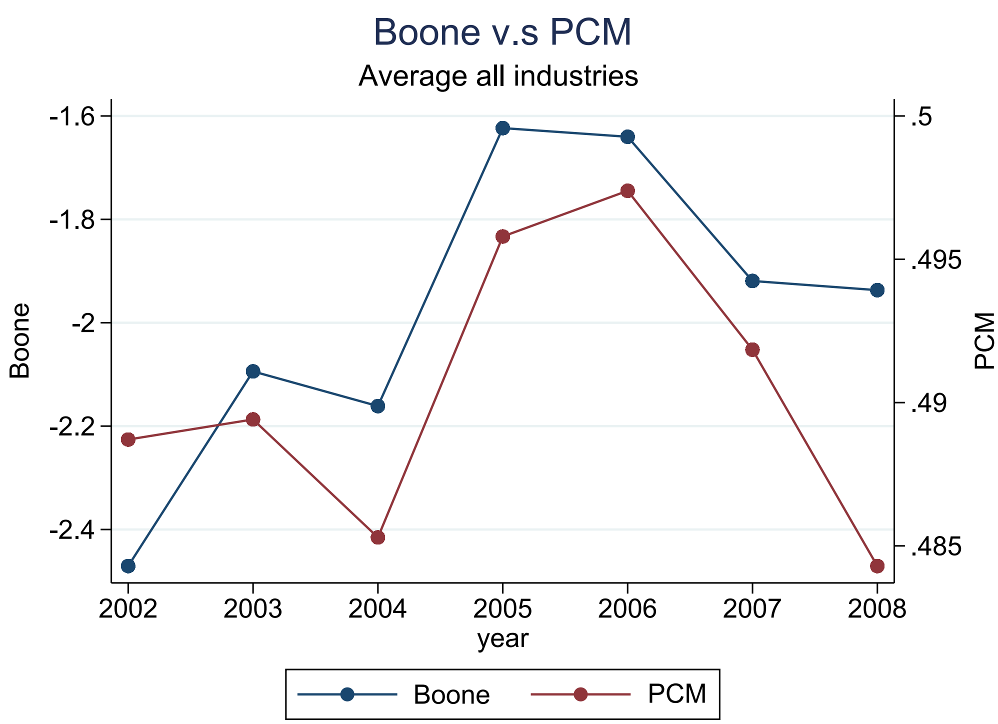
The variable *imitation* captures the proportion of firms not using protection of process innovation. With the theoretical predictions of section 2, higher levels of imitation facilitates the less efficient firms to overcome the efficient firms, so the *action-reaction* process is more likely.

## 3.4 Empirical model and Results

Table 3.2 of section 2 summarises the empirical and theoretical predictions for *process* innovation. Those predictions are empirically tested in this section. After constructing the dataset required for the analysis we end up with a panel of two periods where each period covers three years, $\tau = [(2004 - 2006)]$ and $[(2006 - 2008)]$ and 161 industries. For instance, in the UKIS panel the period between $2004$ and $2006$, means that the outcome of our dependent variable, $AR_{jt}^{process}$ captures the dynamic process of innovation for each industry during this three years time period. For sake of clarity, the first period of the panel denoted by $\tau$ correspond to the years from 2004 to 2006 as $[\underbrace{2004}_{t-2}, \underbrace{2005}_{t-1}, \underbrace{2006}_{t}]$ where the use of $t-2$, $t-1$ and $t$ indicate the last, the medium and the current year within the period covered by the survey. For the second period of the panel $\tau$ covers the years between $[2006 - 2008]$.

The empirical specification implements the three different forms of measuring competition. The competition measurements are expected to have a positive effect on the *action-reaction process*, $AR_{j\tau}^{process}$. The correlation between $PCM$ and Boone measurements show similar results as the one reported in Boone et al. (2005). Interestingly, figure 3.2 shows how Boone and PCM follow the same trend over the years 2002 to 2008 for all the 161 industries depicting a high strong and significant correlation at the 1% of 0.68. This result suggest that both measures of competition captures a similar pattern related to the competition in the industries.

Figure 3.2: Boone and PCM correlation




In order to be consistent with the innovation variables that are taken from UKIS survey (Impact Market Size, Impact Costs Reduction and Imitation) and the years that are covered in each period of the survey, the proxies that capture the level of competition are measured as the difference between the last and the first year covered by each survey. For example, in the survey that covers the period between [2004-2006] or when $\tau = 1$ in the panel, Boone's competition measure is the difference between the coefficients estimated in the empirical specification 3.3.4 for the year 2006 and 2004, that is $Boone_\tau = Boone_t - Boone_{t-2}$[30]. According to the previous explanation about the coefficients that capture Boone's competition, as the difference becomes more positive

[30] In the same way $PCM$ and $HHI$ are also measured.

the less competitive is the industry[31]. Implementing these measures help us to capture in a more accurate way the dynamics of competition for the panel periods. This methodology is also applied for the disparity cost variable[32].

The rest of the variables mentioned in section 3 are treated as follows. The variable that captures the innovation market impact uses the effect that the innovation had on the industry in each of the two periods of $\tau$ (i.e., **d**=impact in market size and reduction costs)[33]. In a similar way the imitation variables described in the previous section as the outcomes generated during the technological competition process are measured in the same panel periods of $\tau$. For the initial disparity cost the variable is measured in the same way as the competition proxies in order to be consistent with the innovation variables that are taken from the UKIS. Finally, a general statistical description of the data is given in table 3.4 where the names correspond to each of the variables explained above.

Table 3.4: Descriptive Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Action-Reaction | 317 | 22.757 | 19.284 | 0 | 100 |
| Boone | 317 | 0.126 | 2.671 | -7.147 | 9.281 |
| PCM | 317 | 0.002 | 0.058 | -0.242 | 0.216 |
| HHI | 317 | 157.080 | 738.464 | -4743.94 | 4101.937 |
| Imitation (1) | 317 | 0.137 | 0.107 | 0 | 0.667 |
| Imitation (2) | 317 | 0.128 | 0.097 | 0 | 0.667 |
| Impact Market Size | 317 | 1.035 | 1.246 | 0 | 3 |
| Impact Costs Reduction | 317 | 2.030 | 0.884 | 0 | 3 |
| Disparity Costs | 317 | 0.076 | 0.0812 | -0.2289 | 0.371 |

[31]For instance, if the estimated coefficient in 2006 is -0.2 and in 2004 is -0.5, then the difference becomes 0.3, which suggest a decrease in competition in this particular example. See also the Supermarket case in Boone et al. (2005) for a similar analysis.

[32]The panel periods are two, when $\tau = 2$ it covers the period [2008-2006] and when $\tau = 1$ which covers the period [2006-2004].

[33]For example, when $\tau = [2004, 2006]$ and $\tau = [2006, 2008]$

Under this clarification, the following fixed effect model is suggested as the empirical specification that evaluates the determinants of the *action-reaction* process when we have *process* innovations in the industry. Hence, the empirical model specification is represented as follows:

$$AR_{j\tau}^{process} = \alpha_j + \underbrace{\beta_1 Competition_{j\tau}}_{HHI, PCM, Boone} + \underbrace{\beta_2 ImpMktSize_{j\tau} + \beta_3 ImpCostsRedu_{j\tau}}_{ImpactInnovation\_(\mathbf{d})} + \underbrace{\beta_4 Imitation_{j\tau}}_{Imitation(1)(2)\_(\boldsymbol{\beta}\mathbf{d})} + \underbrace{\beta_5 DisparityCost_{j\tau}}_{InitialDisparityCosts\_(\mathbf{b})} + \varepsilon_{j\tau} \quad (3.4.1)$$

Where $j$ denotes each of the 161 industries considered at the SIC 3 digits level and $\tau$ correspond to the two periods of the panel. Estimations of the $AR_{j\tau}^{process}$ using HHI and PCM proxies for competition are presented in table 3.5, where the first three columns correspond to the HHI and the two variables that evaluate the imitation (1)(2) effect on the action-reaction process. In the same table, the last three columns correspond to the empirical model estimated using the Lerner index as a measure of competition. All estimations account for cluster panel-robust standard errors in order to have the appropriate statistical inferences and the measurements of competition were tested for outliers using the *Hadi* test[34]. For cases, with the presence of outliers the observations were dropped for $HHI$, $PCM$ and $Boone$ variables.

[34] In appendix A, chapter 2, tables A.14 and A.15 the results for the test are presented. See Hadi (1992) for a technical reference of the test.

Across all the specifications the impact of the new technology have a strong and positive significant effect when the impact is related with an increase in the market size due to the effects of the innovation. Regarding the impact on cost reductions by the effect of innovation, the results suggest a not statistical effect in almost all the specifications. Imitation has a positive and strong significant effect using pooled OLS estimation, but this result might be underestimate. Controlling for the unobserved characteristics (FE specification in table 3.5) the effect of imitation is not longer significant.

Table 3.5: $AR_{j\tau}^{process}$ using HHI and Lerner measurements of Competition

| $AR_{j\tau}^{process}$ | **HHI** | | | | **PCM** | | | |
|---|---|---|---|---|---|---|---|---|
| | Pooled OLS | FE | Pooled OLS | FE | Pooled OLS | FE | Pooled OLS | FE |
| **HHI, PCM** | 0.001 | 0.003 | 0.001 | 0.003 | 16.58 | 26.481 | 17.809 | 26.366 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (22.86) | (29.00) | (22.58) | (29.18) |
| **Impact Market Size** | 3.239*** | 3.007*** | 2.552*** | 2.449*** | 3.124*** | 3.070*** | 2.431*** | 2.486*** |
| | (0.87) | (1.08) | (0.87) | (0.92) | (0.90) | (1.06) | (0.90) | (0.87) |
| **Impact Costs Reduction** | 1.762 | 1.578 | 2.429* | 1.672 | 1.693 | 1.776 | 2.35 | 1.859 |
| | (1.43) | (2.15) | (1.44) | (2.13) | (1.46) | (2.10) | (1.47) | (2.07) |
| **Imitation (1)** | 46.895*** | 34.734 | | | 47.401*** | 39.318 | | |
| | (12.29) | (24.38) | | | (11.98) | (24.22) | | |
| **Imitation (2)** | | | 36.632*** | 30.239 | | | 37.569*** | 36.136 |
| | | | (12.27) | (21.79) | | | (11.98) | (22.56) |
| **Disparity Costs** | -5.245 | -21.451 | -0.982 | -18.353 | -8.16 | -27.598 | -4.108 | -24.407 |
| | (15.7) | (21.99) | (15.09) | (22.09) | (16.53) | (22.42) | (15.92) | (22.43) |
| **Constant** | 9.642** | 12.881* | 10.443*** | 13.935** | 10.132** | 12.586* | 10.923*** | 13.568** |
| | (3.77) | (7.14) | (3.91) | (6.83) | (4.04) | (6.94) | (4.15) | (6.63) |
| **R2** | 0.106 | 0.091 | 0.08 | 0.079 | 0.107 | 0.081 | 0.082 | 0.069 |
| **Observations** | 317 | 317 | 317 | 317 | 317 | 317 | 317 | 317 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

• Robust-Standard errors under coefficients.

The results of table 3.5 show that the *competition* variables HHI and PCM are not statistical significant across all the empirical specifications when using pooled OLS and fixed effects (FE). Imitation and the impact of the new technology seems to favor the action-reaction process, but the initial disparity costs between high and low cost firms seems to do not have any significant effect.

These competition proxies make no distinction about the asymmetries between the most efficient and less efficient firms in the industry which might help to explain the insignificant effects of competition under this ways of measurement. This is why is important to take into account this distinction between high cost firms, $h$, and low cost firms, $l$, that allow us to be consistent between the theoretical and empirical specifications. Using Boone's way of measuring competition in the next section enable us to control for both specifications.

### 3.4.1 Boone measure of competition and endogeneity

Using $Boone's$ measurement allow us to capture different forms of competition from the theoretical point of view as is shown in Boone (2000, 2008) Boone et al. (2005) and Boone et al. (2013). In these papers Boone explored from the theoretical point of view the different forms where competition can be analyzed, using the number of firms, the entry costs, Bertrand and Cournot competition or the low costs levels of rivals as a signal of a more intensive competition.

Table 3.6: $AR^{process}_{j\tau}$ using Boone measurement of Competition

| $AR^{process}_{j\tau}$ | Imitation (1) | | | Imitation (2) | | |
|---|---|---|---|---|---|---|
| | **Pooled OLS** | **FE** | **IV FE** | **Pooled OLS** | **FE** | **IV FE** |
| **Boone** | 0.880* | 1.274** | 2.216** | 0.921 | 1.279** | 2.314** |
| | (0.53) | (0.56) | (0.90) | (0.56) | (0.58) | (1.04) |
| **Impact Market Size** | 3.081*** | 2.938*** | 2.761*** | 2.396*** | 2.362*** | 2.171** |
| | (0.91) | (0.98) | (0.98) | (0.92) | (0.90) | (0.96) |
| **Impact Costs Reduction** | 1.752 | 1.963 | 2.193 | 2.394* | 2.043 | 2.288 |
| | (1.42) | (2.06) | (2.27) | (1.43) | (2.05) | (2.19) |
| **Imitation (1)** | 48.344*** | 39.121* | 40.026* | | | |
| | (11.68) | (22.43) | (22.14) | | | |
| **Imitation (2)** | | | | 39.506*** | 36.244* | 37.905* |
| | | | | (11.47) | (20.82) | (22.1) |
| **Disparity Costs** | -5.165 | -23.612 | -24.461 | -0.883 | -20.51 | -21.491 |
| | (15.58) | (21.03) | (21.05) | (14.94) | (21.23) | (21.93) |
| **Constant** | 9.632*** | 11.976* | 11.513* | 10.306*** | 12.919** | 12.352** |
| | (3.69) | (6.62) | (6.6) | (3.77) | (6.30) | (6.22) |
| **R2** | 0.119 | 0.123 | 0.1614 | 0.095 | 0.111 | 0.1555 |
| **F** | 7.12 | 2.618 | 2.384 | 7.054 | 2.468 | 2.182 |
| **Observations** | 317 | 317 | 317 | 317 | 317 | 317 |
| **Hansen-Test** | | | 0.042 | | | 0.05 |
| **P-value Hansen Test** | | | 0.8377 | | | 0.8229 |
| **F-Statistics First Stage** | | | 33.61 | | | 28.01 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

• Robust-Standard errors under coefficients.

Exploring these different avenues, Boone constructs a robust concept of competition expressed in the relative profits measure. This definition has a pertinent place in the theoretical framework of section 2 because the effect of the inefficient firms (high cost firms, $h$) captured through the relative profit measure that explains that an increase in competition increases the profits of the most efficient firms (low cost firms, $l$) relative to the most inefficient ones. Therefore, through the $\beta$'s estimated in equation 3.2.21, is possible to capture the degree of competition for all the industries explored in the data. Thus, this definition seems to be closer to the concept of *action-reaction* process where the high ($h$) cost firms have greater incentive to innovate than the less inefficient firms ($l$) in the industry. The empirical results using $Boone$ measure of competition are presented in table 3.6 using the two types of imitation. Imitation (1) reflects the lack of protection of the innovation when industry designs registrations are not implemented by the firms, which might facilitate that all the other competing imitate their innovation. In a similar way, imitation (2) captures the facility to imitate innovation when firms do not protect their innovation through patents.

