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Empirical models of firms' innovation, diversity and behaviour

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The undersigned Sonia Foltran, in his quality of doctoral candidate for a Ph.D. degree in Economics granted by the Università Ca' Foscari Venezia attests that the research exposed in this dissertation is original and that it has not been and it will not be used to pursue or attain any other academic degree of any level at any other academic institution, be it foreign or Italian.

Abstract

This dissertation presents three essays on firms' innovation, diversity and behaviour. In chapter 1, that is a joint work with Kevin Boudreau, we consider how the relation between competition and innovation can additionally be shaped by the structure, distribution and heterogeneity of knowledge across competing innovators. In doing so, we highlight that the innovation process is not only influenced by strategic incentives and levels of effort, but also by past knowledge and advances, which are key inputs and affect the innovative search process. We review existing contributions and summarize several key mechanisms, emphasizing the role of past knowledge. We provide panel data evidence using information on the evolution of multi-dimensional features of smartphones. The analysis suggests that i)there are positive returns to recombination of ideas in number of ideas; ii)more diffused knowledge and the presence of an "anchor tenant" positively affect recombinations; iii)the positive returns are more easily realized within firm and then within market boundaries and iv)firm new idea generation is correlated with firm owned ideas but it is not correlated with firm un-owned ideas used in the market.

Chapter 2 explores the implications of the diversity of R&D sources on firm innovativeness, focusing on the different impact on financially constrained and unconstrained firms. Intuitively, since innovation is the process that integrates and recombines different bodies of knowledge, the variety of technological sources implies a larger set of innovation possibilities. The access to diverse sources of knowledge has been recognized as a key element to the success of innovation. We develop a theoretical model that shows the elements playing a role in the choice of firms to diversify the R&D sources. We provide evidence that the diversity of R&D sources has a positive effect on firms' innovation, especially for financially constrained firms. In particular the presence and the heterogeneity of external R&D sources have a greater impact on financially constrained than on unconstrained firms.

Chapter 3 deals with the impact of legal institutions on creditor's protection, firms' investments and access to credit in Italy. The Italian 2002 law on accounting frauds provides the source of exogenous variation to identify the effect of creditors' protection on firms' debt and investment behaviour. The law allows firms to provide slightly "inaccurate" financial statements without incurring in punishments and, as a consequence, may weaken the protection of creditors and shareholders. The analysis is conducted using a dataset of Italian firms before and after the introduction of the new regulation and shows that, for firms affected by the law, bank loans and investments in plant, machinery and R&D have decreased.

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A mia mamma Caterina

Contents

List of Tables

Chapter 1

Competition, Innovation and the Stock and Diversity of Knowledge

1.1 Introduction

Since Joseph Schumpeter (1934; 1942) began theorizing on the relationship between competition and innovation, there has been a hot debate concerning whether monopoly (Arrow, 1962), competition (Porter, 1990) or something in between (Aghion et al., 2005) better incites the advance of productive knowledge and value-creating innovations. Understanding this relationship is, of course, crucial given that market competition is one of our most important institutions for provoking innovation and development and it is the role of public bodies (such as industry regulators and anti-trust authorities) and increasingly the role of private actors (such as upstream technology licensors and platform owners) to deliberately shape the nature of competition that manifests. The evidence suggests that a wide array of possibilities can and do materialize, which places all the more emphasis for researchers on better understanding the underlying mechanisms governing the innovation-competition relation. [1] Nevertheless, even amidst the body of existing contingent theory, it is particularly puzzling to observe that astoundingly high levels of competition will still, in cases, tend to coincide with impressive, on-going streams of innovation and new development. For example, one of the greenest shoots of innovation in the modern economy–the Apple "apps economy" of hundreds of thousands of competing software developer firms–has produced levels of competition that are agreed to often reduce the investment incentives of developers (Boudreau, 2012; Schmidt, 2006). And yet, the number of apps developed is approaching one million, and the rate and levels of creativity do not appear to yet have slowed a bit. Moreover, neither Apple nor public authorities has uttered an inclination to restrict competition. Analogously, Google has promoted high levels of competition around its Android operating system by taking extraordinary actions to reduce entry costs and barriers. For example, it takes costly actions to facilitate the dissemination of a fully functioning platform, documentation, support, reference designs, while demanding no payments to allow hardware device designers to enter. While the company may be motivated for a number of reasons to instill the downstream hardware design industry with high levels of competition, it undoubtedly would also prefer to see high levels of innovation–and indeed it does. In this paper, we theorize and present evidence suggesting a distinct set of mechanisms linking such instances of high levels of competition and high levels of innovation. In particular, we argue that the structure and distribution of knowledge, as inputs to the innovation process in an industry, are influenced by competition in ways that can contribute to its productivity.

Decades of advances in both theory and empirical evidence now clearly demonstrate that competition impacts innovation through its effect on incentives (Aghion et al., 2005; Gilbert, 2006). For example, high degrees of close competition can, for example, make it more difficult to capture profits from innovation and thereby reduce

[1] See for example: Aghion and Griffith (2005); Cohen and Levin (1989) for empirical surveys.

innovators' incentives. By the same token, close competition can stimulate racing and rivalry among competitors while also eliminating "slack" (Aghion et al., 2001). Of course, successful innovation can itself shape market structure and incentives, as when successful innovators grow large in relation to rivals (Cohen and Klepper, 1992a; Klepper, 1996; Sutton, 1996). Higher sustained intensity of competition and resulting strategic incentives to maintain one's position can also produce enduring productivity differences through organizational learning, apart from changing scale alone (Barnett, 1997; Porter, 1990). Therefore, a private or public actor with an interest and ability to shape market structures of entire industries might do so to produce desired innovation outcomes. Competition from this perspective might be shaped in any number of ways to great effect, through means such as entry costs (license fees, provision of development tools and reference designs), direct regulation of entry (certification, licensing), scope for differentiation (limited license concessions, technical constraints of differentiation, standards-based development), or virtually through more artificial forms of regulation and interventions such as price, cost or margin-based regulation.

Of course, the above accounts of the competition-innovation link contain within them a central notion of knowledge. Knowledge, new productive knowledge is indeed the essential output of innovation in these depictions. Further, it is the differential accumulation of knowledge that leads to differences in market structure and consequent strategic incentives to innovate. Here we ask whether the structure of knowledge and its distribution across competitors *per se* shapes cumulative innovation. Here, therefore, we consider knowledge apart from its role as an *output*, but rather in its role as perhaps the most crucial *input* into the innovation process. To the extent that the structure and distribution of knowledge as an input plays a distinct role in shaping innovation outcomes, this could both change our interpretation of the strategic interventions, while also potentially suggesting other interventions that might target the structure and distribution of knowledge in an industry. Furthermore, understanding how knowledge inputs, as moderated by competition, shape the innovation process provides at least one plausible explanation for those industries where on-going streams of innovation persist despite extraordinarily intense levels of competition. [2]

As a cornerstone and starting point, we not only consider that on-going technical change, novelty and advances are largely the result of a cumulative process (Romer, 1990), but also largely the result of (re)combinations and integration of different knowledge and technologies (Fleming, 2001; Nelson and Winter, 1982; Schumpeter and Fels, 1939; Weitzman, 1998). However, notwithstanding considerable attention that has amassed regarding knowledge, diversity, and recombinant processes in innovation (Fleming, 2001; van den Bergh, 2008; Weitzman, 1998) there yet remains little work that explicitly links these knowledge processes to competitive processes.

We begin by considering the most basic features of the recombinatory processes and how these should interact in a context of industrial competition and innovation. Our broadest goal is to set forth a series of basic propositions to demonstrate the existence and operation of a separate logic regarding the structure of knowledge, distinct from market structure in the traditional sense and consequent structure of incentives. Therefore, as a starting point, outcomes of competitive innovation should not only be determined by the structure of incentives, but also simply by the availability of knowledge. Of course, the number of possible ex-post recombinations of "ideas" – recombinable quanta of knowledge or technical advances – within an industry are shaped by a kind of increasing returns. We predict there should be industry-wide collective positive returns in realized recombinations to the overall size of the pool of ideas in the industry. The effects should be large, of first-order magnitude. These and other effects predicted here should also operate independently of changes in traditional measures of industry structure.

[2]See Boldrin and Levine (2008) for kindred arguments regarding the efficacy of intensive competition, even without intellectual property rights, in promoting innovation.

We then develop a series of predictions related to how this general principle of collective positive returns should manifest itself in the context of a population of competing organizations. We strive again to develop a most basic series of predictions. For example, based on incentives, coordination costs and skills, we should expect that recombinations should be more straightforward to execute within rather than across firm boundaries. At the same time, the incidence of recombinations should also depend on the structure of knowledge in the broader industry and we argue this should benefit from both greater heterogeneity of competitors (Cohen and Malerba, 2001; Henderson and Cockburn, 1996), in the sense of more distributed knowledge and greater dissimilarity, and at the same time from the presence of a dominant "anchor tenant" (Agrawal and Cockburn, 2003), with both a concentration of knowledge and market power.

By contrast, we argue that the above dynamic processes of recombination within an industry, as related to competition, should fundamentally differ from those in relation to drawing in new ideas to an industry–and be far more responsive to traditional market structure and incentive structure arguments. Note here that this distinction on its own also highlights the importance of the structure of knowledge in making more precise predictions regarding how competition shapes the nature of innovation, apart from just its level. As regards the structure of knowledge and its distribution, we predict that entrepreneurial entry should play an especially important role by providing a mode through which novel ideas can be communicated to an industry.

Attempting to test these predictions brings several challenges. Chief among these requirements is the ability to observe the key objects of study theorized herein: "ideas" or recombinable quanta of knowledge or technology and recombinations themselves. As implied by the nature of the above arguments, in many cases our relevant unit of observation is the industry or group of competitors, itself. Thus, to implement even basic panel data methods, we must effectively observe multiple comparable industries over time, whilst observing key objects and relevant control variables.

To make progress in documenting and exploring these issues, we study detailed firm, product and product-feature level data on the generation of mobile computers from 1996 to 2005. This industry makes such a study practicable because it provides a continuous and fast flux of feature innovation and cumulative product innovation.

The essential empirical approach we take is to exploit individual product features (these devices could be understood as "bundles" of dozens of features), as the embodiment of individual concepts and ideas. For example, there is the innovation of the "jog-dial", an approach that would let the user select from a menu with one hand, the ability to "hot-synch" with a personal computer, the ability to hot-synch using infra-red or Bluetooth connection rather than a wire. The list goes on and on, as hundreds of new features and performance levels appeared in the products that were innovated in this industry. We define the unit of analysis as the idea, that can be represented by a distinct product feature, and we define a recombination as the combination of one idea with a bundle of different ideas. The number of recombinations per each idea should be related to the stock of previous knowledge, that we represent by the past stock of active ideas. A recombination can be considered as an innovation, since it is the new integration of different pieces of knowledge. Nevertheless, it is a different concept with respect to new ideas: new ideas are completely new features that appear in the market and that can be recombined. The challenge is to measure the diversity and the distribution of knowledge, since ideas are not always proprietary and many firms may own the same ideas. To overcome this issue, we create some specific indexed to capture the diversity of competitors in terms of knowledge. Moreover, we investigate how the presence of an anchor tenant, a large incumbent in terms both of market share and of knowledge capacity, and the diversity of the remaining competitors, are correlated with recombinations. Indeed, in a series of tests, we confirm the series of predictions described above.

The paper proceeds as follows. Section 1.2 documents the abundant prior literature on innovation, recombination, diversity and industry structure. Section 1.3 introduces the hypotheses formulated in order to investigate the relation between the level and the distribution of knowledge and innovation. Section 1.4 presents the dataset and the empirical framework, section 1.5 shows and discusses the results and section 1.6 summarizes the findings and concludes.

1.2 Related literature

1.2.1 Theories of "market structure", strategic incentives and technical change

This section begins by quickly touching on traditions of past research on links between competition and innovation largely related to how market structure and resulting structure of incentives shape innovation and productivity. The treatment of this extensive research in necessarily brief and partial. For a survey see Aghion and Griffith (2005).