The results show a systematic consistency of Boone's measure of competition through all the estimations employed in table 3.6. Controlling competition using Boone reflects consistent results for the effects of imitation either using the lack of industrial designs registrations or patents. The first two columns take into account imitation (1) using OLS and within estimators with a significant effect on competition. The third column control for the potential endogeneity problem that is caused by the simultaneous influence of innovation (i.e., action-reaction process) and competition. This endogeneity problem might bias and underestimate the real effect of competition. Using Boone's competition variables from a period other than the period used in the regressions allow us to construct the instruments used in the columns **IV FE** of table 3.6. The Hansen-test and the F-Statistics in the first stage validate the instruments used to control for endogeneity. The results in these columns confirm the significant effect of competition. In particular, there is an increase in *Boone's* competition measure, which suggest less competition in the market and can be interpreted as a Cournot type of competition. So, a less competitive market affects positively the proportion of less inefficient firms and their incentive to innovate. This result might be the first empirical evidence that supports the VK argument about how these competition conditions are required to meet the *action-reaction* process under *process* innovations and also supports the theoretical predictions of the theoretical model of section 2 when there is the possibility of imitation.

The results also confirm the strong significant effect of the impact of the new technology or innovation registered in the previous section with a slightly decrease on the effect across all the three estimations with OLS, FE and instrumental fixed effects. The superiority of the new technology is not too large which is in line with the theoretical predictions of the model presented in section 2 and VK predictions. Regarding the effect of imitation the results now suggest a consistent and significant vanished effect impact using any of the two versions to capture imitation among all the estimations presented in table 3.6. This result supports the importance that imitation has on the evolution of the market structure and how the imitation of the innovation stimulates the less inefficient firms to overcome the most efficient ones. From the cost part of the model, the results suggest that the initial levels of the initial disparity cost between efficient and inefficient firms do not have a significant role in the evolution of market structure as the results in table 3.5 showed. In general, the results are consistent with the theoretical predictions of equation 3.2.15 in section 2.

Among all the empirical specifications and different forms in measuring competition and imitation, it seems that the fixed effect estimation results when controlling for potential endogeneity and using Boone measure of competition in table 3.6 confirms the theoretical predictions. Comparing the different $R^2$ presented in the results help us to understand more and compare the different empirical results. The null hypothesis (*F-test*) that the joint impact of the coefficients is zero is rejected consistently across all the formulations using Boone's measure of competition at the 5% and 1% critical levels (table 3.6). Under this statistical diagnostic the *action-reaction* process seems to be explained by the theories suggested in VK and the extension that incorporates the possibility of imitation.

## 3.5 Conclusion

The empirical evidence on the outcomes generated by the dynamic process of technological competition described as the increasing dominance and the action-reaction processes have not been explored empirically so far in the innovation literature. To the best of my knowledge this is the first attempt to test the predictions made in VK. This analysis also extended the Vickers's Cournot model incorporating the role that imitation has on this dynamic technological competition framework.

The effect of imitation along with the forces defined by VK such as the initial disparity cost, the impact of the innovation and the competition involved in the market product were empirically assessed for the U.K economy. Some of the theoretical predictions were confirmed in the data. The impact of innovation and the proportion and the proportion of innovation that is imitated seems to have a significant role in the action-reaction process. We also find that competition measured using Boone plays a positive effect on the action-reaction process, while the other measurements of competition such as $HHI$ and $PCM$ were not statistically significant. This may be due to the fact that HHI and PCM might not be appropriate to capture changes in competition as Boone et al. (2013). Boone et al conclude that when there is a change in competition "*the probability that PCM points in the wrong direction increases with industry concentration*"[35]. Also, using Boone's approach helps to identify the differences across industries compared to the $PCM$ approach that usually performs better for industry cases only[36].

There are several points where the theoretical and the empirical models can be improved and extended. On the one hand, the theoretical predictions could be enhanced by incorporating uncertainty in the model and also exploring the case for action-reaction

[35] See p. 46 in Boone et al. (2013).
[36] See for example, Nevo (2001).

process under product innovations as Beath et al. (1987) propose. In addition, the imitation side of the analysis assumes that imitation is taken immediately by the firms. In a more reliable approach imitation requires more time in order to adapt and imitate the new technology. In terms, of the extensions using $N$ firms, the model assumes one innovator and $n$ imitators. It would be interesting to study the cases when there is more than one innovator and also to explore the case of increasing dominant process. From the empirical point of view it would be very interesting to evaluate this model for other industries in different countries and also to explore a better definition of a market in order to understand what drives the evolution of market structures when there are sequences of innovations. Using a 3-SIC digit classification as an approximation of the market could be regarded as as a too aggregated measure of the market. So, considering a more disaggregated SIC could provide us a better approximation in future work. Extending the panel to more periods would also be an interesting exercise to capture more the dynamic effects that competition has on the evolution of the market structure.

Understanding and evaluating these factors on the evolution of the industry can generate important tools to design possible policies in industries. For example, distinguishing between the most inefficient and efficient firms in the industry could be a strong tool in order to incentive innovation and also for controlling the level of competition in the industry.

# 4

# Don't leave me this way!: Mergers, Innovation and Inventors' mobility in the Pharmaceutical Industry

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## 4.1 Introduction

The aim of this paper is to provide fresh evidence on the effects of mergers among the largest pharmaceutical companies on their innovation performance. While most the pre-

[1] In this chapter, I collected, constructed, cleaned and analysed the data. I also contributed in writing up the literature review, the data description and the empirical specifications and results.

vious studies have used data at firm level, we investigate how mergers affect the people working in the research labs of big pharma. In particular, we are interested in understanding: i) if rate of job separation is higher around the period of mergers; ii) whether there are significant changes in the productivity of both inventors that stay or that leave the newly formed companies.

There are few industries that have been shaped more by mergers and acquisitions (M&As) than pharmaceuticals. Recent empirical works suggest that mergers among big Pharmaceutical Companies have on average, a negative effect on the research effort and innovation performance of consolidated companies. In a study of the 25 most important mergers involving "big pharma" between 1988 and 2004, Ornaghi (2009b) finds that consolidated companies tend to perform worse than a control group of non-merging firms in terms of market value, R&D expenditure, number of patents and patent productivity. There are two problems that most of the empirical studies of the effects of mergers need to deal with. First, it is hard to establish a causal link between mergers and following performances because of the difficulties in constructing the counterfactual outcomes of those firms not merged. For instance, the most common methodology used to evaluate the causal effect of mergers, the "Average Treatment Effect", rests on the assumption that individuals used in the control group are not affected by the treatment, but this assumption is questionable when studying the effects of mergers between large innovative companies because the control group will have to be drawn from firms that are competitors in present and/or future markets[2]. In several industries like pharmaceuticals, the construction of the control group is also hampered by the fact that may be few large companies have not been affected by M&As, thus restricting the pool of firms that can be used to construct the counterfactual.

[2] Chon and Linnemer (2012) propose a method of building control groups which is based on the geographic distance and the degree of exposure of competitors of the merging companies.

Second, and more importantly, investigating the average effect of a merger is problematic from a conceptual point of view as there is not such a thing as an "average" merger and averages may not be very informative if there is a lot of heterogeneity in the post-merger innovation performance. This is confirmed with the set of graphs in figure 4.1 that show us the evolution of the average (blue line) of the R&D, Market Value (MV), Patents and Inventors two years before and after the merge, compared to the dynamics of different percentiles (p25%(red), p50%(green), p75%(yellow)) of the distribution of these variables across our sample of merging companies[3]. These statistics were calculated using the list of mergers reported in appendix of chapter 3. The year of the merge was normalized to zero in order to compare all the deals between pharmaceutical companies before and after the merge.

This can explain why averages may not be informative for decision makers. For instance, there is large evidence about the so-called "Dunning-Kruger effect", a cognitive bias whereby individuals overestimate their own qualities and abilities, relative to others. In similar fashion, knowing that the mergers are not successful on average may not dissuade a over-confident manager to take over a competitor. Managers (but also for regulators) are more interested in understanding whether there are variables that can explain differences in post-merger outcomes.

This paper represents a step forward in addressing the technical and conceptual problems described above. First, given that our data allow us to observe the mobility and research productivity of thousands of scientists in the pharmaceutical industry, the performance of inventors affected by a merger can be compared with a large pool of inventors that work in non-merging companies. The latter can be safely assumed to represent a reliable counterfactual of productivity in the absence of a merger. Second, we advance our understanding of the success or failure of mergers by investigating whether the rate

[3]To see the full list of Mergers and Companies see table A.16 in the appendix.

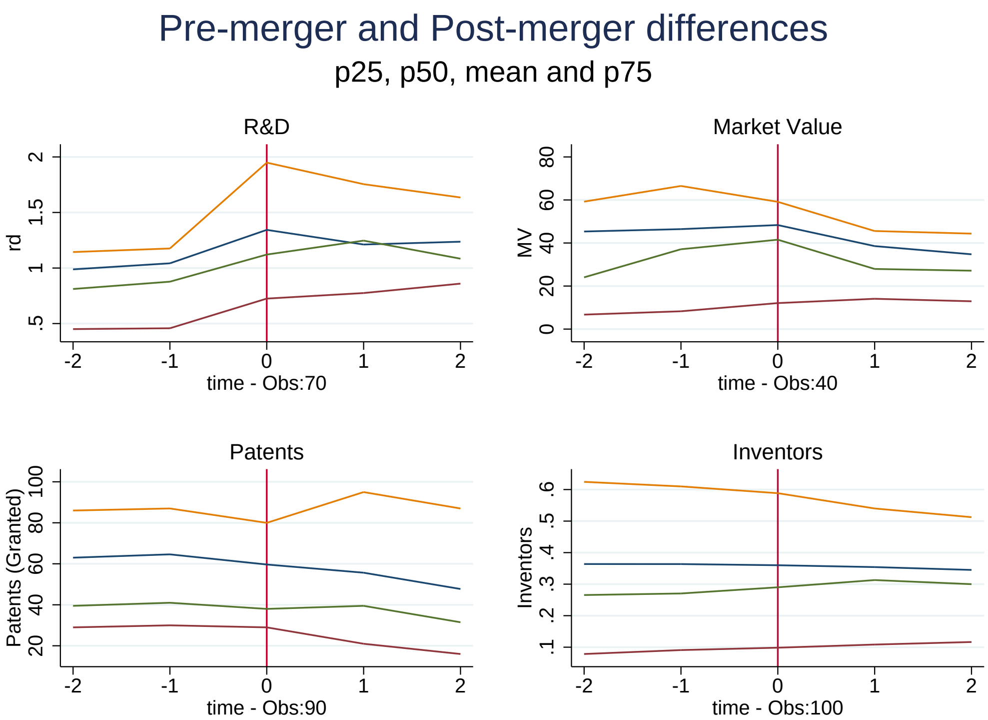



Figure 4.1: Pre-merger and Post-merger differences
Percentile 25 in Red, Percentile 50 in Green, Mean in Blue and Percentile 75 in Orange.

of separation of inventors can explain differences in post-merger outcomes.

Our empirical analysis uses the patent data of the European Patent office (EPO) for the period 1978 to 2008. One advantage of these data compared to those of the US Patent and Trademark Office (USPTO) is that the latter only cover the period up to 2004. The extra four years are particularly important given that several large mergers took place at the beginning of the new millennium. In the data we observe the applicant name (ie. the company that apply for the patent) and the date of the application and also the name and the full address of the inventors of the patent. By looking at the affiliation of inventors over time we can track the mobility of scientists over time.

Focusing on the pharmaceutical industry to investigate the relationship between mergers and innovation presents several advantages. First, pharmaceutical companies have been involved in several mergers over the last three decades[4]. Second, this is one of the sectors with the highest intensity in R&D and innovation is a critical factor to ensure preservation and improvement of human health and well-being. Finally, as "big pharma" tend to patent prolifically, it is possible to construct detailed measures of inventors mobility and innovation performance.

Our results show a negative relationship between inventors mobility and post-merger outcome. On average, mergers have a negative impact on the productivity of inventors in terms of the number of patents and productivity. The post-merger patent performance is negatively affected by those inventors that move and stay after the merge. Also, inventors that come from the target company and stay, impact more negatively the productivity performance, compared to the inventors that are from the acquirer part of the merge. The remainder of the paper is organised as follows. Section 2 reviews the literature and section 3 discusses the data. Section 4 introduces the methodology and the remaining sections 5 and 6 present the results and conclusions.

[4]According to statistics from the Institute of Mergers, Acquisitions and Alliances, three of the ten top mergers in the first decade of this century were among pharmaceutical companies while the merger between Pfizer and Warner Lamber in 1999 was the second largest merger in the previous decade

## 4.2 Theoretical background

There are different streams of literature that are relevant for our research. First, some studies that have looked at the the relationship between mergers and innovation in the pharmaceutical industry. Comanor and Scherer (2013) suggests that the reasons why large mergers adversely affect R&D investment and the probability of discovering new drugs is because the cost-cutting practices that often follow a merger jeopardize the possibility of developing a “parallel path” of research i.e., the pursuit of different approaches when tackling any given medical problem. While parallel paths have been proved to be very important to deal with the uncertainties inevitably involved in the discovery of new drug, it is common for managers to analyse the portfolios of consolidated companies and to prune parallel projects because (often wrongly) considered as “duplicative”. The “parallel paths” thesis is naturally linked to the finding by Ornaghi (2009a) that technology relatedness - i.e. the level of similarities between the research projects of acquirers and targets - is negatively correlated with post-merger performances, to the extent that technological relatedness is a measure of the “parallel paths” developed by merging companies.

Several studies in the management literature have found that managers ability of forging a common corporate culture is very important in the success of consolidated companies (see Gomez-Mejia and Palich (1997) among others). These studies have documented how cultural dissonances and other integration problems disrupt the established routines of merging parties and seriously compromise the innovation performances of consolidated companies[5].

[5] Cultural clashes are cited as one of the main causes for the poor performance of Pharmacia, where US, Swedish, and Italian subcultures had to co-exist after the merger. Similarly, Aventis faced the challenge of integrating German, French, and American business cultures (source: “Innovation in the Pharmaceutical Sector”, November 8, 2004, Charles River Associate, p. 112 )

Another stream of literature has looked at the effects of mergers on inventors mobility and productivity. In a study for the mechanical and electrical engineering, and the chemical industry, Ernst and Vitt (2000) find that one third of *key inventors* left the company and half of the inventors that stayed in the new company, changed their working position with a decline in their patent productivity. But a different picture seems to emerge when looking at small companies where key inventors are not only more likely to stay but also experience a higher productivity in the period after the merger.

In an empirical study of the pharmaceutical industry in the U.S, Paruchuri et al. (2006) investigate the effects of an acquisition on the productivity of 3.933 inventors between 1979 and 1994, find that inventors that lose their social status and centrality, and also those with the technological expertise that does not match the technological field of the acquiring firm, face a strong disruption on their productivity. Similarly, in a study of 673 inventors working in different European companies that has been acquired between 2000 and 2001, Hussinger (2007) finds that key inventors of the targeted firm are more likely to remain in the same firm. The author also finds that on average, the productivity of researchers that stay is higher than those that leave the company and that the productivity of inventors involved in M&A is not lower than the control group of scientists not involved in an acquisition process. As an extension, Hussinger (2012) investigates the role played by the acquiring firms' absorptive capacity in affecting the productivity of the inventors working for the target company. She finds that the absorptive capacity helps acquiring firms to recognize, assimilate and exploit the knowledge produced by researchers of acquired companies.

In a recent paper, Colombo and Rabbiosi (2014) explore the technological similarities between the firms involved in the merge and the reorganization of the R&D activities after the M&A. The data is composed by 31 horizontal acquisitions and 62 firms in Europe between 1987 and 2001 in the medium and high technological industries. The authors find that technological similarities between the firms involved in the acquisition, triggers a reorganization of the R&D activities and also a reduction of the R&D projects of the acquired firm plus a replacement of the R&D top manager. This replacement yields productivity improvements in the new company. They also find that the departure of R&D top managers of the acquiring firms does not lead to a disruption on the R&D activities of newly created firms. This paper goes against the standard evidence that argues that post-merger processes generate disruption in the R&D employees and harms the innovative performance (see Ernst and Vitt (2000)).

Some studies have investigated the characteristics of scientists that decide for any reason, to change company for any reason and the impact of this move on their innovation performance. In a study of inventors mobility (not necessarily triggered by a M&As) based on 3.049 inventors in Germany, Hoisl (2007) finds that mobile inventors tend to be more productive than those inventors that never changed their research lab. In addition, she also finds that an increase in productivity reduces the possibility of moving. In another paper, Palomeras and Melero (2010) explore the main causes that influence the mobility of inventors working for IBM between 1970 and 1999, and they find that the quality of inventors work is the main driver of inventors mobility. Also, the authors found that the complementarity between the knowledge of the inventor and of the other scientists, and the inventors' main area of research where the employer is not a strong competitor, are negatively related with the probability of moving.

Our study differs from the literature above in two important dimensions. First, the number of observations we use to analyse inventors mobility and productivity is drastically higher than those used in previous studies. Given that pharmaceutical companies tend to patent prolifically, our dataset includes more than eighty thousands inventors observed over the period 1978 to 2008. Moreover, the fact that most of big pharma has been involved in M&As (and some of them in multiple mergers) implies that a large proportion of these inventors have been experiencing a consolidation. Second, we will try to establish a link between the inventors mobility and post-merger performances of those inventors that abandon the new entity formed due to internal restructuring. In particular, we will compare how patents productivity in the industry is affected by inventors that leave the new research teams either from the acquirer or target side of the merge.

## 4.3 Data and Variables

The dataset used in our empirical exercise comes from EPO. We retrieve information on the number of patents applied by pharmaceutical companies for the period 1978 to 2008 together with the name and address of scientists named on each patent. All the patents in EPO can be classified using either the Derwent World Patents Index (DWPI) or the International Patent Classification (IPC). The first classifies each patent according to its functionality and therapeutical area while the latter classifies them according to the different areas of technology to which they belong.

As a note of clarification, in the rest of the paper, we will use the subindex, $k$ to indicate the inventor, $i$ to indicate the company, $Acq$ to indicate the acquirer and $Tar$ for the target, whereas the subindex $M$ refers to the year of the merge.

Using the EPO data allow us to shed light into the effects of mergers on innovation at inventors level. The following section describes the general movements of inventors and also how these movements are related to all the big mergers in the pharmaceutical industry.

### 4.3.1 Inventors Mobility

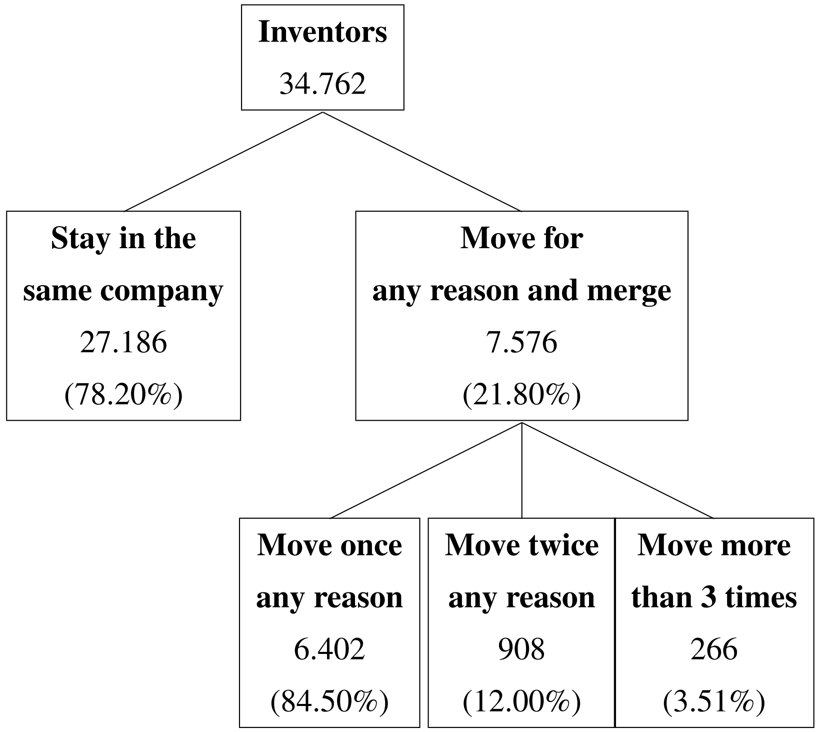
In our final EPO database we observe around eighty thousand inventors working for pharmaceutical companies in the EPO between 1978 and 2008. Inventors with only one patent application are around forty six thousand. These scientists are used to calculate the total number of inventors working in each of the companies of the pharmaceutical Industry, but they can not be included in the analysis of inventors mobility given that they could not be tracked over time[6].

In order to trace inventors over time we construct a unique id for each of the inventors that have applied for a patent. As a first step in the construction of the inventors' id, we follow one part of the methodology suggested in Trajtenberg et al. (2009) in order to standardized all the names[7]. We then use the family name, the first and the middle name to distinguish inventors with similar names, ie. to avoid the so-called "John Smith" problem[8]. Finally, we use the information of the address of the inventor and the company affiliation to further increase the accuracy in constructing the unique id of the inventors.

[6] On average, an inventor works for 5 years in a company, which allow us to identify those inventors that can not be tracked and counted in the pharmaceutical company. For example, an inventor that only has a patent application in the year 2000, will be counted from 1995 to 2005.

[7] For example, names from scandinavian countries presented different non letter characters were modified using the encoding debugging chart to transform these characters into letter characters.

[8] This refers to the problem that most common names can affect the proper identification of inventors due to the fact that several scientists can have the same name.



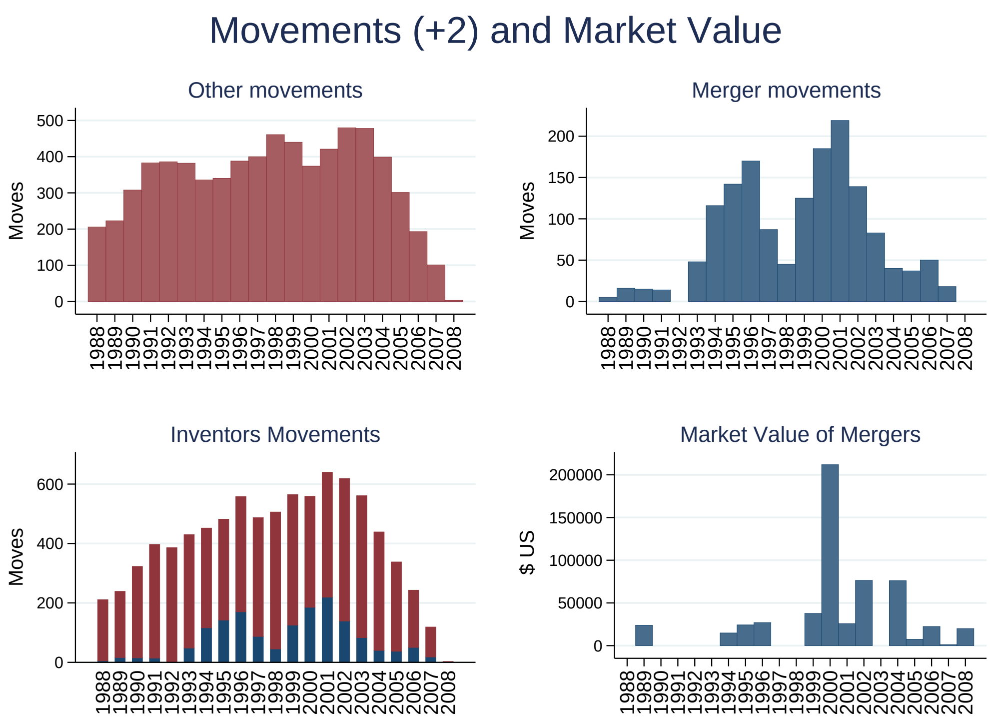

Tree 1: Inventors general mobility

After an extensive work in the construction of the inventors id's, we end up with a sample of 34.762 inventors from 1978 to 2008, for those that have at least two patent applications in different years (see tree 1). Around 22% of the inventors changed company whereas the remanning 78% stayed always in the same company. We define each inventor mobility as the change from one company to another due to the effect of a merge, looking for better job conditions, firing, restructuring during financial crisis, etc. The majority of inventors who moved (84.50%), changed their company once in their professional lives and on average, the time in which they remained in the same company is around 5 years.

Horizontal mergers in the Pharmaceutical Industry have been a dominant characteristic since early nineties[9]. The bottom right graph of figure 4.2 presents the total value

[9]See list of mergers in the appendix of chapter 3.

Figure 4.2: Merger Size and Movements




of the most important deals registered in the industry between 1989 and 2008. The first wave of mergers started in 1994 until 1996 followed by a second, long wave of mergers starting from 1999 and extended until 2004 (see also Morton and Kyle (2012)). A total of 16 pharmaceutical merger deals between the top 20 large companies of the industry was registered in this second wave. During this wave three of the ten top mergers in the first decade of this century were registered in the pharmaceutical industry and in particular, the merge between Pfizer and Warner Lamber in 1999 was the second largest merger of the nineties.

Mergers among big companies have pervasive effect on the newly formed companies, from administrative staff to sales representative passing through the scientist in the labs. The impact of M&As on the R&D activities is confirmed by John L. LaMattina the former president of Pfizer Global Research and Development department, who argues that recent consequences of M&As is not only on reduction and cuts in R&D founds, but also, the elimination of entire research laboratories[10] (see LaMattina (2011)).

### Measuring mobility of inventors due to the effect of a merger: the "Average Rule"

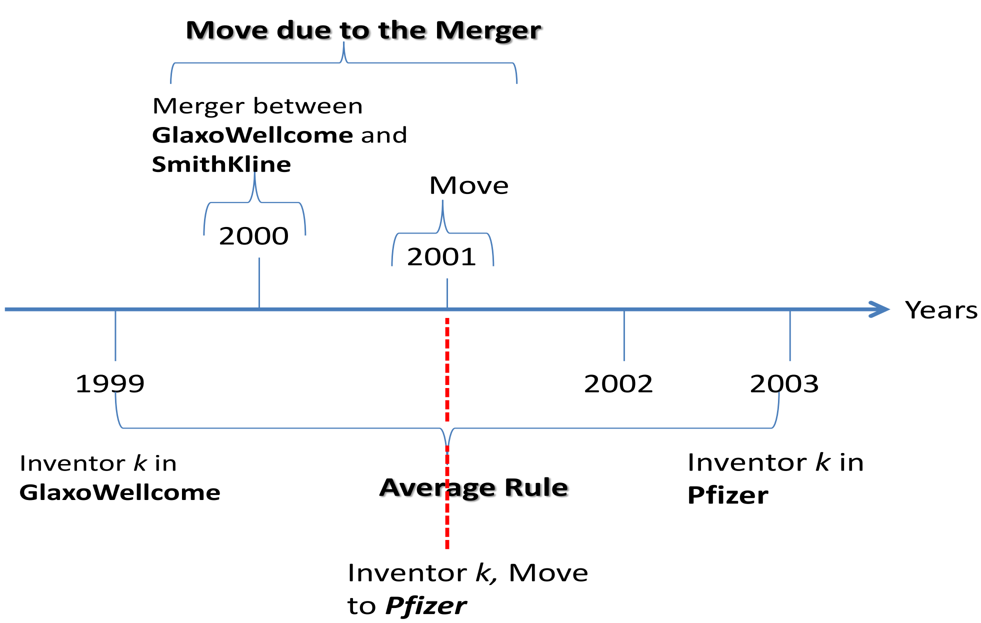
A (possible unwanted) effect of mergers is the increase mobility of inventors that these deals generate. In order to investigate the effects of mergers on patent productivity of inventors leaving the newly formed company we construct a measure of mobility due to mergers. For this we count the number of inventors that leave merging companies up to two years after the merger. Given that we do not observe applications at yearly frequency, we can not identify the exact year a scientist leaves a company. For this we assume that the change of company takes place at the average between the last year we observe the inventor in a company $i$ and the first time we observe this inventor in company $j$. For instance, if in 1999 we observe a patent application from inventor $k$ working for GlaxoWellcome, and in 2003 we observe a patent application from inventor $k$ but this time working for Pfizer, we assume that she moves to Pfizer in the year 2001 ("average rule", see figure 4.3). Because GlaxoWellcome is involved in a merger with Smithkline in year 2000 and the inventor is assumed to move in 2001, we classify the move of inventor $k$ as "due to a merger"[11]. If, following this "average rule" the inventor $k$ was found to move from GlaxoWellcome to Pfizer in 2003, we would have considered

[10] In the U.S, many research labs were closed such as the one in Kalamanzoo, Michigan (formerly a lab for Upjohn) Ann Arbot, Michigan (formerly a lab for Warner-Lambert), and Skoikie, Illinois (formerly a lab for Searle). In these labs were located thousands of researchers and many of the dominant drugs of the company such as Lipitor, Norvasc and Viagra. See LaMattina (2011), p. 560. Recently, the bid offered by Pfizer in 2014 to acquire AstraZeneca was rejected for the potential damage on the research activities and cut jobs in the British company. Another example that support this effect is the case of GlaxoWellcome that closed Wellcome's main research lab in the U.K.

[11] We also calculate, for robustness checks, the cases up to one and three years after the merge, see graphs in appendix of chapter 3. For the sake of clarity, the paper uses up to two years after the merge.

this as a normal move, defined simply as *Move* (because it takes place 3 years after the merger). Following this method, we compute a measure of mobility due to a merger for any inventor $k$ that belongs to the acquirer, taking a value of 1 if the inventor moves because of the merger using the “average rule”, otherwise it takes a value of 0 and it is defined as *Move_Mrg_Acq*. If the inventor belongs to the target company we use the same “average rule” that takes a value of 1 if the inventor moves because of the merger otherwise it takes a value of 0, and we defined it as *Move_Mrg_Tar*. Finally, a measure of mobility for any other reasons different from a merger, takes a value of 1 if the inventor has moved simply to another company, otherwise is 0, and we call this variable simply as *Move*.