The "Neo-Schumpeterian" literature is largely based in the industrial organization economics tradition and was set forth with Arrow (1962) seminal characterization of monopoly versus competition and its effect on willingness to make investments in the risky innovation process. This was followed by a number of other characterizations of industrial market competition and its effects on innovation incentives (Blundell, Griffith, and Van Reenen, 1999; Levin, Cohen, and Mowery, 1985). This literature made precise our understanding of several key tradeoffs created by competition, including for example the "business stealing effect" (Aghion and Howitt, 1990) and the "replacement effect" (Arrow, 1962). The closely-related stream of theoretical models on "patent races" more explicitly captured the process of risky invention itself and as a companion literature highlighted the possibility that "racing" and "rivalry" could even produce high levels, even socially excessive and redundant levels, of investment in innovation.

The endogenous growth evolution, beginning with Romer (1990) seminal contribution, brought important leaps forward in several respects. This began a tradition of explicitly modeling the on-going dynamic nature of technical change and on-going pursuit of novelty and improvement, whereby the outcomes of today's innovation should bear on the conditions of competition seen in the future. Romer's insight stimulated several new theoretical streams that began to explicate this dynamic, on-going, cumulative character of innovation. For example, models of "cumulative innovation" processes, such as those by Green and Scotchmer (1995), Bessen and Maskin (2009) began to illustrate challenges of devising institutions that could simultaneously maintain incentives for both "upstream" innovators to produce seminal innovation and for downstream innovators to build upon these. Closely related were papers that examined "general purpose technologies" whose creation is especially crucial to follow-on, downstream innovation in a wide array of application areas (Bresnahan and Trajtenberg, 1995). Closer to the to the original Romer (1990) model, other theorists attempted to explicate how dynamic processes of industrial competition could inform predictions of macroeconomic growth (Helpman, 1993), and a continuing tradition of industrial economics to predict and explain patterns of innovation within a given sector (Cockburn and Henderson, 1994). Especially notable in this regard is the relatively recent paper by Aghion et al. (2005), which provided within a single, simple model an explanation for why intensified competition may produce either increases or decreases in innovation, as the "business stealing effect" of competition weighs against a possible stimulating effect of rivalry to "escape competition".

Apart from reflecting the on-going dynamic nature of innovation, several theories have gone further towards considering how the *accumulation* of innovation as such might also somehow play a role (i.e., where not every part of a race upwards on a "quality ladder" is not simply the same of as the next). The simplest and most straightforward articulation of this idea is Sutton's (1991) notion of "endogenous sunk costs" and Klepper's (1996) "emergence of oligopoly" models, whereby success in R&D and innovation produces growth in market share, which in turn increases incentives to invest in subsequent rounds of innovation. Ericson and Pakes (1995) provide another such example where the accumulated state and history of innovation play a role in these models. Their model considers that a leading firm might instead cease to invest once it has established a lead and resume investing when its lead narrows. Apart from considering the role of accumulated scale and market structure and its role on incentives, theories of competition and innovation from Strategic Management have gone further to emphasize enduring productivity differences across firms that are themselves stimulated by competition. For example, Porter (1990) has emphasized how local market conditions can create large cross-country differences in the productivity and competitiveness of firms, even apart from their scale. Barnett (1997) emphasizes above all the learning process within industry dynamics and how competition requires investments simply to "stand still" and maintain an existing market position and wider market structure.

Thus, in relation to Romer's (1990) insight of a dynamic and cumulative process of innovation, our existing theories have gone as far as recognizing the on-going, ever ascending and advancing nature of innovation, in clarifying links between market structure, incentives and innovation outcomes due to investment patterns. Accumulation is reflected in several of our models in regards the relative advantages of given firms and consequences in subsequents "rounds" of competition. These models can generate a wide range of predictions regarding innovation and its links to incentives and market structure, depending on assumptions.

1.2.2 Empirical research on competition and innovation

Empirical studies began with many cross-sectional studies which produced all manner of positive and negative correlations between multiple measures of innovation and multiple measures of competition (see Cohen and Levin (1989) for a review). Several panel studies, beginning in the 1990s, began to offer more controlled estimates, and still produce a range of sometimes positive and sometimes negative relationships. The more recent study of aggregate patterns of innovation and competition by Aghion et al. (2005) is notable in flexibly estimating the relationship between rates of patenting and the average price-cost markup among top firms in an industry, while attempting to isolate exogenous variation in the mark-up in an instrumental variables model estimate. They—and now others (Tingvall and Poldahl, 2006)–find evidence of an "inverted-U" relationship between competition and innovation, whereby initially competition stimulates greater innovation and later it dampens it. They interpret both increases and decreases as caused by the incentives induced by variation in market structure. Several recent studies have made advances in studying sector specific data, in attempt of isolating natural experiments to more unequivocally estimate effects (Bresnahan, 1985).

1.2.3 The structure of knowledge and innovation

In this paper we stress that knowledge is also an input of the innovative process and produces itself other new knowledge on the form of recombination and innovation.

What is the effect of knowledge diversity of competitors on innovation apart from market structure in the traditional sense? Intuitively, we can think that diversity fosters innovation and recombinations, but what about the distribution of knowledge:

does a concentration of knowledge in one big competitor enhance innovation? Or does an even distribution of knowledge have a positive effect? On the other hand, what about an uneven distribution, in which competitors own different knowledge?

Innovation has been defined as a problem-solving process, in which search is the source of the discovery of solutions to economically relevant problems (Dosi, 1988). The importance of recombination as a key source of novelty and innovation dates from Schumpeter's argument that recombination is behind most technical progress (Schumpeter and Fels, 1939). Many scholars (Henderson and Clark, 1990; Schumpeter and Fels, 1939) argue that invention can be seen as a new recombination of previous components or a way to find new relationships in an existing combination. This study is in line with this view: innovation is the results of the recombination of previous and diverse knowledge.

According to the idea-based growth model (Weitzman, 1998), existing ideas can be recombined to produce new ideas and new reconfigurations of old elements and the growth of the stock of inventions increases more than exponentially with an increase in the number of ideas. The combination of different ideas leads to better ideas and meeting between agents with diversity in ideas that share their knowledge is the engine of growth. The growth of knowledge is an interactive process in which diffusion and growth are not separable (Jovanovic and Rob, 1989).

While the relevance of recombination has been widely recognised, the extent and the ways in which recombination works have not been deeply analysed. Fleming (2001), having recognised the uncertainty of technological change and inventions, tries to shed light on causes and sources of uncertainty. Recombination is influenced by cognitive, social and technological phenomena and the use and refinement of familiar components increases the usefulness of an invention and decreases the inventive uncertainty, while the cumulative usage of a combination decreases usefulness.

Another strand of the literature concentrates the attention on diversity concept and argues that the tendency to variation, ecletism and diversity seems to spur progress (Nelson and Winter, 1982).

An additional effect that has received attention mostly outside mainstream research on cumulative innovation and competition is the possibility that multiple firms may contribute with some form of "diversity". The simplest form of this may occur if newly entering firms themselves have comparative advantages and distinct ideas that can be combined with the shared pool of knowledge in the industry.

Diversity in innovative activity within industries positively affect the pace of technological change according to the empirical analysis conducted by Cohen and Malerba (2001). Which are the ways through which diversity stimulate technological progress? They argue that there are 3 ways: a selection effect, a breadth effect and a complementarity effect. Selection effect refers to the ex post selection of winning products, chosen typically for the quality and the price, through a market competitive mechanisms. In this sense, the richness of R&D approaches implies a higher expected quality of the winning product. The breadth effect is the pursuing of different, non-competing approaches in order to innovate. Given the diminishing returns to R&D projects, the more approaches and projects are followed and the better it is in terms of progress. The complementarity effect is the positive effect of the combination of knowledge generated by different R&D activities.

Henderson and Cockburn (1996) find results that suggest large returns to size in research in pharmaceutical industry: only a small part of these returns comes from economies of scale, while a key role is played by returns to scope, the diversity in the portfolio of research projects. The underlying question of this related literature is how diversity in innovative activities may stimulate technical advance and industrial performance.

More recently, the optimal level of diversity has been investigating in a model proposed by van den Bergh (2008): here the focus is recombinant innovation, namely the combination of existing alternatives, and diversity, that is an endogenous variable. This model allows to find the optimal balance between recombinant innovation and returns to scale.

Recombination within a single organization may benefit from internal coordination and incentive systems, including common knowledge, culture and jargon and thick social networks or other forms of returns to scale and scope in R&D (Henderson and Cockburn, 1996). Internal governance may therefore have integrative advantages (Teece, 1996).

1.2.4 The role of knowledge and diversity in competition and innovation

Many part of the literature imply a structure of knowledge even if they do not explicitly model it. Among the others, Aghion et al. (2005) incidentally introduce spillovers in modelling the maximum distance in technology between the leader and the follower. Competition can be considered from a different angle, that is in terms of knowledge diversity among firms: the presence of diverse firms brings different knowledge that can be recombined and may provide incentives to firms to exploit new paths and expand the search space. Multiple competitors are instead a primary instrument through which variation in experimentation is generated.

Just a few papers have begun to explicitly model the structure of knowledge and competition. The concept of absorptive capacity is introduced by Cohen and Levinthal (1990): firm investments in R&D foster the ability of firm to exploit spillovers and existing information. In this sense R&D is not only generating new knowledge and innovation, but it is also able to allow to more easily acquire external knowledge. A higher absorptive capacity allows the firm to absorb and exploit external knowledge generated either in the same industry and in outside industries.

A model presented by Acemoglu (2011) shows that equilibrium technological progress may exhibit too little diversity and too much conformity, in particular it may fail to invest in "alternative" technologies, even if it is known that these technologies will become used in the future. The diversity of researchers, that is, the presence of researchers with different interests, competences, ideas or beliefs, is therefore likely to be socially useful, since more diversified research lines are more likely to be explored.

Bresnahan (2011) concentrates his attention on the economic conditions, from an ex ante point of view, that lead the original inventions, in particular general purpose technologies, to be re-used and recombined to create new inventions.

More peripherally there are papers that deal with knowledge and firm interactions in the research on economic geography, as in Agrawal and Cockburn (2003), that bring together the concept of innovation and knowledge diversity and concentration, focusing on regional innovation systems. The results show that the presence of an anchor tenant, a large and R&D intense firm, stimulate regional innovation. The anchor tenant is R&D oriented and has absorptive capacity in a specific technological area and enhances local innovation system: this large firm can confer externalities to small firms, fostering their survival and growth.

In this paper we argue that the ex post recombination processes should be understood as a problem either of incentives in terms of profit possibilities and of recombination of knowledge. The extent of the positive effect of past knowledge on innovation vary with many factors: the total number of ideas in the market, the diversity of these ideas (incorporated in diverse firms) and spillovers create more recombination possibilities, since the process is dynamic. There is a role of formal or informal institutions from this perspective protecting appropriability, emphasis here on intensity of competition as a policy lever, related issues are intellectual property rights (IPR) mechanisms.

The role of formal or informal institution in this context is to protect appropriability of inventions and to enhance first inventor's incentive to innovate (Scotchmer, 1991). The starting point is that social returns of investments in R&D are bigger than private returns (Griliches, 1992) and so policies encouraging R&D are beneficial for the economy and provide an agent the incentive to engage in actions leading to innovate, since he is able to capture the benefits. Patent protection, depending on the length and breadth of the intellectual property right regime, allows the inventor to internalize external costs and benefits that one agent is conferring to another (Frischmann and Lemley, 2007). In setting the efficient property right system the trade off to take into account is between first innovator and second or future innovator.

In the theoretical and empirical literature of competition, innovation and spillovers an element that seems not to be deeply taken into account and recognised is the ex post efficiency effect. Conditional on the innovations and cumulative knowledge, recombination and reuse of other inventions or knowledge may be the engine for further innovations. In this setting, firms need to be able in some way to appropriate other firms' or industry technological knowledge, through spillovers, patents, licensing.