Figure 4.3: Average Rule




Similarly, we compute the number of inventors that carry on working for either the acquirer (*Stay_Acq*) or the target (*Stay_Tar*) after a consolidation in the newly merged company. For example, if we observe a patent application from inventor $k$ in year 1999 and in 2003 with, GlaxoWellcome and GlaxoSmithkline respectively, we assign this inventor to the group of scientists staying in the acquiring firm. In this way, *Stay_Acq* takes a value of 1 if the inventor stays in the same company after the merger and comes from the acquirer side of the deal. In a similar way, an inventor that comes from the target side and stay in the newly merged company will take a value of 1 otherwise 0. The name for this variable is *Stay_Tar*.

The number of scientists moving because of the merger or for other reason are showed in figure 4.2[12]. We identify 8.557 movements in the whole industry between 1988 and 2008, where 1.554 of these movements where due to the effect of mergers[13]. For the merger period that we consider for the analysis between 1988 and 2008, around 18% of the movements are explained by the merger deals whereas the rest 82% of the movements in the industry are due to other reasons such as the change of company due to better job conditions, payments, etc. These movements are illustrated in the first top graphs of figure 4.2. The top left graph shows a stable level of movements not explained by mergers, whereas the top right graph represents the movements of mergers with a more unstable pattern and with different peaks[14]. Interestingly, these peaks are more pronounced during the two mergers waves of mid-nineties and early 2000. For instance, in the second wave of mergers between 1999 and 2004, the most important and high value mergers deals in the industry were presented. Cases like GlaxoWellcome-SmithklineBeechanm in 2000, or Pfizer-WarnerLambert also in the same year, were registered as the top transactions during this second period of mergers[15]. Therefore,

[12]For robustness checks, see appendix of chapter 3, for the cases of movements of one and three years after the merge. These results show the same pattern for the movements due to the effect of mergers and movements for other reasons.

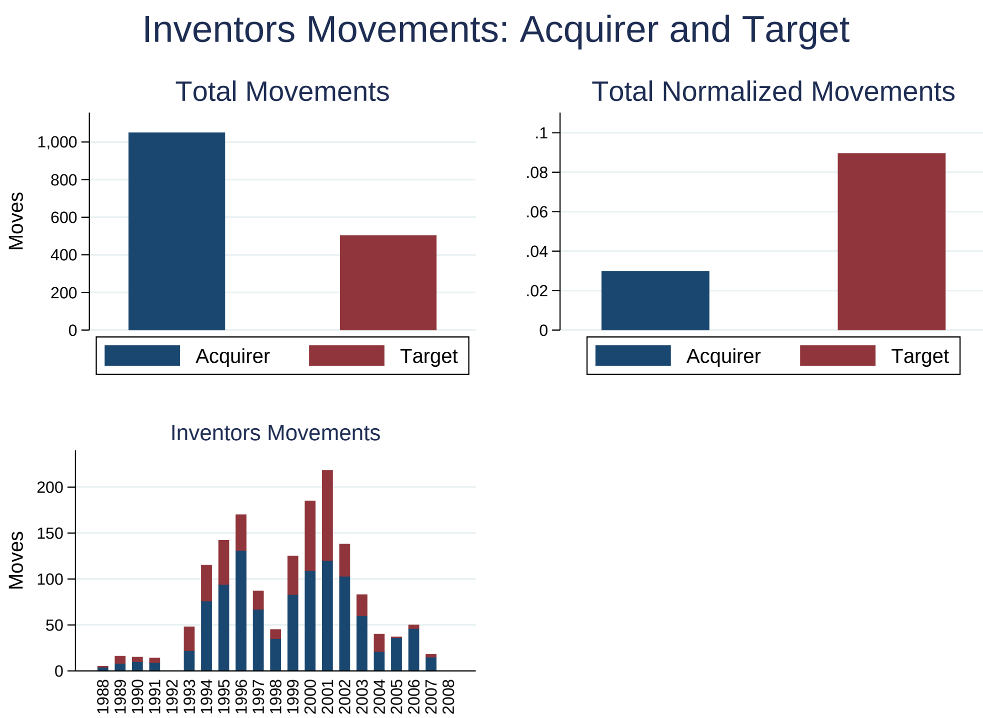
[13]Note that this figure is higher than those reported in the Tree above because there the unit of analysis is an inventor, while here we refer to movements.

[14]The decline in the number of movements towards the last year is due to a truncation problem.

[15]The two deals summed together a monetary value of $US 163.413 millions.

these two important mergers in addition to the other mergers of the industry, have impacted the mobility of inventors in the years 2000, 2001 and 2002. For example, in 2001, one year after the big merger of the second wave, approximately the total number of movements of scientist and researchers, was the highest in the period analyzed. In this year, nearly 30% of these movements in the big pharmaceutical industry were explained by the effects of mergers.

Figure 4.4: Merger Movements




With respect to the merger movements, the bottom left graph of figure 4.4 classifies the movements between the acquirer (blue) and the target (red). The number of movements is higher for the acquiring firms as shown in the top left graph. However, when we normalized the total number of movements by the total number of inventors of the merging companies one year before the merger, we find that there is a higher mobility in the target company. This might indicate that the acquirer are more likely to retain their inventors compare to the inventors of the target. The figures above show that mergers have a major impact on inventors mobility and they confirm the importance of understanding how inventors, as one of the pillars in the innovation process of the industry, are affected by mergers.

### 4.3.2 Inventors Productivity

To study the inventors' performance we classify them between top and not top according to their productivity over their life time. Inventors' productivity is measured as the ratio between the total number of patents granted and the total number of years from the first to the last patent application registered in the EPO as:

$$Patent\_Prod_k^{Granted} = \frac{Num\_Patents_k}{Last_{year} - First_{year}} \tag{4.3.1}$$

We define as top inventors those whose productivity is in the top 30% percentile of the distribution. As shown in table 4.1, top inventors are those with an average of 0.50 patents per year of work.

Table 4.1: Inventors' productivity

| **Percentiles** | **Average Patents per year** |
|---:|---:|
| 10% | 0 |
| 25% | 0.11 |
| 50% | 0.33 |
| 70% | 0.50 |
| 90% | 1 |
| 99% | 2.5 |
| **Mean** | **0.45** |
| **Inventors** | **34.762** |

Table 4.2 describes how mobility change among top and no top inventors with different years of experience. As before, years of work has been computed using the time between the first and the last patent application of the inventor in the EPO. As expected, the average mobility tends to increase with experience. However, top inventors mobility seems to increase less with more years of experience compared to the high mobility of no top inventors presented in the last group of experience. This might suggest that pharmaceutical companies tend to retain their most productive inventors (i.e., with better job conditions, payments, etc.) whatever the reason of movement. One reason why pharmaceutical companies retain the most highly valued inventors might be explained by their high levels of skills and knowledge in biochemistry and pharmacology that provides pharmaceutical firms with potential rewards in developing new drugs, discovering new molecules or patenting new scientific knowledge (see Paruchuri et al. (2006) and Nerkar and Roberts (2004)).

In order to explore further how years of experience ($t$) influence the patents granted by inventor, we evaluate inventors' productivity across his professional life. To do that, we assume that the number of patents granted (P) per inventor follows a Poisson distribution as:

$$Pr(P = p \mid \lambda) = \frac{e^{-\lambda}\lambda^{p}}{p!} \tag{4.3.2}$$

Where the parameter $\lambda$ is the expected number of patents of inventor $k$. This parameter depends on a function of years of experience $h(t_k)$ and a set of dummies such as the inventor place of residence and company, $x_k^{'}\beta$:

$$\lambda_k = E[P_k \mid t_k, x_k] = e^{h(t_k)+x_k^{'}\beta} \tag{4.3.3}$$

The residence set of dummies allows to control for all the difference across countries

Table 4.2: Mobility of Inventors by years of experience

| **Group 1 (0-5 yrs)** | | | | | |
|---|---|---|---|---|---|
| | Mean | Median | p90% | p99% | Inventors |
| All Inventors | 0.108 | 0 | 1 | 1 | 15844 |
| Top Inventors | 0.092 | 0 | 1 | 1 | 6859 |
| No top Inventors | 0.121 | 0 | 1 | 1 | 8985 |
| **Group 2 (6-10yrs)** | | | | | |
| | Mean | Median | p90% | p99% | Inventors |
| All Inventors | 0.289 | 0 | 1 | 2 | 9791 |
| Top Inventors | 0.195 | 0 | 1 | 2 | 3017 |
| No top Inventors | 0.330 | 0 | 1 | 2 | 6774 |
| **Group 3 (11-15yrs)** | | | | | |
| | Mean | Median | p90% | p99% | Inventors |
| All Inventors | 0.426 | 0 | 2 | 3 | 5125 |
| Top Inventors | 0.319 | 0 | 2 | 3 | 1491 |
| No top Inventors | 0.470 | 0 | 2 | 3 | 3634 |
| **Group 4 (16-20yrs)** | | | | | |
| | Mean | Median | p90% | p99% | Inventors |
| All Inventors | 0.549 | 0 | 2 | 3 | 2660 |
| Top Inventors | 0.362 | 0 | 2 | 3 | 809 |
| No top Inventors | 0.630 | 0 | 2 | 3 | 1851 |
| **Group 5 (21 or more yrs)** | | | | | |
| | Mean | Median | p90% | p99% | Inventors |
| All Inventors | 0.721 | 0 | 2 | 4 | 1342 |
| Top Inventors | 0.635 | 0 | 3 | 6 | 447 |
| No top Inventors | 0.764 | 0 | 2 | 4 | 895 |

whereas the company dummies control for the heterogeneity between pharmaceutical companies. Our specification of function $h$, follows a quadratic expression that allow us to explore the relationship between the innovator patents production and their specific experience. Taking the log for each side of equation 4.3.3 yields the following cross-section model specification:

$$ln\lambda_k = c + \alpha_1 t_k + \alpha_2 t_k^2 + x_k^{'}\beta \quad (4.3.4)$$

Empirical specification (eq. 4.3.4) allows to understand the relationship between the innovation performance of inventors and their years of research experience. The results of this simple empirical specification are shown in table 4.3. All our estimated coefficients are statistically significant and with the expected sign. The results confirm that granted patents are increased with more years of experience with a decreasing rate. The $\chi^2$-statistics shows us that the null hypothesis for all coefficients years of work experience and years of work experience squared are equal to zero is rejected at the 1% level for all the different versions of equation 4.3.4 estimated.

Table 4.3: Inventors Patents Poisson Results

| | **1** | **2** | **3** |
|---|---|---|---|
| Experience | 0.199*** | 0.191*** | 0.188*** |
| | (0.005) | (0.005) | (0.004) |
| Experience$^2$ | -0.003*** | -0.003*** | -0.003*** |
| | (0.00) | (0.00) | (0.00) |
| Firm | no | yes | yes |
| Residence | no | no | yes |
| Constant | -0.214*** | -0.520*** | -0.622*** |
| | (0.022) | (0.051) | (0.087) |
| $\chi^2$**-statistics** | 8622.02 | | |
| **Pseudo**$R^2$ | 0.2319 | 0.2913 | 0.3098 |
| **Inventors** | 34.762 | 34.762 | 34.291 |

$^*p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors are given in parentheses.

### 4.3.3 Panel data framework

In addition to these variables, we set up a panel data structure to study the post-merger effects on innovation. In particular, we study the effects of mergers at the inventors' level for applications and patents granted. To analyse these effects, we construct a panel-data set. The time period of our panel structure is based on *phases*. In general, we divide inventors' life in at least two phases to construct a panel data structure. These phases are constructed based on the time period an inventor $k$ has been working for a company. For the case when the inventor has been always working for the same pharmaceutical company and never involved in a merger, we take the average of her life work experience as the starting year of the second phase. For inventors involved in mergers, we create a phase any time the inventor faces a merger or a change of company. For example, in figure 4.3 inventor $k$ has two phases, one that goes from $1999$ to $2001$ and a second phase that goes from $2002$ to $2003$. In this case, the phase has been explained due to the effect of a merger, but it could also be the case that this inventor $k$ has previous or other post phases due to other types of movements. We use $\tau$ to represent the number of phases that an inventor has (i.e., in this example, $\tau = 1, 2$). For each inventor involved in a merger we assigned a pre-merger phase and post-merger phase whether she moves or stays. For each of these *phases* we measure the number of years that the inventor has in a particular *phase*, the patents granted to the inventor and the total number of applications during that *phase* (i.e., for example, for $\tau = 1, 2$). In addition, we calculate the productivity of each inventor in each of the phases using equation 4.3.1, that allow us to calculate the variables *Patents Productivity* and the *Applications Productivity*.

Table 4.4 is divided in different types of data according to the different empirical specifications. The first part summarise all the panel data framework, where the dimension of agents is specified by $i$ the inventor and $\tau$ correspond to the time/phases. The general mobility is also structured as a cross-section dataset for other types of analysis.

### 4.3.4 Cross-section framework

In order to investigate the characteristics of why an inventor is likely to move we construct a set of variables that allow us to understand this probability. The variable *Move* takes a value of 1 when the inventor moves to another pharmaceutical company for any reason, otherwise it takes a value of 0. With respect to *Move_Acq* and *Move_Tar*, these are two dummy variables that takes a value of 1 if the inventor moves to another company, either she is coming from the acquirer or target company, otherwise is 0[16]. The variable *Acquirer*, is a dummy variable that takes the value of 1 if the inventor comes from the acquirer company, otherwise is 0.

Finally, we also construct some variables that will allow us to understand the probability that an inventor stops applying for patents. In order to investigate this, we measure a variable called *"Dead"* that takes a value of 1 for the last application of a patent observed of inventor $k$, otherwise it takes a value of 0. We measure the accumulated years of experience reached from one patent application to the next one called *Exp_acum* and also it includes the squared of *Exp_acum* to investigate no linearities. In addition to these variables, we also add the total number of patents applications accumulated until a new application is made called as *Cum_Patents*. Finally, we also include a dummy variable that takes a value of 1 if the difference between a patent application and the year of a merge is less than 2 years, otherwise it takes a value of 0, and we called this variable simply as *Merger*.

In the next section we specify the empirical models that use these types of data structures for all the different types of analysis.

[16] These variables are presented as a result in table 4.5.