We have little theory to understand the nature of ex post recombination processes that incorporate the effect of spillovers, openness and knowledge sharing. Much of the theory underestimates the ex post efficiency effects of spillovers, as these are simply not theorized or undertheorized in most models (i.e., collective economies of cumulative spillovers). This literature does have spillovers (in the form of catching up) and cumulativeness (in the form of quality ladders), but the idea of spillovers is incidental and effectively ignores ex post efficiency effects, except some recent papers.

More recently, some work has been developed to understand the relationship between institutions and ex post recombination and innovation. Intellectual property rights protection is found to encourage experimentation and ex post socially beneficial transfer of knowledge across firms (Acemoglu, 2011). Adequate and proper incentives for innovations may lack in a competitive market and therefore policy's attention focuses on the design of right institutions to promote innovation, such as intellectual property rights (IPR). IPR aims to provide proper incentives for R&D investments by granting exclusive rights to the inventors for a period of time. Williams (2010) analyses the sequencing of the human genome by the public Human Genome Project and the private firm Celera. The findings show that Celera's IPR produces significant reductions in following scientific research and product development outcomes.

Closer to the spirit of this paper are the studies by Belenzon (2006) and by Yang, Phelps, and Steensma (2010). Spillovers are split by Belenzon (2006) in the categories of internalized spillovers, when they feed back into the research of the original inventor, increasing the private returns, and of externalized spillovers, when the original inventor does not reabsorbe the knowledge obtained by the advancements of other inventors coming from his own innovation. The implicit idea in the model of sequential innovation is that the more people have access to one innovation and can therefore recombine ideas or add new components or knowledge, the more inventions there will be and the more the society will benefit. The incentive effect leading to underinvestment in R&D is mitigated when there are internalized spillovers.

Dynamic processes and the benefits of spillovers are the focus of the paper by Yang, Phelps, and Steensma (2010), that analyse the benefit that originating firms can obtain by their own knowledge spillovers. The pool of external knowledge is unique and specific to each originating firm and it is created when originating firm spillovers are recombined with different knowledge by recipient firms. The firm's rate of innovation and the extent to which these innovations benefit and rely on the spillovers' pool are found to be higher when the spillover pool is bigger in size and the knowledge is similar to the originating firm's knowledge.

1.3 Research questions and hypotheses development

The focus of the paper is to better understand the process of cumulative innovation in terms of idea recombination and in particular to study how it is affected by existing knowledge in terms of ideas. The effect of past knowledge as a key input that influences the productivity in the innovative search process has been already recognized by Romer (1990): "Knowledge enters into production in two distinct ways. A new design enables the production of a new good that can be used to produce output. A new design also increases the total stock of knowledge and thereby increases the productivity of human capital in the research sector."

The first hypothesis to test is therefore:

Hypothesis 1: There are positive returns to recombination of ideas in number of ideas

Nevertheless, the stock of previous knowledge is not the only force driving the recombinatorial process. The structure of knowledge, therefore, has to be included in the analysis. In this sense how the process of recombination of ideas is affected by knowledge distribution across competitors (i.e., heterogeneity of competitors)? The recombination process is affected ambiguously by varying numbers of firms and features and industry structure. However, controlling for other industry structure characteristics, the recombinatoric process is unambiguously accelerated by a more diffused knowledge among competitors.

Hypothesis 2a: More diffused knowledge positively affects recombinations

Here we clarify conditions under which competition can productively shape outcomes when knowledge is imperfectly distributed. Diversity of competitors fosters cumulative innovation at collective level, a kind of industry-level increasing returns of all competitors in the market.

Previous literature (Agrawal and Cockburn, 2003) has investigated the effect of the presence of an anchor tenant firm on regional innovation systems. The anchor tenant is defined as a R&D oriented firm with absorptive capacity in a specific technological area.

The presence of an anchor tenant can enhance recombinations for the following reasons:

- It creates knowledge spillovers and externalities to small firms in the same market.
- It stimulates upstream R&D and creates a demand for new innovation.
- It has great market power and absorptive capacity in demanding and adopting new technologies and innovation.

On the other hand, diversity of small firms creates spillovers towards anchor tenant, that has a high absorptive capacity and is more able to exploit spillovers. Furthermore, R&D projects are by their inherent nature risky: the risk is lower for a large firm, due to economy of scale and scope.

Here we test if the presence of an anchor tenant, defined as the biggest incumbent and clear leader either in sales and in knowledge, is able to affect recombination possibilities. Moreover, we analyse the impact of the distribution of knowledge among the remaining competitors on recombinations.

Hypothesis 2b: The presence of an anchor tenant is positively correlated with the number of recombinations, particularly when knowledge is more distributed across the rest of the competitors

The first two hypotheses deal with aggregate analysis at market level and do not explicitly highlight firm differences and dynamics. Next, we study how firm's characteristics, specificities and knowledge affect the innovation process, in order to investigate the innovation process also at firm level. Intuitively, firm existing knowledge enhances the recombination possibilities. And which is the role played by existing knowledge in the same market? The existing knowledge in the same market may have a twofold effect: on the one hand there is a negative incentive effect, while on the other hand, in presence of spillovers, the effect is positive.

Hypothesis 3: All else being equal, the positive returns are more easily realized within firm and then within market boundaries

Firms can innovate in two ways: they can recombine existing knowledge present in the market or they can generate completely new ideas, created ex novo or imported from other industries. Here we consider the introduction of new idea process and how this process is different from the recombination of ideas present in the market. Which are the factors that foster new idea introduction by firms? This is an interesting aspect, since the more ideas are present and the larger the set of recombination possibilities.

Hypothesis 4: Firm new idea introduction is correlated with firm owned ideas but it is not correlated with firm un-owned ideas present in the market

We define firm owned ideas as the ideas that have been incorporated in products introduced by the firm. Firm un-owned ideas are ideas that the firm has not used in its products and that have been introduced in the products of other firms present in the market.

1.4 Data and empirical methods

1.4.1 Data

To test our four hypotheses we need a detailed dataset providing information about recombination of knowledge and about the stock of knowledge and its evolution and distribution across competitors over time. The appearance of new ideas and the recombination with different ideas should be observable over time. We need also data about market structure, market and firm characteristics, in order to control for the market environment and isolate the knowledge accumulation process.

Firm data that we use in our analysis come from the personal digital assistant (PDA) and smartphone industry and provide detailed information on firms, products and product features over a decade, from 1996 to 2005. We consider in the analysis only the three most important operating systems: Microsoft, Palm and Symbian. Each operating system is considered as a separate market, since it has different peculiarities and features are not easily transferable among operating systems. The sample is made of 595 products, distributed over three operating systems and 93 firms. Table 1.1 reports summary statistics that describe the data.

In this dataset we represent an idea by every individual product feature of a device: a product, in this sense, is a recombination or a bundle of dozens of ideas. The stock of knowledge is therefore the pool of relevant available features upon which a new recombinations may be created. An example of feature is the "jog-dial", that allows the user to select from a menu with one hand. The incorporation of features within physical artefacts or components (Bhechky 2003, Carlile 2004) may help recall and recombine distinct pieces of knowledge in a tangible form.

We define a recombination as the incorporation of an idea with a bundle of other ideas. Our dependent variables are the number of recombinations (*Recombos*) of a given idea by OS and by year in the aggregate analysis and the number of recombinations of a given idea by OS, by firm and by year in the firm level analysis. Moreover, we use the number of new ideas by OS, by firm and by year as a dependent variable when analysing the process of firm new idea introduction.

In the aggregate level analysis our dependent variables are the lagged stock of ideas ($IdeasStock$), *Diversity index*, that measures the distribution of knowledge across firms, and a dummy variable that accounts for the presence of an anchor tenant. In the firm level analysis the dependent variables are the lagged stock of *Owned ideas*, that is the pool of ideas used in previous products by the firm, and the lagged stock of $Un - Owned\ Ideas$, that is the pool of ideas not embedded in the firm products, but embedded in products by the other competitors in the same OS.

We control for operating system effects, for time effects and we use lagged sales at the OS level to control for market size. Moreover, we also include a control for market structure introducing the index $1 - HI$, where HI is the Herfindahl index built using firm market shares at the OS level. Finally, in the firm level analysis we add a firm sales to control for firm size, firm seniority in the market after the introduction of the first product and a dummy variable that takes value one if the firm is a new entrant.

1.4.2 Empirical approach

Our interest is in looking for evidence of a knowledge accumulation process that exhibits some sort of recombinatorial returns, and particularly whether this knowledge accumulation process is influenced also by the distribution and diversity of knowledge.

As this study represents a preliminary investigation, we employ a straightforward, transparent regression approach, as described in this section, to reveal key patterns.

In principle, a set of ideas, concepts or features might be recombined according to some recombinatoric function, R, where the feasible scope for recombinations depends on the stock of ideas ($IdeasStock$). If it is recombinatoric in nature, the function R is increasing ($R' > 0$) and convex ($R'' >> 0$). The particular form of R will depend on the internal technical logic of the design space.

In our analysis, we do not observe the full set of recombinatoric possibilities, R, that emerges as a result of an expanding pool of ideas. We observe - and are most practically interested in - the "realized" recombinations (*Recombos*). We simply presume that the recombinations that are realized are some function r that determines the fraction of feasible recombinations that are realized.

In attempting to assess any inherent effects of competition on knowledge accumulation processes, an immediate concern is if these same variables should themselves directly bear on innovation outcomes through their effect on incentives and strategic interactions. How can we discern any effects intrinsic to the knowledge accumulation processes from these effects?

As a first step towards isolating knowledge accumulation processes, we define the unit of analysis and key variables in terms of knowledge-related objects. While this does not exclude how strategic incentives might shape the knowledge accumulation, it at least allows us to abstract from the investments, profits and efforts of any one firm, as a starting point.

We define the unit of analysis as the idea, itself, and we measure the likelihood and extent to which a given idea, once created, is incorporated into novel recombinations (*Recombos*). This dependent variable (*Recombos*) is related to the stock of ideas ($IdeasStock$).

As a second step towards isolating knowledge accumulation processes, we simply directly control for the market structure including measures for competition (Herfindahl index) and market related variables (Sales).

Thus, we control for variation in factors shaping competition and appropriability conditions and this allows us to measure the link between recombinations and the distribution of ideas. Of course, no number of control variables can ever wholly control for relevant effects.

Important to note, adding these controls still allows us to study the interactions between market structure and knowledge recombination processes (i.e., the link between recombinations and the stock of knowledge). Of course, strategic incentives effects might still play a role in these interactions. We discuss this possibility while interpreting results.

Based on the preceding discussion, we model recombinations of a given idea as a function of the existing stock of knowledge, the intensity and the heterogeneity of competitors in terms of knowledge and market structure variables. Most important, given our research questions, we are particularly interested in how a set of variables related to diversity and distribution of knowledge are affecting recombination outcomes.

We should also expect that number of realized recombinations may be shaped in important ways by the inherent nature of the underlying recombinatoric logic of the technology, such as the fixity or flexibility of the technology and any number of other factors. Clearly, each particular idea or feature should have rather different scope for recombination in this sense.

Therefore, we control for inherent differences across different ideas with idea fixed effects. Further, the broader, technological regime in which innovations are developed and recombined should vary in different contexts. Fortunately, we may directly control for this variation using fixed effects corresponding to each operating system.

To go a step further, given these systems were innovated in a context of broader technological change that might have impinged on technical possibilities in unobservable ways, we also include time dummies, as controls to account for general change that may have somehow affected all the operating systems.

Given the dependent variable is a non-negative count of recombinations in a given period, we model the conditional mean as an exponential function. The exponential function also helps "scale" differences across different ideas, along with the use of idea fixed effects. As is customary, we allow idea fixed effects to enter the model in a multiplicative fashion.

A linear regression model is not appropriate since the dependent variable is a positive integer number and it can lead to biased, inconsistent and inefficient coefficients. Poisson models are often use with count data, but they have a strong assumption, since they assume that the mean and the variance of the distribution are equal. This strong assumption is not necessary using negative binomial regressions and the variance can be greater than the mean.

Here the model is estimated in a robust count model specification, to estimate autocorrelation-heteroskedastic robust standard errors and point estimates that are robust to the particular distribution of the data (Wooldridge, 1999).

This specification has the advantage to provide distribution-free estimation and consistent estimates under relatively weak assumptions: only the conditional mean needs to be correctly specified, but the standard errors usually need adjustment to account for over (under) dispersion.

To estimate the link between between recombinations and the stock and distribution of ideas, the model effectively controls for differences across systems, over time and across features. To further reduce the most obvious possible sources of endogeneity bias or correlation by construction, we lag explanatory variables.

Notwithstanding the stringent controls and narrow source of variation exploited to estimate the relationships of interest, this remains a panel model for which we cannot unequivocally rule out endogeneity bias.

1.5 Results

In this section we discuss the results on the testing of our four hypotheses. We clarify the link between recombinations and the stock and distribution of knowledge at market level and at firm level.

Hypothesis 1: There are positive returns to recombination of ideas in number of ideas

To test hypothesis 1 we run fixed-effects Poisson regressions with robust standard errors, where the dependent variable is the number of recombination a given idea (i), by OS (j) and by year (t).

The econometric specification is the following:

$$Recombos_{ijt} = exp(\alpha \cdot IdeaStock_{j,t-1} + X'_{jt} \cdot \beta + \gamma_i + \epsilon_{ijt})$$

where the variable X_{jt} represents the control variables introduced in the analysis: we use dummy variables to control for operating system effects and time effects and we control for lagged sales at the OS level. Table 1.2 shows that the coefficient of the lagged stock of ideas in the same OS is positive and significant across many specifications and control variables.

Hypothesis 2a: More diffused knowledge positively affects recombinations

To test hypothesis 2a we run fixed-effects Poisson regressions with robust standard errors, where the dependent variable is the number of recombination (*Recombos*) of a given idea (i), by OS (j) and by year (t).

The econometric specification is the following:

$$\begin{aligned} Recomb_{ijt} = exp(&\alpha \cdot IdeaStock_{j,t-1} + \alpha_2 \cdot (Div.\ index)_{j,t-1} \\ &+ X'_{jt} \cdot \beta + \gamma_i + \epsilon_{ijt}) \end{aligned}$$

where X_{jt} includes also a control for market structure, the index $1 - HI$, where HI is the Herfindahl index built using firm market shares at the OS level.

To create an index that measures the distribution of knowledge among competitors we compute a "share of ownership" for each idea present in the market by OS and by year. A firm owns an idea when the idea has been introduced in its products. The share of ownership is 1 over the number of firms that own the idea. If the share is 1, it means that only one firm has the idea, while the lower is the share and the more shared is that idea. We select only the ideas owned only by one or two firms (with a share of ownership of 1 or $\frac{1}{2}$), that is the ideas that are proprietary of either one or two firms. We drop the other ideas from the computation of the index. [3] We compute for each firm the square of the sum of the shares for all the ideas that the

[3] The same analysis was repeated including only unique ideas, that is ideas that are owned only by a firm and it leads to similar results.

firm owns, divided by the number of ideas (that are owned by one or two firms) in the same OS and same year.

The Herfindahl index built using the firm shares of diverse knowledge is used to compute *Diversity index*:

$$Diversity\ index = 1 - \sum_k \left(\frac{\sum_i \frac{1}{n_{ik}}}{\sum_k \frac{1}{n_{ik}}}\right)^2$$

where n_{ik} is the number of firms in the same OS owning idea i and k represents the firm.

Therefore *Diversity index* is an index that is higher when the knowledge in terms of diverse ideas is more distributed among competitors.

Many diversity and concentration indices are present in the literature and have their origins in ecological science, engineering and mathematics. In our case the ideas could be shared among firms and therefore it is not possible to assign a size in terms of ideas as a fraction of the total ideas, since there are overlapping ideas. Computing a share of ownership for each idea as a fraction that considers the number of firms owning the idea is a way to overcome this issue. Moreover, we are interested in the distribution of knowledge among competitors and the Herfindahl index is therefore an appropriate index.

Table 1.3 shows that the coefficients of the variable of the lagged number of ideas is positive and significant with many specifications and control variables and the more distributed is knowledge and the more recombinations are present, since the coefficient of *Diversity index* is positive and significant.

Hypothesis 2b: The presence of an anchor tenant is positively correlated with the number of recombinations, particularly when knowledge is more distributed across the rest of the competitors

Here we test if the presence of an anchor tenant, defined as the biggest incumbent either in sales and in knowledge ownership, is able to affect recombination possibilities. An anchor tenant is present in an OS when there is a clear leadership in both the two dimensions of sales and knowledge. We create a Gini index to measure the inequality in market share and we select top 25% of this index, where the market shares are unevenly distributed. An anchor tenant exists if in the selected top 25% there is a firm that is the market share leader and at the same time it is also the clear leader of the share of diverse owned ideas (used to compute the diversity index). [4]

We add the anchor tenant dummy and compute the *Diversity index* on all the competitors except the anchor tenant, when it is present.

Table 1.3 highlights that the presence of an anchor tenant fosters recombination, particularly when the knowledge is more distributed among the rest of the competitors. The lagged stock of ideas is positive correlated with the dependent variable.

After having seen the recombination dynamics at the OS level, we now turn to a firm level analysis.

Hypothesis 3: All else being equal, the positive returns are more easily realized within firm and then within market boundaries

Does firm knowledge in terms of the pool of own ideas play a role in determining firm recombinations? What about the pool of diverse ideas present in the same OS: are these ideas an advantage for the firm, for appropriability conditions, or a disadvantage in terms of incentive effects?

We consider a firm as the firm operating in a distinct OS: the same firm active in two OS is considered as two firms. The reason is that each OS has some peculiarity

[4] Palm is found to be the anchor tenant in Palm Operating System in the years 2003-2005 and HP is the anchor tenant in Microsoft Operating System in 2004 and 2005.

and ideas are not easily transferred from one OS to another and in any case few firms work in more than one OS.

To test hypothesis 3 we run fixed-effects Poisson regressions with robust standard errors, where the dependent variable is the number of recombination (Recombos) of a given idea (i), by OS (j), by firm (k) and by year (t). Features peculiarity and differences are taken into account with a model with idea fixed effect.

The econometric specification is the following:

$$Recombos_{ijkt} = exp(\alpha_1 \cdot Owned\ Ideas_{ik,t-1} + \alpha_2 \cdot Un - owned\ Ideas_{ij,t-1}$$
$$+ \alpha_3 \cdot NewEntrant_{kt} + X'_{jkt} \cdot \beta + \gamma_i + \epsilon_{ijkt})$$

where the variable X_{jt} includes also firm sales to control for firm size and the firm seniority in the market, that represents a count of the years after the first introduction of a product in the market by the firm. *NewEntrant* is a dummy variable that is equal to one when it is the first year in which the firm introduces a product in the market.

Results in Table 1.4 clearly show that own ideas largely affect the number of recombinations and that the pool of diverse ideas in the same OS seems to represent an opportunity for the firm, since the coefficient is positive and significant. The effect of own ideas is twice the impact of the stock of diverse ideas in the same OS. These findings seem to support the fact that the presence of spillovers, and in particular of internalized spillovers (Belenzon, 2006), in this sense the pool of external ideas, represent an opportunity for the firm, contrary to the incentive effect motivation.

New entrant firms foster recombinations, while the productivity in terms of recombinations is decreasing with the firm seniority in the market.

Hypothesis 4: Firm new idea introduction is correlated with firm owned ideas but it is not correlated with firm un-owned ideas present in the market

New idea introduction is a process that we expect related to firm knowledge capacity and R&D activities, that in our analysis are indirectly represented by the stock of owned ideas. Nevertheless we expect that the firm ability to generate new ideas is not necessarily related to the un-owned ideas in the same OS. These pool represents an opportunity for firms in terms of recombinations, as seen in the previous hypothesis testing, but it is not directly related to the firm ability to introduce new ideas and new knowledge.

The econometric specification is the following:

$$NewIdeas_{ijkt} = exp(\alpha_1 \cdot Owned\ Ideas_{k,t-1} + \alpha_2 \cdot Un - owned\ Ideas_{kj,t-1}$$
$$+ \alpha_3 \cdot NewEntrant_{kt} + X'_{jkt} \cdot \beta + \gamma_i + \epsilon_{ijkt})$$

Results reported in Table 1.5 confirm the effect of the stock of owned ideas on idea recombinations and of a lack of correlation between un-owned ideas in the same OS and recombinations. New entrants seem to bring more new ideas than firms already present in the OS and the productivity in terms on new ideas is decreasing with firm seniority in the market. The variable representing market structure ($1 - HI\ market\ share$) is not significant, while the same variable was significant in Table 4, where the dependent variable was recombinations. Therefore, these findings show that there are differences in the recombination of old ideas and the introduction of new ideas processes.

1.6 Conclusion

This paper investigates the process of "cumulative" innovation, defined in terms of the process of building on the existing ideas to create new innovations. A key point that has been explicitly theorized is the notion of complementarities-positive returns-to ideas, whereby bringing ideas together unlocks the possibility of still new possibilities (Cohen and Malerba, 2001). Adding more ideas to the pool, all else being equal, increases the scope for recombinations.

In this work we analyse competition from a different point of view and we clarify conditions under which competition can productively shape outcomes according to the intensity and the distribution of knowledge among competitors.

Panel data analysis using information on PDA and smartphone industry shows that the existing stock of knowledge positively affects recombinations in the market. Moreover, the process of recombinations is influenced by diversity in knowledge among the different competitors operating in the market and the presence of an anchor tenant fosters recombinations. In particular, we show that a greater distribution of knowledge among competitors fosters cumulative innovation at aggregate level-i.e., a kind of industry-level positive returns of all competitors in the market. Knowledge intensity and distribution across competitors should be of primary interest when studying innovation and competition relationship.

At firm level, firm owned ideas largely affect the firm number of firm recombinations and the pool of un–owned ideas in the same market is an opportunity to create new recombinations for the firm. The correlations found in the empirical analysis show that when studying innovation we should consider and distinguish the processes of recombinations of old ideas and the process of introduction of new ideas. Firm ability to introduce new ideas is related to firm knowledge capacity, represented by the stock of owned ideas, but it is not related to the un–owned ideas in the same market.

In this work, we have recognized the importance of the intensity and the distribution of knowledge in studying the relation between competition and innovation. However, a possible limitation of our findings is that they refer to a particular industry. Therefore, future research will be devoted to study the role of knowledge and distribution of knowledge for innovativeness in other industries, to generalize the results. Another related interesting aspect that can be investigated is the diffusion of knowledge patterns and the role of spillovers for recombinations.