Table 4.4: Descriptive Statistics

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| ***Productivity (panel data)*** | | | | | |
| Applications phase | 73.407 | 3.55 | 5.73 | 1 | 363 |
| Applications productivity | 73.407 | 1.09 | 2.41 | 0.03 | 181.5 |
| Granted Patents | 73.407 | 1.622 | 3.063 | 0 | 50 |
| Granted Patents Productivity | 73.407 | 0.456 | 1.083 | 0 | 35 |
| Years of exp per phase | 73.407 | 4.814 | 2.819 | 1 | 29 |
| Years of exp per phase | 73.407 | 31.131 | 47.197 | 1 | 841 |
| ***Mobility due to a merger (panel data)*** | | | | | |
| $Move\_Mrg\_Acq$ | 73.407 | 0.016 | 0.128 | 0 | 1 |
| $Move\_Mrg\_Tar$ | 73.407 | 0.007 | 0.087 | 0 | 1 |
| $Stay\_Acq$ | 73.407 | 0.098 | 0.297 | 0 | 1 |
| $Stay\_Tar$ | 73.407 | 0.021 | 0.144 | 0 | 1 |
| ***Moving (cross-section)*** | | | | | |
| Move | 10.548 | 0.167 | 0.373 | 0 | 1 |
| Move Acq | 8.432 | 0.144 | 0.352 | 0 | 1 |
| Move Tar | 2.137 | 0.262 | 0.440 | 0 | 1 |
| Acquirer | 10.548 | 0.797 | 0.401 | 0 | 1 |
| ***Stop observing an inventor (cross-section)*** | | | | | |
| "Dead" | 142.917 | 0.243 | 0.429 | 0 | 1 |
| $Exp\_Acum$ | 142.917 | 4.758 | 5.194 | 0 | 29 |
| $Exp\_Acum^2$ | 142.917 | 49.629 | 92.832 | 0 | 841 |
| $Cum\_Patents$ | 142.917 | 4.172 | 7.525 | 0 | 190 |
| Merger | 142.917 | 0.200 | 0.400 | 0 | 1 |

## 4.4 Empirical Models and Estimation

Before describing the empirical specifications, it is important to clarify that we will refer to the number of applications and patents granted as applications and patents, respectively.

To understand the mobility of inventors that leave company after the merger, we estimate a specification which evaluates the probability of inventors moving as a function of their levels of productivity and experience. Accordingly, we use the following probit model:

$$Prob[Move = 1|\mathbf{X}] = \int_{-\infty}^{\mathbf{X}'\alpha} \phi(w)dw = \Phi(\mathbf{X}'\alpha) \tag{4.4.1}$$

where $\phi(w) = \left(\frac{1}{\sqrt{2\pi}}\right)e^{\frac{-w^2}{2}}$ represents the standard normal density distribution and $\Phi$ is the normal distribution. The covariates $\mathbf{X}$, include five different groups of experience that are increasing with years. For example, the first group captures inventors with less than two years whereas the last group contains inventors with more than ten years of experience in a research lab. In the same way $\mathbf{X}$ also includes five groups of productivity. In the first group we include all inventors whose productivity is zero and the last group includes all the inventors with a patent productivity greater than two. The coefficients of our second specification are estimated using the maximum likelihood method.

Our main objective is to understand how mergers affects the performance of both inventors staying and inventors departing from the newly formed company. For this we define a specification that compares the number of applications or patents granted to inventors before and after the merger. We estimate this specification using two different econometric models: Count data models (Poisson or Negative Binomial) and fixed-effects model.

Similarly to equation 4.3.3, our count data model is:

$$\lambda_{k\tau} = E[P_{k\tau} \mid x_{k\tau}] = e^{f(t_{k\tau})+x_{k\tau}'\beta} \tag{4.4.2}$$

where $\tau = 1, \ldots, T$, is the number of phases of each inventor as explained in the previous section. $x_{k\tau}$ represents all the covarieties related to mobility due to mergers *Move_Mrg_Acq* and *Move_Mrg_Tar*, and the inventors who stay in the new merged company *Stay_Acq* and the inventors that come from the target side of the agreement, *Stay_Tar*. $f(\cdot)$ is function that takes a quadratic specification with the years of work and years of work squared in each pharmaceutical company. Taking logs we obtain the following specification:

$$ln\lambda_{k\tau} = \gamma_1 t_{k\tau} + \gamma_2 t_{k\tau}^2 + x_{k\tau}^{'}\beta \tag{4.4.3}$$

An important assumption of the Poisson model is that the variance equals the mean, $\lambda_{kt} = E[P_{k\tau} \mid x_{k\tau}] = Var[P_{k\tau} \mid x_{k\tau}]$. However, this assumption does not hold for the variables we are using in our sample. In particular, there is a large difference between the variance and the mean for our applications and patents variables registered. This overdispersion problem leads to a bad specification of the variance-covariance matrix. A way to tackle this issue is implementing an estimation of 4.4.3 using a negative binomial regression. Using this approach the $Var[\cdot]$ is independently adjusted of the mean using a parameter $\theta$ that controls for the overdispersion problem[17] as $Var[P_{kt} \mid x_{k\tau}] = E[P_{k\tau} \mid x_{k\tau}](1 + \theta P_{k\tau} \mid x_{kt})$. Therefore, with this adjustments, the empirical model in expression 4.4.3 is our second (II) specification which represents a static fixed effect count panel data model. This empirical specification allow us to investigate the effects of mobility because of the merge on the innovation performance of the inventor.

The second econometric approach used to evaluate the effect of mergers on inventors productivity is a fixed-effects model:

$$y_{k\tau} = \alpha_k + x_{k\tau}^{'}\beta + \gamma_1 t_{k\tau} + \gamma_2 t_{k\tau}^2 + u_{k\tau} \tag{4.4.4}$$

[17] See Cameron and Heckman (1998) for a detail explanation.

Where, $y \equiv \{\text{Applications Productivity; Patents Productivity}\}$. The years of experience in each phase is represented by $t$ and $\alpha_k$ captures the unobserved heterogeneity across inventors that is likely to be correlated with the observed regressors and $u_{k\tau}$ is the disturbance term that assumes that $E[u_{k\tau} \mid \alpha_k, x_{k1}, \ldots, x_{kT}] = 0$. The set of covarieties in $x'_{k\tau}$ are conformed by all our mobility variables, *Move_Mrg_Acq* and *Move_Mrg_Tar* and all the stay variables, *Stay_Acq* and *Stay_Tar*. The model is estimated through the within estimator which yields consistent estimates of the $\beta$'s and $\gamma$'s of the fixed effect model. As a potential problem when the error term is potentially correlated over $\tau$ for a given inventor $k$, and/or a heteroscedasticity problem is likely to be present, we control these issues through robust standard errors estimations that allow us to make valid statistical inferences of our estimations.

Finally, we also investigate the probability that an inventor stops patenting due to the effect of mergers. In other words, the probability that we stop observing the inventor. In order to estimate this, we use a logit and a probit empirical specifications. For the probit specification we follow the same expression as 4.4.1. Regarding the logit empirical model we use the following specification:

$$Prob[y = 1|\mathbf{X}] = \frac{e^{\alpha'\mathbf{X}}}{1 + e^{\alpha'\mathbf{X}}} \tag{4.4.5}$$

where y takes a value of $1$ for the last application observed of inventor $k$, otherwise y takes a value of $0$. The covarieties in $\mathbf{X}$ are the accumulated years of the experience reached from one application to the next one, *Exp_acum*, and it also includes the squared of *Exp_acum*. In addition to these variables, we also add the total number of patents accumulated every time an application is made *Cum_Patents*. Finally, we also include a dummy variable that takes a value of 1 if the difference between a patent application and the year of a merge is less than 2 years, otherwise it takes a value of 0, *Merge*.

## 4.5 Empirical Results

### 4.5.1 Probability of moving

Table 4.5 reports the coefficients of the probit regression specified in equation 4.4.1. The specification compared the characteristics of inventors moving ($y$=1) to those that stay ($y$=0). The left column shows the results for both acquirer and targets, while the following two columns report the results for acquirer and target, respectively. In general, our probit model predicts correctly around 83% of the values of move, represented in this column. The coefficients confirm that inventors from the acquirer side are less likely to move compared to the inventors from the target side. Moreover, the higher the years of experience an inventor has in an specific research lab, the less likely they move from the company. This is confirmed through the different decreasing coefficients of groups of experience. In the same way, the productivity group coefficients follow the same pattern as the experience groups.

Table 4.5: Probability of moving

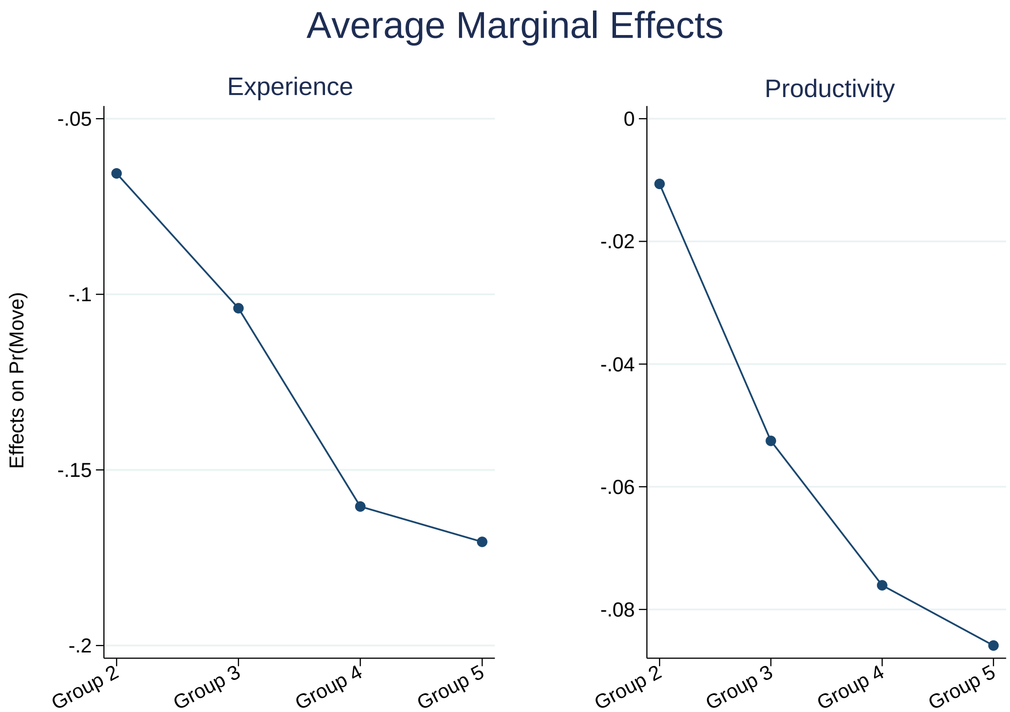
| | **All** | **Acquirer** | **Target** |
|---|---|---|---|
| Acquirer | -0.486*** | | |
| | (0.03) | | |
| Group experience 2 | -0.217*** | -0.435*** | 0.633*** |
| | (0.06) | (0.06) | (0.14) |
| Group experience 3 | -0.361*** | -0.613*** | 0.587*** |
| | (0.05) | (0.05) | (0.13) |
| Group experience 4 | -0.622*** | -0.929*** | 0.380*** |
| | (0.06) | (0.07) | (0.14) |
| Group experience 5 | -0.678*** | -0.959*** | 0.261* |
| | (0.06) | (0.07) | (0.14) |
| Group productivity 2 | -0.042 | -0.043 | -0.094 |
| | (0.03) | (0.04) | (0.06) |
| Group productivity 3 | -0.234*** | -0.334*** | -0.010 |
| | (0.05) | (0.06) | (0.11) |
| Group productivity 4 | -0.357*** | -0.460*** | -0.275 |
| | (0.08) | (0.09) | (0.19) |
| Group productivity 5 | -0.416** | -0.472*** | -0.74 |
| | (0.16) | (0.17) | (0.53) |
| Constant | -0.530** | -0.787*** | -1.444*** |
| | (0.24) | (0.30) | (0.42) |
| Residence | yes | yes | yes |
| **pseudo-R2** | 0.0527 | 0.0575 | 0.0287 |
| $\chi^2$ | 495.06 | 372.69 | 66.330 |
| **Observations** | 10.531 | 8.421 | 2.124 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors are given in parentheses.

To provide a better understanding of the different groups of experience and productivity, the average marginal effects of the probit model are plotted in figure 4.5. These graphs show how the impact on mobility is reduced with increasing experience and productivity.

Figure 4.5: Marginal Effects




Column 3 shows that the probability of moving of those inventors that work in the target firms increases with experience. However, the more years of practice in research labs an inventor has, the less is the increase on the probability of leaving the research team. This might help us to explain the results from previous section where the target inventors tend to move more than the acquirers. In addition, the levels of productivity seems to be not relevant as a driver of mobility for inventors from target firms. As far as the mobility of inventors working for the acquirer, we find that mobility is driven by the same factors that were explained for the general model of the left column of table 4.5.

### 4.5.2 Post-merger Inventors performance

Our last specification based on equations 4.4.3 and 4.4.4, investigates the relationship between inventors performance and mobility after the merge.

Table 4.6: Inventors performance after the merge

| | **Poisson** | **NB** | **FE** | **Poisson** | **NB** | **FE** |
|---|---|---|---|---|---|---|
| | *Applications* | *Applications* | *Applications Productivity* | *Patents* | *Patents* | *Patents Productivity* |
| $Move\_Mrg\_Acq$ | -0.067 | -0.051* | -0.074 | -0.347*** | -0.309*** | -0.219*** |
| | (0.05) | (0.03) | (0.18) | (0.06) | (0.04) | (0.03) |
| $Move\_Mrg\_Tar$ | 0.008 | 0.029 | -0.081 | -0.326*** | -0.268*** | -0.165*** |
| | (0.06) | (0.04) | (0.11) | (0.09) | (0.07) | (0.04) |
| $Stay\_Acq$ | 0.112*** | 0.036*** | 0.092** | -0.134*** | -0.261*** | -0.131*** |
| | (0.02) | (0.01) | (0.03) | (0.02) | (0.01) | (0.01) |
| $Stay\_Tar$ | 0.014 | -0.415 | -0.831 | -0.208*** | -0.229*** | -0.136*** |
| | (0.04) | (0.03) | (0.07) | (0.07) | (0.04) | (0.03) |
| Experience | -0.053*** | -0.028*** | -0.630*** | 0.047*** | 0.073*** | -0.227*** |
| | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) |
| $Experience^2$ | 0.006*** | 0.004*** | 0.028*** | 0.002*** | 0.000 | 0.010*** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Constant | | 1.393*** | 3.344*** | | 0.489*** | 1.183*** |
| | | (0.04) | (0.15) | | (0.07) | (0.06) |
| Firm | yes | yes | yes | yes | yes | yes |
| **R2 within** | | | 0.182 | | | 0.120 |
| **R2 overall** | | | 0.128 | | | 0.094 |
| $\chi^2$**p-value** | 0.000 | 0.000 | | 0.000 | 0.000 | |
| **Observations** | 73.345 | 73.345 | 73.407 | 58.776 | 58.776 | 73.407 |

$^*p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors are given in parentheses.

**NB**: Negative Binomial Regression.

**FE**: Fixed Effects.

The results on table 4.6 report the estimations for patents applications and patents granted with their respective productivity. The first three columns correspond to the applications part whereas the last three to the patents granted. For the latter, we find strong significant evidence that the performance of those inventors who move after is on average worse than those inventors that stay. Moreover, the results for inventors that stay in the newly formed company suggest that scientist working for the acquirer side experience a lower negative impact on the patents productivity with respect to the inventors from the target side.

To sum up, mergers affect negatively the productivity of both researches staying and scientist leaving the newly formed entity. On average, the post-patent performance is less affected by the inventors who stay in the new company compared to the ones that leave. To extend this results, columns 4 and 5, that correspond to our Poisson and Negative Binomial (NB) results, corroborate the results for the patents granted per inventor.