1.7 Tables

Table 1.1: Sample frequencies

	Microsoft	Palm	Symbian	All
Number of products	459	109	27	595
Number of firms	73	14	6	93
Average number of ideas per year	126	55	43	80

Table 1.2: Hypothesis 1

VARIABLES	Recombos	Recombos	Recombos	Recombos
IdeaStock (t-1)	1.26***	0.85***	1.43***	1.17***
	(0.057)	(0.064)	(0.121)	(0.118)
OS sales (t-1)				0.36***
				(0.035)
OS dummies		yes	yes	yes
Time dummies			yes	yes
Observations	3,223	3,223	3,223	3,223
Number of ideas	455	455	455	455

Standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Note: the dependent variable is the number of recombination of a given idea, by OS and by year; IdeaStock is the lagged number of ideas in the same OS divided by 100; sales are the lagged units in the same OS divided by 1000

Table 1.3: Hypothesis 2a and 2b

VARIABLES	Recombos	Recombos	Recombos
IdeaStock OS (t-1)	1.37***	0.97***	0.80***
	(0.121)	(0.110)	(0.118)
Diversity index (t-1)	2.69***	2.58***	
	(0.353)	(0.346)	
Diversity index except anchor tenant (t-1)			2.99***
			(0.364)
Anchor tenant dummy			0.36***
			(0.063)
(1- HI market share) (t-1)		-0.96***	-1.36***
		(0.240)	(0.231)
OS sales (t-1)	0.21***	0.28***	0.28***
	(0.037)	(0.030)	(0.031)
OS dummies	yes	yes	yes
Time dummies	yes	yes	yes
Observations	3,223	3,223	3,223
Number of ideas	455	455	455

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Note: the dependent variable is the number of recombination of a given idea, by OS and by year; IdeaStock is the lagged number of ideas in the same OS divided by 100; sales are the lagged units in the same OS divided by 1000

Table 1.4: Hypothesis 3

VARIABLES	Recombos	Recombos
Owned Ideas (t-1)	4.60***	7.59***
	(0.251)	(0.311)
Un-owned ideas same OS (t-1)		3.44***
		(0.235)
New entrant dummy	1.73***	1.45***
	(0.097)	(0.096)
Seniority in the market	-0.23***	-0.19***
	(0.024)	(0.023)
(1-HI market share) (t-1)	-0.24	-1.04***
	(0.324)	(0.300)
Firm sales (t-1)	-0.84***	-1.01***
	(0.108)	(0.117)
OS sales (t-1)	1.27***	0.77***
	(0.051)	(0.055)
Time dummies	yes	yes
OS dummies	yes	yes
Observations	17,680	17,680
Number of ideas	301	301

Standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Note: the dependent variable is the number of recombination of a given idea, by OS, by firm and by year; owned ideas is the lagged number of ideas owned by the firm and divided by 100; un-owned ideas are the ideas of other firms in the same OS divided by 100; OS sales are the lagged units in the same OS divided by 1000; firm sales are firm lagged sales in thousand dollars

Table 1.5: Hypothesis 4

VARIABLES	New ideas	New ideas
Owned Ideas (t-1)	8.74***	9.08***
	(0.857)	(1.234)
Un-owned ideas same OS (t-1)		0.42
		(1.096)
New entrant dummy	2.43***	2.39***
	(0.564)	(0.570)
Seniority in the market	-0.67***	-0.66***
	(0.096)	(0.097)
(1- HI market share) (t-1)	-0.02	-0.12
	(0.874)	(0.902)
Firm sales (t-1)	-0.09	-0.10
	(0.251)	(0.249)
OS sales (t-1)	1.42***	1.36***
	(0.194)	(0.248)
Time dummies	yes	yes
OS dummies	yes	yes
Constant	-11.95***	-12.64***
	(1.930)	(2.588)
Observations	253	253

Robust standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Note: the dependent variable is the number of new ideas by OS, by firm and by year; owned ideas is the lagged number of ideas owned by the firm and divided by 100; un-owned ideas are the ideas of other firms in the same OS divided by 100; OS sales are the lagged units in the same OS divided by 1000; firm sales are firm lagged sales in thousand dollars

Chapter 2

Diversification of R&D sources, financial constraints and innovation

2.1 Introduction

Innovation has been recognized as a critical element in sustaining corporate survival and growth in increasing competitive markets. Accordingly, firm innovative strategies and strategic choices of R&D activities are becoming crucial to respond to market challenges. In particular, knowledge acquisition and integration play a key role in achieving innovation success. The novel combination and integration of different bodies of knowledge is the source of innovation (Nelson and Winter, 1982; Schumpeter, 1934): the greater the variety of the available inputs and the more innovation possibilities exist.

This paper explores the link between diversification of the investment in different R&D sources and innovation, focusing on the impact on financially constrained and financially unconstrained firms. A parallelism with the CAPM (Capital Asset Pricing Model) can be seen in the analysis of the diversification across different R&D sources:

the diversification in the research portfolio may decrease the risk by reducing the variance of the portfolio itself.

The first part of the paper presents a theoretical model describing the factors that determine the firms' choice to diversify the investment in R&D. According to Garcia-Vega (2006), the risk of R&D activities decreases with the diversification in the research portfolio. The variance of the returns of different R&D projects is reduced by diversifying the research sources. Moreover, technological diversification allows to avoid a lock-in effect in one technology.

A trade-off exists between the benefit and cost of diversification: on the one hand diversification decreases the risk, while on the other hand, a greater level of diversification is more expensive, because it implies to play with unfamiliar components or to have to integrate different bodies of knowledge. The final impact of diversification on innovation and on product introduction depends on the net effect of benefits and costs.

A firm that invests in more R&D sources diversifies the risk, since the portfolio exhibits less variance. Moreover, knowledge coming from different research sources brings diversity to the available pool of knowledge and this heterogeneous knowledge can be recombined and reused by the firm for different purposes.

R&D activities and their diversity have a double positive effect that creates a virtuous circle: they generate innovation and new knowledge and they also enhance the absorptive capacity, the ability of the firm to learn and assimilate other knowledge (Cohen and Levinthal, 1989). On the other hand diversification has a cost: the more a firm diversifies the investment, the less the firm specializes and exploits economy of scale and familiarity with certain research sources. In the real world firms do not exploit the advantages of diversification and are typically shown to search too locally (Dosi, 1988), in the neighbourhood of the knowledge base and in line with the past experience and routines.

The theoretical model presented in this work defines the elements and investigates the parameters' regions that lead firms to diversify or to concentrate the R&D investment. Moreover, we use data to track evidence of the correlations and the results found with this model.

The second part of the paper focuses on the impact of diversity in R&D sources on innovation success, using a large sample of Italian manufacturing firms.

The Italian innovation activities are a step back with respect to the most industrialized countries and this is also due to the predominance of small and medium firms (SMEs). SMEs face more problems in taking charge of the R&D high fixed costs and facing risky activities. Financial constraints represent another issue and access to credit for Italian firms becomes crucial to sustain firm survival and growth. Over the last years bank loans account on average for 70% of the firm financial debts, a percentage higher than in other developed countries. Moreover, the stock market is less developed than in other countries and almost 40% of bank loans are made by short term loans (12 months), while the euro area average is around 24% (Banca d'Italia, 2006-2011). Therefore, this particular debt structure has contributed to make Italian firms especially exposed and vulnerable to interest rates and refinancing risks and dependent on bank credit offer. Financial intermediaries and their credit offer limitations are likely to have a role in this Italian lack of firm size growth. R&D investments are key to achieve innovation success and at the same time these investments are more vulnerable to restrictions to the access to credit, since they are not collateralizable and are risky by their inherent nature, given that the outcome is uncertain.

Other empirical studies have been dealing with this topic and the evidence is supporting the idea that diversity fosters innovation success and patents (Berchicci, 2011; Leiponen and Helfat, 2009). The new element introduced in this analysis is the interaction between financial constraints and the diversification of the sources of R&D and its impact on innovation. We provide evidence that the diversity of

R&D investments has a positive effect on firms' innovation, especially for financially constrained firms: in particular the presence and the diversity of external research sources have a higher impact on financially constrained firms than on unconstrained ones.

The introduction of financial constraints in this analysis is particularly interesting for the Italian case, since Italy is lagging behind in terms of innovativeness with respect to other developed countries and the cause of this situation may be found in the system fragmentation in small and medium firms that have difficulties in sustaining the high fixed costs of risky R&D activities. The lack of financial resources is commonly mentioned by entrepreneurs as one of the main barrier for innovation. The stock market is a less widespread source of financing in Italy than in other countries and therefore firms are forced to turn to banks, that generally ask for collaterals to grant loans, to overcome asymmetry and information problems. Investments in R&D are often financed with internal funds, but their availability is linked to economic cycle and may not be sufficient to finance innovation activities in a continuous way.

This paper is organized as follows. Section 2.2 documents the literature on diversity and innovation on the one hand and on financial constraints and investment decisions on the other hand. Section 2.3 presents the theoretical model illustrating the trade-off between diversification and concentration of R&D investments. Section 2.4 and 2.5 illustrate the data, the variables used in the analysis and the econometric specification. Section 2.6 discusses the results of the empirical analysis and section 2.7 concludes the paper summarizing the main findings. An appendix with a detailed description of the variables used in the empirical analysis can be found in section 2.8.

2.2 Related literature

Innovation has been characterized as a problem-solving process, in which search is the source of the discovery of solutions to economically relevant problems (Dosi, 1988). The novel combination and integration of different bodies of knowledge results in innovation (Nelson and Winter, 1982; Schumpeter, 1934).

A relatively recent strand of the literature concentrates the attention on how diversity in innovative activities may stimulate technical advance, growth and industrial performance. The tendency to diversity seems to foster progress according to Marshall (1961) and Nelson and Winter (1982). The combination of different ideas leads to better ideas and meeting between agents with diversity in ideas that share their knowledge is the engine of growth (Jovanovic and Rob, 1989).

Henderson and Cockburn (1996) find results suggesting large returns to size in research in pharmaceutical industry: however, only a small part of these returns comes from economies of scale, while a key role is played by returns to scope, the diversity in the portfolio of research projects. A model presented by Acemoglu (2011) shows that equilibrium technological progress may exhibit too little diversity and too much conformity, in particular it may fail to invest in "alternative" technologies, even if it's known that these technologies will become used in the future. The diversity of researchers, that is, the presence of researchers with different interests, competences, ideas or beliefs, is therefore likely to be socially useful, since more diversified research lines are more likely to be explored.

The dilemma concerning the choice and the trade-off between exploration of new possibilities and exploitation of old certainties is studied by March (1991). More recently, the optimal level of diversity has been investigating by van den Bergh (2008) in a model of endogenous diversity that allows to find the optimal balance between recombinant innovation and returns to scale.

Firms search and solve problems in order to create new products: according to Katila and Ahuja (2002) the two dimensions of search are depth and scope. Search depth has been defined as the depth in reusing the actual knowledge, while search scope has been described as the degree of exploration of new knowledge. Search depth has a positive impact on innovation, because of experience with the same elements that reduces the likelihood of errors, makes effects more predictable and increases the knowledge of the concepts. On the other hand, rigidity, diminishing returns and negative effects on innovation can emerge in presence of excessive depth. Search scope positively affects innovation, through the diversity brought to the available pool of knowledge and enhancing recombinatory search. Excessive scope negatively impacts the possibility of finding new combinations, because of the costs of integrating extremely diverse piece of knowledge and because of the organizational challenge.

Diversity in innovative activity within industries positively affect the pace of technological change according to the empirical analysis conducted by Cohen and Malerba (2001). Which are the ways through which diversity stimulate technological progress? They argue that there are 3 ways: a selection effect, a breadth effect and a complementarity effect. Selection effect refers to the ex post selection of winning products, chosen typically for the quality and the price, through a market competitive mechanisms. In this sense, the more competing R&D approaches, the more diverse firms to solve problems, the more competing variants of a product and the higher is the expected quality of the winning product. The breadth effect is the pursuing of different, non-competing approaches in order to innovate. Given the diminishing returns to R&D projects, the more approaches are followed and the better it is in terms of progress. The complementarity effect is the positive effect of the combination of knowledge generated by different R&D activities.

The implications of technological diversity on innovative activity have been studied using a dataset of European firms by Garcia-Vega (2006): a higher degree of diversification fosters R&D intensity and patents. The possible explanations are that diversification prevents lock-in effect in one technology, reduces the risk associated to innovative activities and creates incentives to invest more in technology. Furthermore, it allows to better exploit spillovers from other related technological fields.

Leiponen and Helfat (2009) provide evidence that multiple parallel innovation objectives and a large number of knowledge sources are associated with successful innovation in a sample of firms in Finland: pursuing more objectives or having more R&D sources increases the probability of a successful innovation. Innovation is the result of a combination of knowledge: increasing the number of knowledge sources fosters the likelihood of innovation success, even though diminishing marginal returns may affect the breadth of knowledge sources. The findings of a study on a large sample of R&D - intensive Italian firms suggest that the heterogeneity and the intensity of R&D partnership positively affect innovative activity success (Berchicci, 2011).