In the first three columns of table 4.6, we have also explored the results for patent applications and their respective productivity. These models are estimated using the same estimators as the granted patents part. Interestingly, it seems that the post-merger effects on patents applications are basically explained by those inventors who stay in the new merged company. The results show us that applications are strongly positive influence by the inventors that come from the acquirer side of the deal. This might suggest that the acquiring inventors take over the leadership of new research projects leaving aside the participation of the new researchers and scientist from the target company. This might be another signal of how hard is the merging integration process. The results also suggest an insignificant role by the target inventors in terms of patents applications in the new merged company which might suggest their marginal impact on the new pharmaceutical company.

### 4.5.3 Probability an inventor stops applying for patents

We also use a probit and logit models to estimate the probability that an inventor stops applying for patents after her company has been involved in a merge. Table 4.7 reports the main findings of the probability of "dead" of inventor $k$.

Table 4.7: Probability of "dead"

| | **logit 1** | **logit 2** | **Probit** |
|---|---|---|---|
| $Exp\_Acum$ | 0.129*** | 0.269*** | 0.125*** |
| | (0.00) | (0.01) | (0.00) |
| $Cum\_Patents$ | -0.091*** | -0.092*** | |
| | (0.00) | (0.00) | |
| Merge | 0.617*** | 0.743*** | 0.434*** |
| | (0.01) | (0.01) | (0.01) |
| $Exp\_Acum^2$ | | -0.008*** | -0.004*** |
| | | (0.00) | (0.00) |
| Constant | -1.629*** | -2.544*** | -1.220*** |
| | (0.01) | (0.01) | (0.05) |
| Firm | no | yes | no |
| **R2-pseudo** | 0.075 | 0.099 | 0.062 |
| **Observations** | 142917 | 142522 | 142917 |
| $\chi^2$ | 9157.656 | 13441.11 | 11006.103 |
| **Log-likelihood** | $-73373.104$ | $-71278.424$ | $-74347.782$ |

$^*p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors are given in parentheses.

The results suggest that the probability that an inventor stops applying for a patent is increased when there is a merge one or two years after. This result suggest that mergers might have a strong significant effect on stop inventors in applying for patents. This probability is also positively related with the years of experience accumulated by the inventors every time an inventor $k$ applies to a patent. In other words, the more years of experience the inventor has the more likely she stops applying for patents. Finally, the more accumulated patents an inventor has the less likely she ceases to apply for patents.

## 4.6 Conclusion

Existing evidence suggests that M&As between big pharma are not on average, successful experience. This view is obviously not shared by industry leaders when they acquire or merge with competitors with the expectation of reviving the research pipelines and boost the performances of the newly formed companies.

This paper provides fresh evidence on how mergers affect innovation outcome by looking at patents and inventors data. We show that there is a high rate of job separation around the period of the merger which can be due either to the company decision to eliminate research projects that are considered "duplicative" or less promising, or to the scientists decision to leave a company because of cultural clashes. In particular, the movements of inventors seems to be higher when the value of the deal is higher, for example in the second wave of mergers.

We also show that on averages, mergers have a negative impact on the productivity of inventors in terms of patens, applications and their productivity. This effect impacts more inventors that change company compared with the new team of scientific researchers of the new pharmaceutical company. The post-merger performance in terms of innovation outcomes and the market value of the new firm strongly depends on the retention of inventors.

Our findings have also important policy implications. In the last two decades merger analysis have moved beyond its traditional focus on static efficiency to account for innovation and address dynamic efficiency. Katz and Shelanski (2007) observes that "In order fully to assess the impact of a merger on market performance, merger authorities and courts must examine how a proposed transaction changes market participants incentives and abilities to undertake investments in innovation". Our results suggest that mergers should be the object of a more careful scrutiny given that they do not seem to produce any dynamic efficiency, at least if we look at the performance of inventors that used to work in the company.

Finally, the future extension of this paper will include the firm level analysis that will evaluate the post-merger effect on firms in terms of patents productivity and market value of the newly merged companies. Also, the paper will analyse the probability that a quality inventor moves to another company for any reason using the number of citations received per patent granted.

# 5

# Conclusion

This thesis explores three different topics in innovation economics. The first chapter investigates the impact of tacit and no tacit knowledge on the innovation process of the firm in the Colombian manufacturing industry. In three different stages, decision, completion and impact, we understand which types of knowledge (tacit and explicit) are relevant for each of the innovation stages. Interestingly, the marketing department, as an internal source of knowledge has a strong and significant effect during the impact stage of the innovation process. Similarly, when exploring internal sources of tacit knowledge, the marketing department ideas seems to have a stronger significant effect than the explicit one. In addition, knowledge from directors and managers of the firm is crucial during all stages of the innovation process, with a strong and significant effect at each stage. Moreover, by types of knowledge, engineering play an important role when the firm decides whether or not to innovate; biotechnology has a significant positive effect during the completion stage of the innovation process. Finally, during the impact stage the abilities of the firm related to math and statistics, is an important knowledge that increases the probability of success in the impact stage.

The second chapter explores the action-reaction process when the firms have the possibility to imitate an innovation. This effect is explored from a theoretical and empirical point of view. Using the innovation surveys and the Annual Respondents Database for the U.K, the theoretical predictions are tested using data. The empirical results suggests that imitation has a positive and significant effect as the theory predicts. Implementing different forms of competition, the Boone parametric measure of competition gives a positive and significant result for all the empirical specifications explored. This positive and significant result suggest a less intensified competition, which can be close to a Cournot type of competition. Boone measure of competition captures the effect of the inefficient firms consistent with the definition of the action-reaction process. In addition, the impact of the innovation as another explanatory variable has a strong positive effect and plays an important role as an incentive for the less efficient firms to innovate. The results suggest that the impact of the innovation has consistent explanatory power across all the empirical specifications for the action-reaction process.

The final chapter explores the post-merger effects on innovation. In particular, we explore in this chapter the effects of mergers at the inventor level. At the inventor level, we found that inventors productivity and mobility are affected by mergers. Firms tend to retain those inventors that are most productive. Also, firms seem to be affected by mergers. Firstly in their productivity in terms of patents is particularly affected by the mergers. Second, mergers triggers mobility of inventors in the pharmaceutical industry. On average, mergers have a negative impact on the productivity of inventors in terms of patens, applications and their productivity. Inventors that change company are affected more than those in the new team of scientific researchers of the new pharmaceutical company. In particular, the movements of inventors seem to be greater when the value of the deal is higher, for example in the second wave of mergers. Moreover, the post-merger performance in terms of innovation outcomes and the market value of the new firm strongly depends on the retention of inventors.

In conclusion, innovation economics has to be understood from different angles. First, the managerial angle is a pillar for the development and creation of innovative ideas. It is crucial to understand the drivers that affect the innovation process. Not only the external and traditional effects such as the market structure are relevant for the analysis. Also, the management part and the internal organisation and structure of the firm are fundamental for a better understanding of the innovation process of the firm. Innovation is a dynamic process that depends on many factors, but especially in the internal organisation of the firm, including the role of managers and the R&D department, and the external forces that also shape this dynamic process such as the market structure. Hence, future research on innovation should combine elements from the economic and management points of view in order to have a better picture of the innovation process of the firm. Second, incentives and market structure are still another set of important elements to understand innovation from a different angle. These topics have been studied from the theoretical point of view very intensively in the last decades. However, the empirical evidence about the conclusion of many of these theoretical models remain without any exploration. The results of the action-reaction process help us to understand much better the dynamics of industries and the role that innovation has played to shape those industries with relevant empirical evidence and the possibility of imitation.

Finally, the role of competition policy is also crucial in understanding innovation. Competition policy is another important element to spur innovation. Competition policy is an instrument that should be designed to stimulate innovation. Competition policy needs to be adapted to each particular situation, case, industry and country in order to minimise the inefficiencies and negative effects that might hurt the dynamics of innovation. Exploring the pharmaceutical industry is an interesting case that enable us to understand the effects of mergers on post innovation outcomes. Managers use mergers as a growth strategy and face competition pressures in the market. This strategy might hurt or spur innovation in the newly merged company. Managers need to consider the potential effects on post-merger outcomes such as innovation and employability in order to reduce any negative effect that might hurt the new company. In addition, competition authorities need to put some weight on the dynamic efficiencies when approving a merging deal. Not only are the effects on prices, quantities and quality important, but the dynamic effects on innovation are also fundamental for social welfare outcomes, as the case investigated in the pharmaceutical industry revealed. Therefore, innovation economics is fundamental for economic analysis from the theoretical and empirical point of view. Innovation economics has to be understood and analysed as a process that combines management, strategies, competition and polices as the drivers of innovation outcomes. The wide range of topics is an incentive to keep investigating and understanding the innovation process from the management and economic point of view, in order to implement recommendations and polices which are useful for policy makers, managers and regulation authorities.

# APPENDIX A

# Appendix

## A.1 Appendix Chapter 1

Table A.1: Definitions by type of innovative firm

| | |
|---|---|
| ***Strictly innovative firms*** | These are the firms that obtained at least a new good or service, or goods or services that could be also significantly improved and sold it in foreign markets. |
| ***Wide innovative firms*** | These are the firms that obtained at least a new good or service, or at least have a significantly improved (good or service) and sold it within the country. It could be also the firms that have a new or improved good or service, to use within the firm. These firms could also have implement a new productive process for the main production chain or other secondary chains of production. Finally, these firms could have developed a new organizational form or a new marketing form. |
| ***Potentially innovative firms*** | These are the firms that at the moment of answering the survey had not obtained any kind of innovation, but reported an innovation project (or abandoned) being in process to obtain a new product for the foreign or national market, or for using within the firm. Or an innovation project to obtain a productive process, or a new organizational form or a new marketing form. |
| ***No innovative firms*** | These are the firms that at the moment of answering the survey did not get any kind of innovation, not even a potential innovation process, or at least to have abandoned one. |

Table A.2: Definitions dependent variables

| ***Dependent Variables*** | |
|---|---|
| *Innovate* | 1 if the firm is classified as wide, potential or strictly innovative, 0 otherwise. |
| *Complete* | 1 if the firm is classified as wide or strictly, 0 otherwise. |
| *Impact* | 1 if the firm reached an impact in product, process or market, 0 otherwise. |

Table A.3: Definitions explanatory variables

| ***Firm Characteristics*** | |
|---|---|
| Size | Is the total workforce of the firm. |
| $Size^2$ | Is the square of size. |
| ***External Knowledge*** | |
| Research Institutions | Is a dummy variable equal to 1 if the firm has cooperated in scientific, technological or innovative activities with Research Institutions (e.g., Universities, Technological Development Centers and Research centers.) |
| Clients | Is a dummy variable equal to 1 if the firm has cooperated in scientific, technological or innovative activities with clients/consumers. |
| Suppliers | Is a dummy variable equal to 1 if the firm has cooperated in scientific, technological or innovative activities with suppliers. |

Table A.4: Definitions explanatory variables

| ***External Ideas*** | |
|---|---|
| External | Is a dummy variable equal to 1 if the firm has reported that the source of ideas to develop goods or services, process, organizational methods or new techniques for sales have come at least from suppliers, clients, internet, universities, intellectual property information system, consultants and books, catalogs. |
| Internal | Is a dummy variable equal to 1 if the firm has reported that the source of ideas to develop goods or services, process, organizational methods or new techniques for sales have come at least from the R&D, production, marketing and sales, employees and director or C.E.O of the company. |
| Interaction | Is a dummy variable equal to 1 if the firm has used both, internal and external sources of ideas, otherwise 0. |

Table A.5: Definitions explanatory variables

| ***Internal Knowledge*** | |
|---|---|
| Training | Is a dummy variable that takes the value of 1 if the firm has perform high training, otherwise 0. |
| Production Knowledge=$\frac{\sum_{i=1}^{N^{Prod}} N_i^{Prod}}{N_i^{tot}}$ | Is the ratio between all employees with technical qualifications, school (e.g. technicians) and $N_i^{tot}$, the total number of employees of the firm. |
| Marketing Knowledge=$\frac{\sum_{i=1}^{N^{Mrktg}} N_i^{Mrktg}}{N_i^{tot}}$ | Is the ratio between all employees with university degree (undergraduate and postgraduate) in the Marketing and Sales Department and $N_i^{tot}$, the total number of employees of the firm. |
| R&D Knowledge=$\frac{\sum_{i=1}^{N^{R\&D}} N_i^{R\&D}}{N_i^{tot}}$ | Is the ratio between all employees with university degree (undergraduate and postgraduate) in the R&D Department and $N_i^{tot}$, the total number of employees of the firm. |

Table A.6: Definitions explanatory variables

| | |
|---|---|
| ***Firms Restrictions*** | |
| Lack Cooperation | Is a dummy variable that takes 1 if the firm has not had cooperated with other firms or institutions, 0 otherwise. |
| Easy imitation | Is a dummy variable that takes 1 when the facility to imitate the firm by other firms is perceived, and 0 otherwise. |
| Lack IP System | Is a dummy variable that takes 1 when the lack of own resources to invest in R&D is answered, and 0 otherwise. |
| ***Industry Characteristics*** | |
| Concentration | It is measured as the sum of all the total workforce of the large firms divided by the total workforce of the industry. |
| Medium low Tech | Is a dummy variable that gathers all medium-low technological firms. |
| Medium high Tech | Is a dummy variable that gathers all medium-high technological firms. |
| High Tech | Is a dummy variable that gathers all high technological firms. |

## A.2 Appendix

Table A.7: Linktest for specification Error in the sequential logit

| ***Innovate*** | | | |
|---|---|---|---|
| | *Coeff* | *Std. Err* | *Pvalue* |
| hat | 0.997 | 0.019 | 0.000 |
| hatsq | -0.0103 | 0.015 | 0.51 |
| cons | 0.0333 | 0.061 | 0.588 |
| ***Complete*** | | | |
| | *Coeff* | *Std. Err* | *Pvalue* |
| hat | 1.1289 | 0.1799 | 0.000 |
| hatsq | -0.041 | 0.0557 | 0.458 |
| cons | -0.0224 | 0.0932 | 0.810 |
| ***Impact*** | | | |
| | *Coeff* | *Std. Err* | *Pvalue* |
| hat | 0.6665 | 0.4219 | 0.114 |
| hatsq | 0.0904 | 0.1124 | 0.421 |
| cons | 0.271 | 0.3699 | 0.464 |

Table A.8: Hosmer and Leweshow test for goodness of fit

| | ***Innovation*** | ***Complete*** | ***Impact*** |
|---|---|---|---|
| ***Observations*** | 7674 | 3311 | 2092 |
| ***Groups*** | 10 | 10 | 10 |
| ***Hosmer-Lemeshow*** | 12.74 | 3.02 | 10.49 |
| ***Pvalue*** | 0.1213 | 0.9333 | 0.2325 |

This is a diagnostic for multicollinearity. The Variance Inflation Factor (VIF), is an indicator of how much of the inflation of the standard errors is caused by collinearity.

Table A.9: Collinearity Diagnostics

| | ***Innovation*** | ***Complete*** | ***Impact*** |
|---|---|---|---|
| ***Observations*** | 7674 | 3311 | 2092 |
| ***Mean VIF**** | 3.14 | 2.82 | 2.95 |
| ***Condition number*** | 36.56 | 49.935 | 52.203 |

*VIF=Variance inflation factor.

# A.3 Appendix

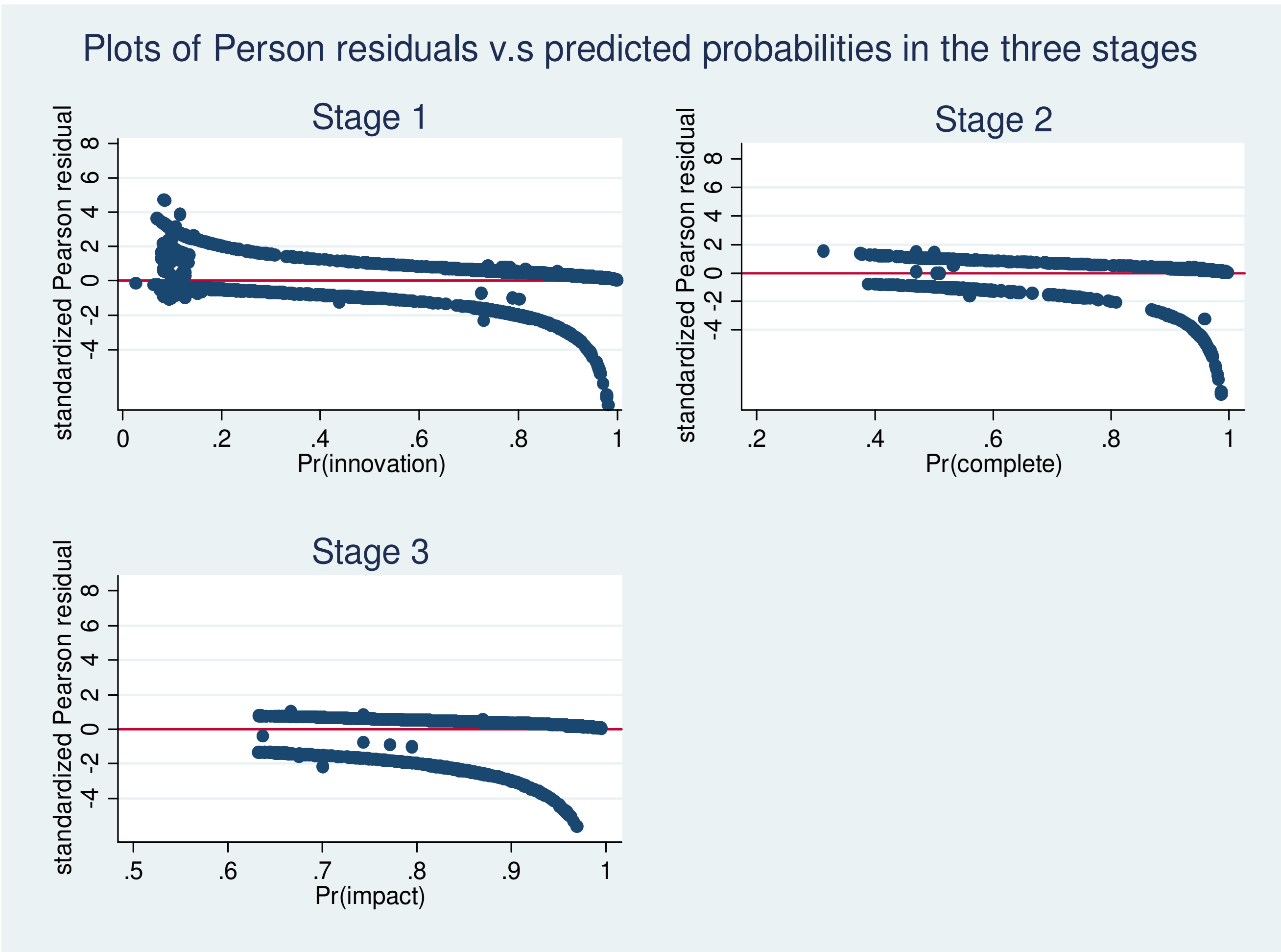



Figure A.1: Detecting Outliers

# A.4 Robustness checks

Table A.10: Sequential Logit and Probit Estimations(Robustness)

| Sequential Logit | | | | Sequential Probit | | |
|---|---|---|---|---|---|---|
| | **Stage 1** | **Stage 2** | **Stage 3** | **Stage 1** | **Stage 2** | **Stage 3** |
| | Innovation | Completion | Impact | Innovation | Completion | Impact |
| ***Firm Characteristics*** | | | | | | |
| Size | 0.002*** | 0.001 | -0.001* | 0.001*** | 0.000 | -0.000* |
| | (0.00) | (0.000 | (0.00) | (0.00) | (0.00) | (0.00) |
| $Size^2$ | -0.000*** | 0.000 | 0.000 | -0.000*** | 0.000 | 0.000 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Lack Cooperation | 0.009 | 0.049 | 0.044 | 0.012 | 0.000 | 0.028 |
| | (0.10) | (0.15) | (0.14) | (0.06) | (0.08) | (0.08) |
| Easy imitation | 0.392*** | 0.103 | 0.240* | 0.226*** | 0.048 | 0.131* |
| | (0.11) | (0.15) | (0.14) | (0.06) | (0.08) | (0.08) |
| Lack IP System | -0.117 | -0.099 | 0.498*** | -0.071 | -0.032 | 0.273*** |
| | (0.11) | (0.16) | (0.16) | (0.06) | (0.09) | (0.08) |
| Concentration | 0.635** | -0.005 | 0.281 | 0.357** | 0.012 | 0.209 |
| | (0.29) | (0.55) | (0.52) | (0.16) | (0.30) | (0.28) |
| Medium low Tech | 0.123 | -0.177 | 0.255* | 0.073 | -0.108 | 0.148* |
| | (0.08) | (0.15) | (0.15) | (0.05) | (0.08) | (0.08) |
| Medium high Tech | 0.03 | -0.14 | 0.151 | 0.021 | -0.082 | 0.079 |
| | (0.11) | (0.20) | (0.19) | (0.06) | (0.11) | (0.10) |
| High Tech | 0.055 | -0.318 | -0.178 | 0.025 | -0.154 | -0.087 |
| | (0.13) | (0.20) | (0.20) | (0.07) | (0.11) | (0.11) |
| constant | -2.340*** | -0.222 | 0.386 | -1.372*** | -0.151 | 0.28 |
| | (0.28) | (0.63) | (0.58) | (0.16) | (0.34) | (0.32) |
| ***Firms*** | 7671 | 3311 | 2902 | 7671 | 3311 | 2902 |

$^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

Robust Standard Errors listed beneath coefficients.

General diagnostic of logit and probit models from results reported in tables 2.11, 2.12 and A.10.

Table A.11: General Diagnostic of the sequential logit and probit estimations

| Sequential Logit | **Pseudo-R2** | **Log-likelihood value** | **Correctly predicted** | **Iterations** | $\chi^2(df)$ | **Obs.** |
|---|---|---|---|---|---|---|
| **Stage 1** | 0.413 | -3076.862 | 83.90% | 5 | 1655.133(21)*** | 7671 |
| **Stage 2** | 0.203 | -985.78 | 87.62% | 5 | 305.52(21)*** | 3311 |
| **Stage 3** | 0.0794 | -1091.4087 | 85.80% | 4 | 181.17(21)*** | 2902 |
| Sequential Probit | | | | | | |
| **Stage 1** | 0.411 | -3088.491 | 83.60% | 5 | 2118.08(21)*** | 7671 |
| **Stage 2** | 0.196 | -995.11 | 87.68% | 5 | 338.92(21)*** | 3311 |
| **Stage 3** | 0.0805 | -1090.05 | 85.80% | 4 | 189.56(21)*** | 2902 |

## A.5 Appendix Chapter 2

Following Belleflamme and Peitz (2010) is possible to derive equation 3.2.10. We have to maximize the profit of firm $i$:

$$\pi_i = (a - m(q_i + q_{-i}))q_i - c_i q_i \tag{A.5.1}$$

Taking first order conditions we have:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2bq_i - bq_{-i} - c_i = 0 \tag{A.5.2}$$

$$a - bq_i - c_i = 2bq_i$$

Therefore the best response of firm $i$ is:

$$q_i(q_{-1}) = \frac{a - bq_{-i} - c_i}{2b} \tag{A.5.3}$$

Now adding for all the $n$ firms we have:

$$\sum_{i=1}^{n} q_i = \frac{1}{2b}\Big(na - \sum_{i=1}^{n} c_i - b\sum_{i=1}^{n} q_{-i}\Big) \tag{A.5.4}$$

By definition we know that:

$$\sum_{i=1}^{n} q_i = q$$

Hence, for all firms except firm $i$ we have that:

$$\sum_{i} q_{-i} = nq - q = (n-1)q$$

And the costs are:

$$\sum_{i} c_{-i} = C$$

Therefore expression A.5.4 becomes:

$$q = \frac{1}{2b}\big(na - C - b(n-1)q\big)$$

$$2bq = na - C - bnq + bq$$

$$bq = na - C - bnq$$

$$bq + bnq = na - C$$

$$q(b(n+1)) = na - C$$

$$q = \frac{na - C}{b(n+1)} \tag{A.5.5}$$

Where A.5.5 is the total quantity produced at the Cournot equilibrium. With this result we can also calculate the expression for firm $i's$ quantity in equilibrium as:

$$q_i^* = \frac{1}{2b}\Big(a - c_i - b\big(\frac{na - C}{b(n+1)} - q_i^*\big)\Big)$$

$$2bq_i^* = a - c_i - b\big(\frac{na - C}{b(n+1)}\big) + bq_i^*$$

$$bq_i^* = a - c_i - \frac{na - C}{b(n+1)}$$

$$q_i^* = \frac{a}{b} - \frac{c_i}{b} - \frac{na - C}{b(n+1)}$$

$$q_i^* = \frac{a(n+1) - c_i(n+1) - na + C}{b(n+1)}$$

$$q_i^* = \frac{a - c_i(n+1) + C}{b(n+1)}$$

$$q_i^* = \frac{a - c_i - c_i + C}{b(n+1)}$$

Where $C = \sum_{i=1}^{n} c_i = c_1 + c_2 + ... + c_n$. Therefore,

$$q_i^* = \frac{a - nc_i + C_{-i}}{b(n+1)}$$

Now is possible to calculate the equilibrium profit of firm $i$:

$$\pi_i^* = (P(q^*) - c_i)q_i^*$$

$$\pi_i^* = (a - bq^* - c_i)q_i^*$$

$$\pi_i^* = (a - bq_{-i}^* - bq_i^* - c_i)q_i^*$$

$$\pi_i^* = aq_i^* - bq_{-i}^* q_i^* - bq_i^{2*} - c_i q_i^*$$

Substituting the equilibrium expression derived above we have:

$$\pi_i = \Big(a - b\frac{na - C}{b(n+1)} - c_i\Big)\Big(\frac{a - nc_i + C_i}{b(n+1)}\Big)$$

$$\pi_i = \Big(\frac{a(n+1) - (na - C) - c_i(n+1)}{n+1}\Big)\Big(\frac{a - nc_i + C_i}{b(n+1)}\Big)$$

$$\pi_i = \frac{a(n+1) - (na - C) - c_i(n+1)(a - nc_i + C_{-i})}{b(n+1)^2}$$

$$\pi_i = \frac{(an + a - na + C - c_i n + c_i)(a - nc_i + C_{-i})}{b(n+1)^2}$$

$$\pi_i = \frac{(a - c_i n - c_i + C)(a - nc_i + C_{-i})}{b(n+1)^2}$$

$$\pi_i = \frac{(a - c_i n + C_{-i})(a - nc_i + C_{-i})}{b(n+1)^2}$$

$$\pi_i = \frac{(a - nc_i + C_{-i})^2}{b(n+1)^2} \tag{A.5.6}$$

Where A.5.6 is the profit in equilibrium for firm $i$.

To reach equation 3.2.15 we procedure as follows. Taking the equations in 3.2.11 and 3.2.13 :

$$\pi^l_{innovator} = \frac{[a + (c + b - \beta d) - 2(c - d)]^2}{9}; \quad \pi^h_{imitator} = \frac{[a + (c - d) - 2(c + b - \beta d)]^2}{9} \tag{A.5.7}$$

$$\pi^h_{innovator} = \frac{[a + (c - \beta d) - 2(c - d)]^2}{9}; \quad \pi^l_{imitator} = \frac{[a + (c - d) - 2(c - \beta d)]^2}{9} \tag{A.5.8}$$

And adding them as the following expression shows, we will get the aggregate profits when $h$ wins the patent and also when $l$ does:

$$\underbrace{\pi^h_{innovator} + \pi^l_{imitator}}_{\sigma_h} > \underbrace{\pi^l_{innovator} + \pi^h_{imitator}}_{\sigma_l} \tag{A.5.9}$$

Hence, we have the case when $\sigma_h > \sigma_l$:

$$\frac{[B+(2-\beta)d]^2 + [B+(2\beta-1)d)]^2}{9} > \frac{[B+b+(2-\beta)d]^2 + [B-2b+(2\beta-1)d)]^2}{9}$$

To simplify the calculations we can call $z = 2-\beta$ and $x = 2\beta-1$ and also cancelling out $1/9$ we have:

$$[B+zd]^2 + [B+xd]^2 > [B+b+zd]^2 + [B-2b+xd]^2$$

Expanding the previous expression yields A.5.10:

$$\begin{aligned} B^2 + 2Bzd + z^2d^2 + B^2 + 2Bxd + x^2d^2 > \\ & B^2 + Bb + Bzd + Bb + b^2 + \\ & bzd + zdB + zdb + z^2d^2 + \\ & B^2 - 2Bb + Bxd - 2bB + 4b^2 - \\ & 2bxd + Bxd - 2bxd + x^2d^2 \end{aligned} \tag{A.5.10}$$

Cancelling common terms lead us to:

$$0 > Bb + Bb + b^2 + bzd + zdb - 2Bb - 2Bb + 4b^2 - 2bxd - 2bxd$$

$$0 > 5b^2 - 2Bb + 2bzd - 4bxd$$

$$2Bb > 5b^2 + 2bzd - 4bxd$$

$$2B > 5b + 2zd - 4xd$$

$$2B > 5b + (z - 2x)2d$$

Replacing the values of $z$ and $x$:

$$2B > 5b + (2 - \beta - 2(2\beta - 1))2d$$

$$2B > 5b + (2 - \beta - 4\beta + 2)2d$$

$$2B > 5b + (4 - 5\beta)2d$$

$$2B > 5b + 8d - 10\beta d \tag{A.5.11}$$

Equation A.5.11 shows the calculations that derive equation 3.2.15.