An aspect that has been neglected in these studies is that the R&D investments are difficult to finance, since they are not easily collateralizable. In this sense, financial constraints play a key role in the investments in innovative activities. A large body of the literature has been investigating the link between financial constraints, firm investments and innovative activities. According to Modigliani and Miller (1958), internal and external sources of finance are perfect substitute, under perfect capital market: the availability of internal liquidity should not have an impact on investments. However, the real world presents frictions, information asymmetry and contract enforcement problems and a large number of empirical studies shows that financial constraints matter in investment decisions (Himmelberg and Petersen, 1994) and that the access to adequate financing influences the growth and entry of firms (Aghion, Fally, and Scarpetta, 2007).

The identification of internal finance as an important determinant of firm investments in R&D dated back to Schumpeter (1942). The presence of information asymmetries between firms and external suppliers of money makes it difficult and expensive to raise external funds and it is one reason of the use of internal funds for R&D investments (Myers and Majluf, 1984). Moreover the output of R&D investments cannot be forecasted in advance and it is uncertain.

An empirical study conducted in high-tech industries by Himmelberg and Petersen (1994) finds that the effect of internal finance on R&D investment is fundamental. However, the empirical studies concerning the effect of financial constraints on R&D investment are not conclusive and financial constraints are often measured only by cash flow (Himmelberg and Petersen, 1994). Cash flow sensitivities reflect financial constraints in a biased way. Savignac (2008) overcomes this issue using a direct qualitative indicator of financial constraints based on firms' own assessment. He finds that the likelihood to have innovative activities is reduced in presence of financial constraints, taking into account the endogeneity of financial constraints.

The impact of financial constraints on firm investment in innovative activity in the UK is the focus of the paper by Canepa and Stoneman (2008): they find out, using firms' answers to a survey, that financial factors do matter on innovative activity and in particular that this impact is greater for firms in high-tech sectors than in low-tech sectors and for small firms than for large firms.

Aghion, Fally, and Scarpetta (2007) find in their empirical analysis that finance matters most for the entry of small firms, in particular in sectors more dependent upon external finance. This is not surprising because small firms, as stated in previous works, face the largest financial constraints. Moreover, post-entry growth of firms is enhanced by financial development and regulations may influence entry and post-entry growth.

2.3 Model

We consider a risk averse firm. In order to innovate the firm has two possible research sources, A and B, and has to decide the level of investment in R&D for the two sources (α for source A and $= 1 - \alpha$ for source B, where $0 \leq \alpha \leq 1$). Innovation is a risky activity and the likelihood of an innovation success is uncertain.

We suppose that the profits of the two sources and the associated probabilities of success of the relative innovation are the following:

$$\begin{cases} p_{LL}, \quad \pi_A = 0 \quad \text{and} \quad \pi_B = 0 \\ p_{HH}, \quad \pi_A = 1 \quad \text{and} \quad \pi_B = 1 \\ p_{HL}, \quad \pi_A = 1 \quad \text{and} \quad \pi_B = 0 \\ p_{LH}, \quad \pi_A = 0 \quad \text{and} \quad \pi_B = 1 \\ \end{cases}$$

where p_{LL} is the probability when the state of the world is *low* for both the sources, p_{HH} is the probability when the state of the world is *high* for both the sources, p_{LH} is the probability when the state of the world is *low* for the source A and *high* for source B and p_{HL} is the probability when the state of the world is *high* for the source A and *low* for source B.

The firm faces a trade-off between the concentration of the investment in only one source and the diversification in two sources: if the firm invests in only one source the expected profit is higher (for example because of economy of scale and familiarity and less costs in integrating the knowledge) but also the variance of the profit may be higher. The net effect of these elements will determine the firm's choice in term of diversification.

The firm has to maximize the following objective function:

$$\alpha \cdot \pi_A + (1 - \alpha) \cdot \pi_B - \frac{\gamma}{2} \cdot \text{Var}(\pi) - c \cdot \alpha \cdot (1 - \alpha)$$

where γ is the risk aversion coefficient and c represents the cost of R&D. The total costs of R&D is minimized when the firm does not diversify and invests only in one research source: this makes the expected profit higher when the firm does not diversify. On the other hand, we have to carefully consider the other component of the expected profit ($\frac{\gamma}{2} \cdot \mathrm{Var}(\pi)$) that depends on the variance-covariance matrix and in particular on the covariance between the two sources.

Given that x is the pay-off linked to a R&D source, the variance-covariance matrix Σ is:

$$\begin{bmatrix} E[(x_A - \mu_A)(x_A - \mu_A)] & E[(x_A - \mu_A)(x_B - \mu_B)] \\ E[(x_B - \mu_B)(x_A - \mu_A)] & E[(x_B - \mu_B)(x_B - \mu_B)] \end{bmatrix}$$

where

$$E[(x_A - \mu_A)(x_A - \mu_A)] = \alpha \cdot (p_{LL} + p_{LH}) \cdot (p_{HH} + p_{HL})$$

$$E[(x_A - \mu_A)(x_B - \mu_B)] = E[(x_B - \mu_B)(x_A - \mu_A)] = \alpha \cdot (1 - \alpha) \cdot (p_{HH} \cdot p_{LL} - p_{HL} \cdot p_{LH})$$

$$E[(x_B - \mu_B)(x_B - \mu_B)] = (1 - \alpha) \cdot (p_{LL} + p_{HL}) \cdot (p_{HH} + p_{LH})$$

Therefore, the firm's objective function is:

$$\begin{aligned}
&\alpha \cdot (p_{HH} + p_{HL}) + (1-\alpha) \cdot (p_{HH} + p_{LH}) \\
-\frac{\gamma}{2} \cdot [\alpha \cdot (p_{LL} + p_{LH}) \cdot (p_{HH} + p_{HL}) &+ (1-\alpha) \cdot (p_{HH} + p_{LH}) \cdot (p_{LL} + p_{HL})] \\
&-\gamma \cdot (\alpha - \alpha^2) \cdot (p_{HH} \cdot p_{LL} - p_{HL} \cdot p_{LH}) - c \cdot (\alpha - \alpha^2)
\end{aligned}$$

where $c \geq 0$ and typically the risk aversion coefficient γ ranges between 2 and 4.

To discuss the possible outcomes with respect to diversification choices, we present and show the results for two different cases.

In the first case $p_{HH} = p_{LH} = p_{HL} = p_{LL} = \frac{1}{4}$ and the firm's objective function is:

$$\frac{1}{2} - \frac{\gamma}{8} - c \cdot \alpha + c \cdot \alpha^2 \tag{2.1}$$

Therefore the firm does not diversify the investment in R&D ($\alpha = 0$ or $\alpha = 1$), because the diversification implies only more costs and does not imply advantages in terms of a decrease in the associated risk. The case in which $p_{HH} = p_{LL} = \frac{1}{2}$ and $p_{LH} = p_{HL} = 0$ is a similar case that implies a no diversification strategy and can be included in this first scenario.

In the second case $p_{HH} = p_{LL} = \frac{1}{10}$ and $p_{LH} = p_{HL} = \frac{4}{10}$ and the firm's objective function is:

$$\frac{1}{2} - \frac{\gamma}{8} + \frac{15}{100}\gamma \cdot (\alpha - \alpha^2) - c \cdot \alpha + c \cdot \alpha^2 \tag{2.2}$$

The diversification choice in this case depends on the cost c and on the coefficient of risk aversion γ:

$$
\begin{cases} \alpha = 0 \quad \text{or} \quad \alpha = 1 & \text{if} \quad c \geq \frac{3\gamma}{20} \\ \alpha = \frac{1}{2} & \text{if} \quad c < \frac{3\gamma}{20} \end{cases} \tag{2.3}
$$

The firm diversifies the investment only if the cost of diversification is under a certain threshold ($c < \frac{3\gamma}{100}$), when the benefit from a reduction in the risk of the portfolio overcomes the cost.

Firms with financial constraints face more frictions in asking financial resources in order to sustain R&D investments. We now examine how R&D expenses vary with respect to the presence of financial constraints and in particular we focus on the two scenarios analysed in the previous section. We assume that firms without liquidity problems can finance a R&D project if the expected profit is positive, while firms with financial constraints need to have the expected profit greater than a positive parameter r, that represents the opportunity cost of money.

In the first case, where $p_{HH} = p_{LH} = p_{HL} = p_{LL} = \frac{1}{4}$, the firm does not diversify the R&D investment and invests if the following condition applies:

$$
\frac{1}{2} - \frac{\gamma}{8} > r \tag{2.4}
$$

Considering the typical risk aversion coefficient γ that ranges from 2 to 4, the firm is able to finance the project if $0 \leq r < \frac{1}{4}$: in particular for $\gamma = 2$, $0 < r < \frac{1}{4}$, while for $\gamma = 4$, the firm can invest only if there is no financial constraints ($r = 0$).

In the second case, where $p_{HH} = p_{LL} = \frac{1}{10}$ and $p_{LH} = p_{HL} = \frac{4}{10}$, the firm diversifies the investment only if the cost of diversification is under a certain threshold ($c < \frac{3\gamma}{100}$). If the cost c is higher than the threshold $\frac{3\gamma}{100}$, the firm focuses in only one R&D sources and we end up to the first case.

If the cost is lower than $\frac{3\gamma}{100}$, the firm diversifies the R&D effort when the following condition applies:

$$\frac{1}{2} - \frac{\gamma}{8} + \frac{15}{400}\gamma - \frac{1}{4} \cdot c > r \tag{2.5}$$

When $\gamma = 2$ the firm invests in the two projects if $r < \frac{31}{50}$ and $c < \frac{3}{50}$, while when the firm is more risk averse with $\gamma = 4$, the projects are financed if $r < \frac{3}{20}$ and $c < \frac{3}{25}$.

This model therefore shows that there are regions of the parameters where financial constraints have a role in influencing the choice of firms to diversify R&D investments.

2.4 Econometric specification

In this section we aim at investigating the interaction between the diversification of R&D investments and the presence of financial constraints in a dataset of Italian manufacturing firms.

We use probit maximum likelihood estimation to analyse the data, since the dependent variable is binary. Our first baseline model is the following:

$$\begin{aligned}
\text{Innovation} = {} & \alpha_0 + \alpha_1 \cdot \text{fin. constraints} + \alpha_2 \cdot \text{External R\&D} \\
& + \alpha_3 \cdot \text{External R\&D } \cdot \text{fin. constraints} + \alpha_4 \cdot \text{Internal R\&D} \\
& + \alpha_5 \cdot \text{Internal R\&D} \cdot \text{fin. constraints} + \alpha_6 \cdot \text{Control} + \epsilon_i
\end{aligned} \tag{2.6}$$

We repeat the same analysis splitting the sample in two subsets: a group of financially constrained firms and another group of financially unconstrained firms and the econometric specification is the following:

$$\begin{aligned}
\text{Innovation} = {} & \beta_0 + +\beta_1 \cdot \text{Presence or number of external R\&D} \\
& + \beta_2 \cdot \text{Internal R\&D} + \beta_3 \cdot \text{Control} + \epsilon_i
\end{aligned} \tag{2.7}$$

In the analysis of this model we compare the coefficients β_1 and β_2 for the two subsets of firms, to see if there are any relevant differences.

2.5 Dataset

Firm data come from the Unicredit survey "Indagine sulle imprese manufatturiere" ("Surveys of Italian Manufacturing Firms") on Italian manufacturing firms with more than 10 employees, published every 3 years. [1] We explore two waves of data: the 2001 survey, which refers to 1998-2000, and the 2004 survey, that refers to 2001-2003. The dataset is not a panel dataset, since the firms analysed are not necessarily the same in the two waves and it is supplemented also with standard balance sheet variables. The data include all the firms with more than 500 employees and a selection of smaller firms, obtained using a sampling design stratified by area, industry and firm size. The sample is statistically representative of the Italian firms in the manufacturing sector.

The surveys contain respectively 4680 firms for 2001 wave and 4289 firms for 2004 wave, although for many variables the dataset shows incomplete information.