To derive the general expression in equation 3.2.21 we follow:

$$\frac{[a-N(c-d)+(N-1)(c-\beta d)]^2+[a-N(c-\beta d)+(c-d)]^2}{(N+1)^2} >$$
$$\frac{[a-N(c-d)+(N-1)(c+b-\beta d)]^2}{(N+1)^2}+\frac{[a-N(c+b-\beta d)+(c-d)]^2}{(N+1)^2} \tag{A.5.12}$$

Simplifying expression A.5.12 yields:

$$-b(b-2a+2c-4Nc+2N^2c-2Nb-2\beta d+2N^2b+2N^2d+4N\beta d-4N^2\beta d)>0$$

$$0>(b-2a+2c-4Nc+2N^2c-2Nb-2\beta d+2N^2b+2N^2d+4N\beta d-4N^2\beta d)$$

$$2a-2c+4Nc-2N^2c>b(1-2N+2N^2)-(1-2N+2N^2)2\beta d+2N^2d$$

$$2a-2c+4Nc-2N^2c>b(1-2N+2N^2)-(1-2N+2N^2)2\beta d+2N^2d$$

Replacing $B=a-c$ we reach:

$$2B+2Nc(2-N)>(1-2N+2N^2)b-(1-2N+2N^2)2\beta d+2N^2d$$

$$2B > (1 - 2N + 2N^2)b - 2N(2 - N)c + 2N^2d - (1 - 2N + 2N^2)2\beta d \quad \text{(A.5.13)}$$

Equation A.5.13 represents the derivation for expression 3.2.21.

### A.5.1 U.K Innovation and the Annual Respondents Database

The survey already contains an unbalance panel at the firm level for three UKIS surveys corresponding to the periods, $2002 - 2004$, $2004 - 2006$ and $2006 - 2008$, with 12.162 observations. After cleaning for all the repetitions cases the number of observations were reduced to 12.144 observations. With this cleaning the dataset is balanced with gaps. In order to be consistent with all the different answers reported for product and process innovations, such as the answers classified as *yes*, *no*, *not answers* and *no applicable*, the firms that answer exclusively new to the market were 537, and 1553 firms innovated in process but not new to the market. The rest of the answers were classified according to the following criteria. Those firms that innovate in process but did not answer if their innovation was new or not new to the market (i.e. *no answer*) were added to the innovation in process.

The ARD was provided yearly since 2002 to 2008 by different sectors in the economy named as catering, construction, motor trades, production, retail, and wholesale sectors that gathers all the 3-SIC industries. All these files were appended to construct a unique file for all this period and industries. In order to built the panel a cleaning process was carried out. Firstly, the data at the firm level, was checked for repetitions in all years, dropping those observations that that were duplicated. Secondly, those firms with no information on the number of employees and turnover. Thirdly, it was calculated the growth rate of turnover and employment. Those observations that showed huge increments, for example more than $500\%$ and decreases about $80\%$ were dropped from the sample. Finally, all negative and zero turnover observations were also deleted from the sample. After these cleaning process all the information required to calculated the different measures of competition $HHI$, $PCM$ and $Boone's$ are explored at the 3-SIC digits industry level. Finally, with the final dataset from the UKIS and ARD, the information was merged at the industry level in order to set up the final dataset utilized in the analysis.

The following tables A.12 and A.13 present the correlation matrix of the variables utilized in the empirical model and the correlation matrix between the current values of the competition measures.

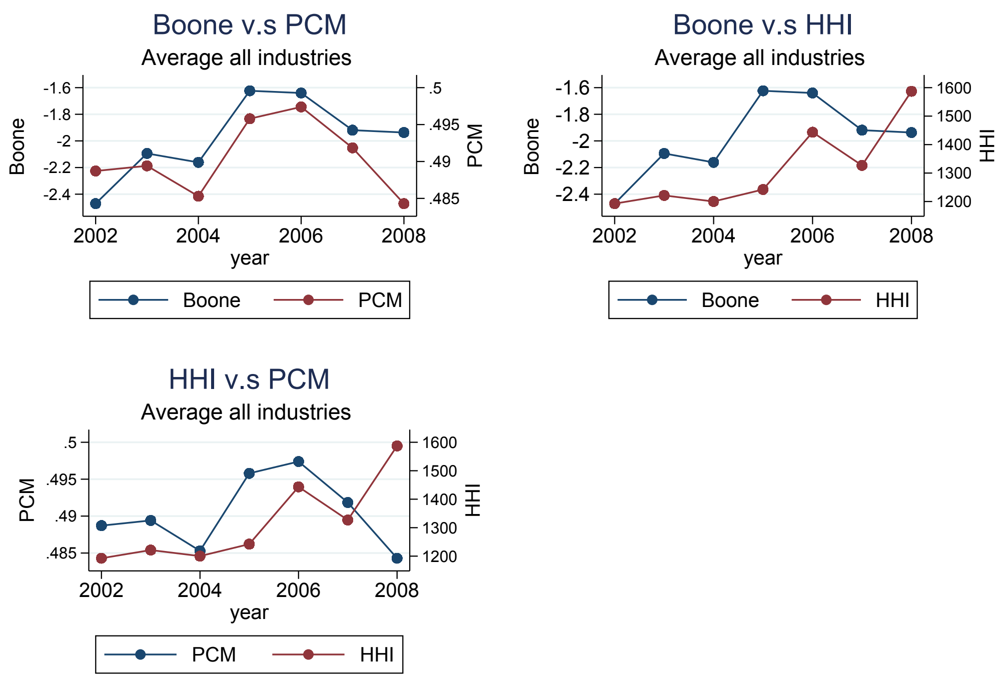
Table A.12: Correlation Matrix

| | AR_year_process | boone_chg1 | PCM_chg1 | hhi_chg1 | impa_process | impa_market | per_imita | disp_cost_chg1 | own_cost_chg1 |
|---|---|---|---|---|---|---|---|---|---|
| **AR_year_process** | 1 | | | | | | | | |
| **boone_chg1** | 0.1245 | 1 | | | | | | | |
| **PCM_chg1** | 0.0922 | 0.3050* | 1 | | | | | | |
| **hhi_chg1** | 0.0122 | 0.0902 | -0.1022 | 1 | | | | | |
| **impa_process** | 0.1855* | 0.1176 | -0.0188 | 0.0891 | 1 | | | | |
| **impa_market** | 0.1546* | 0.1528* | 0.2128* | 0.1141 | 0.1942* | 1 | | | |
| **per_imita** | -0.1505* | 0.0677 | -0.0234 | 0.073 | 0.2250* | 0.144 | 1 | | |
| **disp_cost_chg1** | -0.067 | -0.0384 | 0.0298 | 0.0248 | -0.0806 | 0.0606 | 0.0033 | 1 | |
| **own_cost_chg1** | -0.0141 | -0.2123* | -0.8680* | 0.1803* | 0.0426 | 0.0421 | 0.0146 | 0.0556 | 1 |

Table A.13: Correlation Matrix: Boone, PCM and HHI

| | Mean_Boone | Mean_PCM | Mean_HHI |
|---|---|---|---|
| **Mean_Boone** | 1 | | |
| **Mean_PCM** | 0.7979* | 1 | |
| **Mean_HHI** | 0.2341* | -0.0524 | 1 |

Figure A.2: Boone, PCM and HHI correlation




Source: Own calculations using ARD at Industry level SIC-3

The outlier test for the three measures of competition were carried out through the *Outlier Hadi test* as is shown in tables A.14 and A.15. The following tables show the results for each of the competition variables.

Table A.14: Outlier Hadi test: Boone and PCM

| | ***Boone*** | |
|---|---|
| Beginning number of observations | 318 |
| Initially accepted | 2 |
| Expand to (n+k+1)/2 | 160 |
| Expand, p=0.01 | 317 |
| Outliers remaining | 1 |
| ***PCM*** | |
| Beginning number of observations | 318 |
| Initially accepted | 2 |
| Expand to (n+k+1)/2 | 160 |
| Expand, p=0.01 | 318 |
| Outliers remaining | 0 |

Table A.15: Outlier Hadi test: HHI

| ***HHI*** | |
|---|---|
| Beginning number of observations | 318 |
| Initially accepted | 2 |
| Expand to (n+k+1)/2 | 160 |
| Expand, p=0.01 | 317 |
| Outliers remaining | 1 |

# A.6 Appendix Chapter 3

List of mergers in the Big pharmaceutical industry between 1989 and 2011.

Table A.16: List of Mergers

| Acquirer(A) | Target(T) | Year Merge | Deal ($US m) |
|---|---|---|---|
| American Home Product | Robins | 1989 | $ 3.190 |
| Novo | Nordisk | 1989 | |
| Bristol Myers | Squibb | 1989 | $ 12.500 |
| Smithkline | Beecham | 1989 | $ 8.276 |
| Roche | Syntex | 1994 | $ 5.307 |
| American Home Product | Lederle (Amer. Cynamid) | 1994 | $ 9.560 |
| Hoechst | Marion Roussell | 1995 | $ 7.121 |
| Glaxo | Wellcome | 1995 | $ 14.284 |
| Pharmacia AB | Upjohn | 1995 | |
| Rhone Poulenc Rorer | Fisons | 1995 | $ 2.888 |
| Ciba | Sandoz | 1996 | $ 27.000 |
| Amersham | Nycomed | 1997 | |
| Astra | Zeneca | 1999 | $ 34.636 |
| Sanofi Sterling | Synthelabo | 1999 | |
| Johnson & Johnson | Centocor | 1999 | $ 3.110 |
| GlaxoWellcome | Smithkline | 2000 | $ 76.000 |
| Pfizer | Warner Lambert | 2000 | $ 87.413 |
| Hoechst Marion Roussell | Rhone Poulenc Rorer | 2000 | $ 21.918 |
| Pharmacia & Upjohn | Searle (Monsato) | 2000 | $ 26.486 |
| Johnson & Johnson | Alza Corp | 2001 | $ 11.070 |
| Abbot | Knoll | 2001 | $ 6.900 |
| BMS | Dupont Pharma | 2001 | $ 7.800 |
| Pfizer | Pharmacia Corp | 2002 | $ 59.515 |
| Amgen | Immunex | 2002 | $ 16.900 |
| Amgen | Tularik | 2004 | $ 1.300 |
| Teva | Sicor | 2004 | $ 2.036 |
| Yamanouchi | Fujisawa | 2004 | $ 7.700 |
| Sanofi Synthelabo | Aventis | 2004 | $ 65.000 |
| Daiichi | Sankyo | 2005 | $ 75.55 |
| Bayer | Schering | 2006 | $ 16.900 |
| Novartis | Chiron | 2006 | $ 5.555 |
| Eli Lilly | Icos | 2007 | $ 1.226 |
| Takeda | Millennium | 2007 | |
| Eli Lilly | Imclone | 2008 | |
| Sanofi Aventis | Genzyme | 2008 | $ 20.000 |
| Roche | Genetech | 2009 | $ 46.800 |
| Merck | Schering Plough | 2009 | |
| Pfizer | Wyeth | 2009 | $ 68.000 |
| BMS | Medarex | 2009 | |
| Abbot | Solvay | 2010 | |
| Teva | Cephalon | 2011 | |

## A.6.1 Movements up to one and three years after the merge and other movements

Figure A.3: Merger Size and Movements

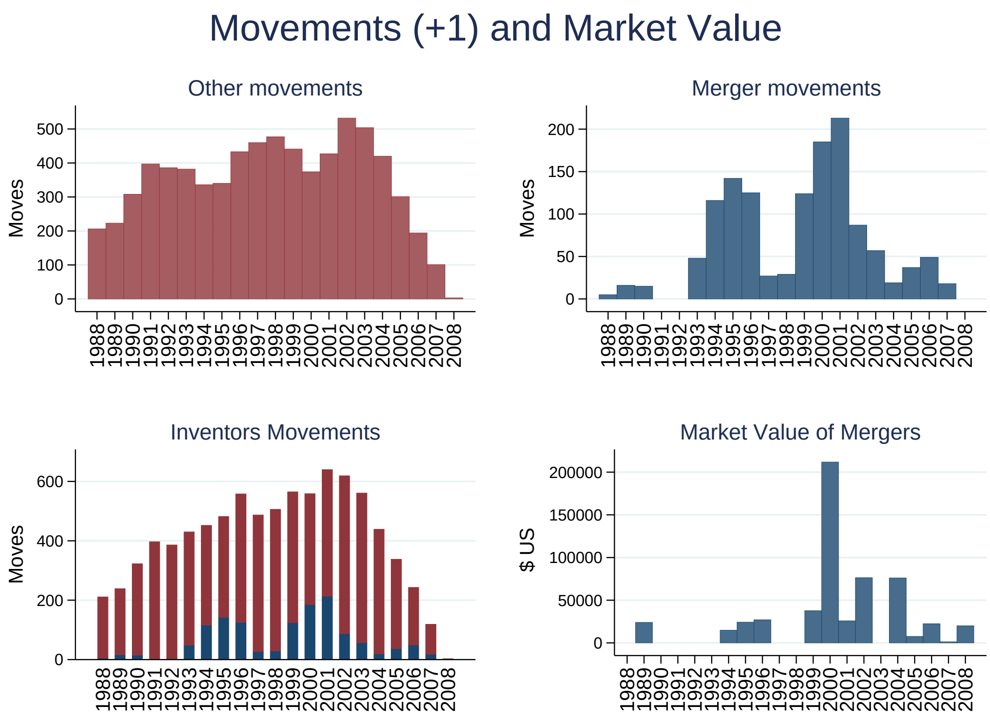
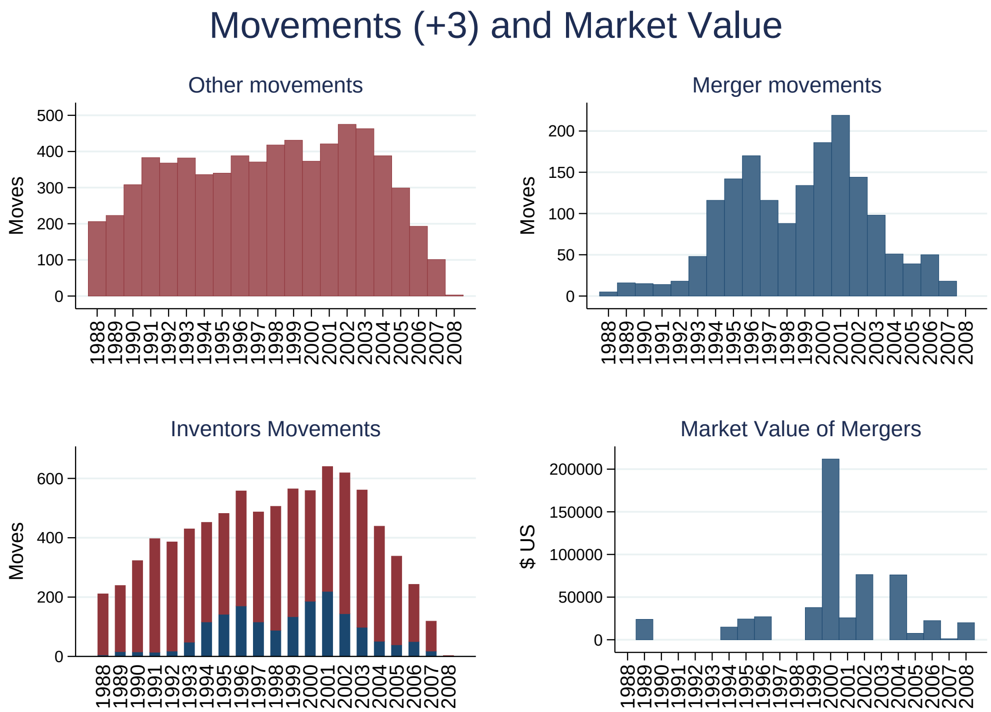


Figure A.4: Merger Size and Movements



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