We measure innovation success building a binary variable (0,1) using the following questions answered in the survey:

- In the last 3-year period have the firm realized product innovation?
- In the last 3-year period have the firm realized process innovation?
- In the last 3-year period have the firm realized organizational-management innovation connected to product innovation?
- In the last 3-year period have the firm realized organizational-management innovation connected to process innovation?

[1] The surveys considered in this work were carried out by the Research Department of Capitalia Banking group. In 2007 Capitalia was acquired by Unicredit Group.

The dependent binary variable indicating the innovation success takes value 1 if at least one of the innovations has been realized (at least one of the questions with a "yes" answer).

We use a direct measure of the existence of financial constraints, using a specific question of the survey. The question asks if the firm would have desired a higher amount of credit at the same interest rates agreed with the bank. Therefore we are able to identify two subsets of firms: firms that we can define as financially constrained, for which the variable takes value 1, and firms that are not, for which the variable takes value 0. This measure of financial constraints is in line with the definition provided by Stiglitz and Weiss (1981): a firm is considered to be credit rationed when it does not get as much credit as it wants, even if the firm is willing to meet the conditions established by the lenders.

We build a series of variables of interest indicating the number of R&D sources, the presence of internal or external R&D sources and we provide different indicators to test the robustness of the findings. [2]

We construct a variable indicating the number of R&D sources, by summing the binary variables indicating the presence of a different source. The available sources are: internal research, universities, research centres (National Research Council or CNR, specialized centres), other firms and other external sources. Thus, this variable has a maximum value of five.

The existence of internal R&D is captured by a binary variable that takes value 1 if the firm has invested in internal R&D and 0 otherwise, while we use a binary variable indicating the presence of external R&D sources, that takes value 1 if the firm has invested in at least one external source of R&D (universities, research centres, other firms and other external sources) and 0 otherwise. An interaction term between financial constraints and either the the existence of internal sources or of external

[2] In the appendix all the variables are explained in details.

sources is created.

We build a variable indicating the number of external R&D sources, by summing the binary variables indicating the presence of different external sources (universities, research centres, i.e. National Research Council, specialized centres, other firms and other external sources). This variable has a maximum value of four.

The presence and the diversification of R&D activities are not the only variables that matter for innovation. Therefore we control for many factors that may have an impact on firm innovation success. Firm size in terms of employees (natural logarithm of number of employees) is likely to affect innovativeness, because larger firms generally have more human and financial resources and they are more able to achieve innovation success. The percentage of total employees in R&D activities may also have an impact, since the greater the number of employees in R&D and the higher the likelihood to have innovations. The percentage of total employees with a degree is used to proxy for education, skills and knowledge that may foster innovation. We also control for the presence of exportations over the last 3 years, because the incentives to innovate may be higher in presence of exportations. A firm may belong to a business group, either in a subsidiary or a holding company position, and this may affect the knowledge and the resources available and therefore indirectly affect innovation. Moreover, some firms receive R&D tax incentives or R&D national and/or European public incentives and have an advantage in undertaking innovation activities. Finally, we also control for the sector of activity, the region where the firm is located and for patent acquisition over the last 3 years.

Table 2.1 illustrates the descriptive statistics of the variables used in the empirical analysis.

2.6 Results and discussion

Table 2.2 reports the results from probit regressions. Column 1 shows that a greater breadth of R&D sources, measured by the total number of R&D sources, is associated with a higher innovation success: this finding is in line with the investigation of previous empirical analyses (Berchicci, 2011; Leiponen and Helfat, 2009).

Columns 2-4 report probit regressions investigating the effect of the interaction term between the presence of financial constraints and the presence of external or internal R&D sources. The coefficients of the interaction term between the presence of financial constraints and the presence of external sources (α_3) is positive and significant in all the three specifications with different control variables: this means that the presence of external sources for financially constrained firms has a positive greater effect on innovation success than for unconstrained firms. The coefficient of the presence of external sources is positive and significant in all the models.

The presence of internal R&D sources has a positive and significant impact on the innovation success, while the interaction term with the financial constraint variable is not significant: there is not a difference in the effect of the existence of internal research between financially constrained and unconstrained firms.

The models displayed in Table 2.3 are similar to Table 2.2, but present different specification of the external R&D sources variables: in columns 1 and 2 the presence of external sources means all the types of external research (including patent acquisition), while in columns 3 and 4 it means the existence only of external sources (included patent acquisition) without having internal sources.

As previously mentioned, a direct measure of the existence of financial constraints, using a specific question of the survey, allows us to split the sample in two subsets of firms: firms that we can defined as financially constrained (that answered "yes" to that question) and firms that are not (that answered "no" to that question). The partition of the sample is not made using financial and cash flow indicators or firm size, that can present more endogeneity issues, but using a question not related to R&D investments and innovation activities that directly ask the firms if they are financially constrained (if they would have desired a higher amount of credit at the same interest rates agreed with the bank).

Table 2.4 presents the results of probit regression with the sample split: columns 1 and 2 concern financially constrained firms and columns 3 and 4 show the findings for firms without financial constraints. These results confirm the previous analyses showed in Table 2.2: the diversification of external R&D sources (the variable number of external R&D sources) is more important for the innovation success for financially constrained firms than for unconstrained ones.

The external diversification of research activities is found to be an important element for achieving innovations, but the importance is more striking for financially constrained firms.

The returns of R&D investments are uncertain by their inherent nature and take time to realize. Firms in good financial shape can invest in internal research and wait for the returns over time, but financially constrained firms have more troubles in affording these uncertain returns. Therefore, it is more promising for them to turn to external sources, that allow them to internalize knowledge and to be more innovative: financially constrained firms face more obstacles in asking to lenders money to invest in internal R&D, since this is not a collateral and because of the uncertainty associated.

2.7 Conclusion

This work studies the mechanisms that shape the link between diversity of R&D sources and innovation, focusing on the presence of financial constraints.

We investigate the trade-off that a firm faces between the concentration of the investment in only one source and the diversification in two sources. If the firm invests only in one source, the expected profit is higher and this is due to economy of scale, familiarity and because it is less expensive in terms of cost of integrating knowledge. On the other hand, the diversification in the research portfolio may decrease the risk by reducing the variance of the portfolio itself: the impact on the risk depends on the correlation between the outcome of the two R&D sources. The net effect of these elements determines the firm's choice in terms of diversification.

The empirical analysis uses a sample of Italian manufacturing firms and clearly shows that the diversity of R&D sources has a positive effect on firms' innovation, especially for financially constrained firms.

The introduction of financial constraints in this analysis is particularly interesting for the Italian case, since Italy is lagging behind in terms of innovativeness with respect to other developed countries and the cause of this situation may be found in the fragmentation in small and medium firms that have difficulties in sustaining the high fixed costs of risky R&D activities. The lack of financial resources is commonly mentioned by entrepreneurs as one of the main barrier for innovation. Access to credit for Italian firms becomes crucial to sustain firm survival and growth.

The external diversification of research activities is found to be a powerful element for achieving innovations, but the importance is more striking for financially constrained firms. In particular, the presence and the diversity of external research sources have a higher impact on financially constrained firms than on unconstrained ones. Financial constrained firms face more obstacles when asking to lenders money to invest in R&D, because of the lack of a collateral and because of the uncertain returns associated. Therefore it is more crucial for them to turn to external sources, in order to compensate the lack or financial resources. R&D source diversification allows to reduce the risk of the investments, to prevent lock-in effect and to acquire different knowledge that enhances firm absorptive capacity allowing to exploit more external spillovers from related technological fields. Therefore, the access to different sources becomes key for financially constrained firms to compensate the lack of financial resources that does not allow them to heavily invest in R&D, particularly in internal R&D activities, that require high fixed costs and that are risky.

2.8 Data appendix

Below we describe the variables used in the regressions.

Financial constraints: we use a direct measure of the existence of financial constraints, using a specific question of the survey. The question asks whether the firm would have desired a higher amount of credit at the same interest rates agreed with the bank. Therefore we are able to identify two subsets of firms: firms that we can define as financially constrained, for which the variable takes value 1, and firms that are not, for which the variable takes value 0. This measure of financial constraints is in line with the definition by Stiglitz and Weiss (1981): a firm is considered to be credit rationed when it does not get as much credit as it wants, even if the firm is willing to meet the conditions established by the lenders.

We build a series of variables indicating the number of R&D sources, the presence of internal or external R&D sources and we provide different indicators to test the robustness of the findings.

Number of R&D sources: we construct this variable indicating the number of R&D sources, by summing the binary variable indicating the presence of different sources. The different sources are: internal research, universities, research centres (National Research Council or CNR, specialized centres), other firms and other external sources. This variable has a maximum value of five.

Existence of internal R&D: this binary variable takes value 1 if the firm has invested in internal R&D and 0 otherwise.

Existence of external R&D: this binary variable takes value 1 if the firm has invested in at least one external source of R&D (universities, research centres, other firms and other external sources) and 0 otherwise.

Existence of external R&D or patent acquisition: this binary variable takes value 1 if the firm has invested in at least one external source of R&D (universities, research centres, other firms and other external sources) or have acquired patents and 0 otherwise. In this case we consider patent acquisition as a form of indirect investment in external research sources.

Presence of only external R&D or patent acquisition: this binary variable takes value 1 if the firm has invested in only at least one external source of R&D (universities, research centres, other firms and other external sources) or has acquired patents and has not invested in internal R&D and 0 otherwise.

Number external R&D sources: we construct this variable indicating the number of external R&D sources, by summing the binary variables indicating the presence of different external sources (universities, research centres, i.e. National Research Council or CNR, specialized centres, other firms and other external sources). This variable has a maximum value of four.

The natural logarithm of number of employees: we control for firm size in terms of employees.

R&D employees over total employees: the percentage of total employees employed in R&D activities.

Export: this is a binary variable that indicates if a firm has exported in the last 3 years. This variable takes value 1 in presence of exportations and 0 otherwise.

Patent acquisition: this is a binary variable with value 1 if a firm has acquired patents in the last 3 years and 0 otherwise.

Employees with a degree over total employees: the percentage of total employees with a degree.

Group: this binary variable that takes value 1 if the firm belongs or not to a business group (either in a subsidiary or a holding company position) and 0 otherwise.

R&D incentives: binary variable that accounts for the R&D tax incentives or R&D national and/or European public incentives. This variable has value 1 if the firm has received at least one of the two incentives in the last 3 years and 0 otherwise.

Sector of activity: the sector of activity is assigned following the Pavitt classification, that distinguishes traditional sectors, scale sectors, specialized sectors, high technology sectors and other sectors. Traditional sectors include textiles, footwear, food and beverages, paper and printing and wood; scale intensive sectors include basic metals and motor-vehicles, trailers and semi-trailers; specialized sectors include machinery and equipment, office, accounting and computing machinery and medical, precision, and optical instruments; high technology sectors include chemicals, pharmaceuticals and electronics.

Region: the region of Italy where the firm is located. The regions are: Abruzzo, Basilicata, Calabria, Emilia-Romagna, Friuli-Venezia Giulia, Lazio, Liguria, Lombardia, Marche, Molise, Piemonte, Puglia, Sardegna, Sicilia, Toscana, Trentino-Alto Adige, Umbria, Valle d'Aosta and Veneto.

2.9 Tables

Table 2.1: Descriptive statistics

	Mean	Std. Dev.	Min	Max
Innovation	0.59	0.49	0.00	1.00
Number R&D sources	0.65	0.91	0.00	5.00
Number external R&D sources	0.27	0.58	0.00	4.00
External R&D	0.23	0.42	0.00	1.00
Internal R&D	0.38	0.48	0.00	1.00
External R&D or patent acquisition	0.24	0.43	0.00	1.00
Only external R&D	0.24	0.43	0.00	1.00
Financial constraints	0.17	0.38	0.00	1.00
Logarithm employees	3.78	1.11	2.40	9.44
R&D employees over total employees	0.05	0.08	0.00	1.00
Patent acquisition	0.02	0.14	0.00	1.00
Export	0.71	0.45	0.00	1.00
Belong to a group	0.26	0.44	0.00	1.00
R&D subsidies	0.45	0.50	0.00	1.00

Table 2.2: Probit regression: breadth of R&D sources and interaction between external or internal sources and financial constraints

VARIABLES				
Fin. constr.	0.02	0.10	0.11	0.12
	(0.055)	(0.068)	(0.069)	(0.071)
Number R&D sources	0.50***			
	(0.031)			
Internal R&D		0.77***	0.77***	0.84***
		(0.051)	(0.051)	(0.068)
Internal R&D * Fin. constr.		-0.18	-0.19	-0.22
		(0.107)	(0.107)	(0.131)
External R&D		0.35***	0.35***	0.31***
		(0.055)	(0.055)	(0.070)
External R&D * Fin. constr.		0.27*	0.26*	0.39*
		(0.131)	(0.131)	(0.169)
Log employees	0.15***	0.14***	0.15***	0.12***
	(0.023)	(0.020)	(0.022)	(0.025)
R&D employees	2.44***	1.90***	1.89***	1.86***
	(0.374)	(0.325)	(0.327)	(0.373)
Export	0.12*	0.14**	0.14**	0.14**
	(0.049)	(0.044)	(0.044)	(0.048)
Empl. with degree	0.04			
	(0.273)			
Patent acq.	0.41*		0.51**	0.64**
	(0.178)		(0.164)	(0.203)
Group			-0.05	-0.03
			(0.046)	(0.053)
R&D subsidies				0.77***
				(0.050)
Year	0.22***	0.23***	0.24***	-0.13*
	(0.051)	(0.044)	(0.044)	(0.056)
Sector	yes	yes	yes	yes
Region	yes	yes	yes	yes
Constant	-0.87***	-0.85***	-0.85***	-0.94***
	(0.145)	(0.130)	(0.132)	(0.151)
Observations	4,729	5,790	5,754	4,470

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Note: the dependent binary variable indicating the innovation success takes value 1 if at least one of the innovations among product, process and organizational-management innovation linked to product or process innovation has been realized

Table 2.3: Probit regression: alternative specification of the interaction between external or internal sources and financial constraints

VARIABLES	.				
Fin. constr.	0.11	0.12	0.10	0.11	0.05
	(0.068)	(0.071)	(0.068)	(0.071)	(0.062)
R&D ext. or patent acq. * fin. constr.	0.25*	0.41*			
	(0.130)	(0.168)			
R&D ext.or patent acq.	0.37***	0.33***			
	(0.054)	(0.068)			
Internal R&D	0.77***	0.83***	0.77***	0.84***	
	(0.051)	(0.068)	(0.051)	(0.068)	
Internal R&D * fin. constr.	-0.18	-0.22	-0.18	-0.24	
	(0.107)	(0.131)	(0.108)	(0.133)	
Only ext. R&D or pat. acq. * fin. constr.			0.27*	0.45**	0.29*
			(0.130)	(0.167)	(0.143)
Only ext. R&D or pat. acq.			0.34***	0.29***	0.55***
			(0.054)	(0.070)	(0.062)
Log employees	0.14***	0.12***	0.14***	0.12***	0.17***
	(0.020)	(0.025)	(0.020)	(0.023)	(0.022)
R&D employees	1.89***	1.88***	1.92***	1.89***	3.71***
	(0.326)	(0.372)	(0.326)	(0.370)	(0.342)
Export	0.14**	0.15**	0.14**	0.15**	0.19***
	(0.044)	(0.048)	(0.044)	(0.048)	(0.047)
Group		-0.03			
		(0.053)			
R&D subsidies		0.78***		0.78***	0.67***
		(0.050)		(0.050)	(0.048)
Year	0.23***	-0.13*	0.23***	-0.14*	-0.33***
	(0.044)	(0.055)	(0.044)	(0.055)	(0.051)
Sector	yes	yes	yes	yes	yes
Region	yes	yes	yes	yes	yes
Constant	-0.84***	-0.95***	-0.84***	-0.94***	-0.84***
	(0.130)	(0.150)	(0.130)	(0.149)	(0.146)
Observations	5,790	4,493	5,790	4,501	4,537

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Note: the dependent binary variable indicating the innovation success takes value 1 if at least one of the innovations among product, process and organizational-management innovation linked to product or process innovation has been realized

Table 2.4: Probit regressions with sample split

VARIABLES	Firms with financial constraints		Firms without financial constraints	
No. R&D sources	0.46***		0.49***	
	(0.090)		(0.045)	
Internal R&D		0.65***		0.93***
		(0.175)		(0.086)
No. ext. R&D sources		0.33*		0.22***
		(0.131)		(0.061)
Log employees	0.11	0.10	0.15***	0.13***
	(0.070)	(0.071)	(0.029)	(0.029)
Empl. with degree	1.00	0.98	0.01	0.03
	(0.912)	(0.917)	(0.341)	(0.342)
R&D employees	0.52	0.29	3.45***	2.40***
	(0.745)	(0.778)	(0.582)	(0.596)
Export	0.16	0.17	0.13*	0.12*
	(0.130)	(0.130)	(0.060)	(0.060)
Patent acquisition			0.53*	0.51*
			(0.230)	(0.229)
R&D subsidies	0.50***	0.51***	0.78***	0.83***
	(0.133)	(0.134)	(0.062)	(0.063)
Year	-0.17	-0.13	-0.10	-0.05
	(0.144)	(0.147)	(0.069)	(0.070)
Sector	yes	yes	yes	yes
Region	yes	yes	yes	yes
Constant	-0.98*	-1.01*	-1.02***	-1.05***
	(0.411)	(0.411)	(0.182)	(0.183)
Observations	565	565	3,012	3,012

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Note: the dependent binary variable indicating the innovation success takes value 1 if at least one of the innovations among product, process and organizational-management innovation linked to product or process innovation has been realized

Chapter 3

Bank loans, corporate investments and accounting fraud regulation

3.1 Introduction

The connection between legal systems, investor protection and the development of capital markets has been investigated by a growing stream of literature. In the last years many policy makers have been improving laws, procedures or regulations in order to increase creditor protection.

The three parties involved when credit is issued are the creditor, the debtor and also the legal institutions. The legal framework has a fundamental role, guaranteeing that the other two players' rights are protected. Inadequate institutions may prevent credit contract realization and may imply an increase in firm financial constraints.

Asymmetric information problems may arise when an investor finances a firm: creditor rights over a collateral are a way to overcome this issue. Policies aimed at preventing default are designed to stabilize the market. The aim of these interventions is to facilitate the screening process of the good projects, working on the transparency between the lender and borrower.

What is the effect of weakening creditors' protection on firms' access to credit? Moreover, what will be the effect on the growth and on the financial performance of firms?

Italy provides an ideal environment to run a quasi-natural experiment. In 2002, the policy maker envisaged an area of no legal sanction for those firms who report their financial statements slightly incorrectly. [1] The adduced motivation was to help firms to deal with increasing complexity when they have to communicate information to the stakeholders. The law keeps sanctions over all those behaviours with the aim to cheat stakeholders and relaxes those for which the stakeholders are not induced to form wrong beliefs or wrong evaluations about the firm itself. The recent trend in other countries has been one of improving laws, procedures and regulations in order to improve creditors' protection. However, Italy with this law makes a departure from this direction.

This decriminalization of the accounting fraud may weaken the protection of creditors and shareholders and may also imply that banks reduce firms' line of credit. Banks need to be more cautious on the information provided by firms and need to be more prudent in providing loans. This can adversely affect credit conditions.

Italian firms heavily rely on bank loans to finance their activity, since the role that stock market plays is very limited. Italy is lagging behind in terms of innovativeness with respect to other developed countries and the cause of this situation may be found in the predominance of small and medium firms, that have difficulties in sustaining the high fixed costs of risky R&D activities. The lack of financial resources is commonly mentioned by entrepreneurs as one of the main barrier for innovation at any stage of the life cycle. R&D investments are key to achieve innovation success and at the same time these investments are more vulnerable to restrictions in the access to credit, since they do not have a collateral and are risky by their inherent nature, given that

[1] In section 3 the regulation is explained in details.

the outcome is uncertain. Access to credit for Italian firms becomes crucial to sustain firm survival and growth. Over the last years bank loans account on average for 70% of the firm financial debts, a percentage higher than in other developed countries (Banca d'Italia, 2006-2011). Therefore, this particular debt structure has contributed to make Italian firms especially exposed to interest rate variations and refinancing risks and dependent on bank credit offer. Financial intermediaries and their credit offer limitations have a key role in firms' survival and growth.

With this change in the regulation, firms can present themselves better when they ask for loans, without fearing any legal sanctions if they change a little bit the data regarding their economic performance. Therefore, a possible but unlikely first result if banks trust corporate account reports may be that firms could become less financial constrained and able to invest more. The main consequence would be an impulse to the growth of the firms' sector. On the other hand, the other possible and more likely consequence is that banks would take into account the possible behaviour to cheat and they may react by making stricter and more prudent lending criteria.

We are interested to use the Italian case, pre and post the reform, to work out the effect of a reduction of credit protection on the access to credit and corporate investments. Do the banks take into account the firm's opportunity to cheat and make the criteria of lending decisions stricter? Or do the banks trust the financial data reported by the firms? This paper tries to shed light on these issues focusing on credit allocation to Italian firms and corporate investments.

This paper is organized as follows. Section 3.2 documents the literature on legal institutions, corporate investments and economic growth. Section 3.3 presents the new regulation concerning the penalization of the accounting fraud. Section 3.4 illustrates the data, the variables used in the analysis and the econometric specification. Section 3.5 discusses the results of the empirical analysis and section 3.6 concludes the paper summarizing the main findings.

3.2 Related literature

Over the last years a stream of research has investigated the implications of policies and legal institutions on corporate investment, financial markets and economic growth. Understanding how regulations affect corporate investment and real decisions is an important and interesting topic.

The research area that sheds light on the significant link between legal institutions, investor protections and capital market development dated back to La Porta, Lopez-de Silanes, Shleifer, and Vishny (1999) and has stimulated the policy makers attention and a growing research interest. Findings in this topic generally point out that capital market development is promoted by a stronger investor protection.

Fabbri and Padula (2004)investigate the effect of the quality of judicial enforcement on the allocation of credit to households. Using both a theoretical model and an empirical analysis they find out that poor enforcement implies that it is more likely that households are credit-constrained and that the household debt is affected by the quality of contract enforcement. The reasons of these effects are the reduced incentive to repay debts by households that induce banks to limit credit allocation and to increase the cost of debt.

An U.S. federal law, the Sarbanes-Oxley Act of 2002, provides an example of an attempt to restore investor confidence in U.S. capital market and was a reaction to a number of corporate and accounting scandals (e.g. Enron and Tyco International). This new legislation has risen an intense debate on the real implication on capital markets and on the cost and benefit balance. Kang, Liu, and Qi (2010) assess the implication of this law on corporate investment using a Euler equation. They discover that initially the Sarbanes-Oxley Act has had a negative impact on corporate investment in U.S., but the effect was not homogeneous across firms: for example smaller firms and riskier firms have become more prudent about the capital spending.

Information sharing among banks is found to affect credit market performance by Brown, Jappelli, and Pagano (2009). The empirical analyses focus on a sample of firms coming from the countries of Eastern Europe and the former Soviet Union. The results highlight that an increase in the availability and a lower cost of credit for firms is correlated with more information sharing. In particular, this association is stronger in countries with poor legal environment and for opaque firms. A greater information sharing is correlated with lower bank risk and higher economic growth and stronger creditor rights with higher growth according to Houston, Lin, Lin, and Ma (2010).

Unlisted companies are the object of the analysis of Giannetti (2003): institutions that protect creditor rights and enforce stricter enforcement favour higher leverage and long-term debt higher availability. It is more easy for firms to invest in intangible assets to obtain loans in countries in which the creditor protection is high.

Firms can find funds without using the bank system, by delaying payments to suppliers. This is another way to finance investments and activities and also unconstrained firms are using this method. Firms' suppliers have an advantage in case of firms' default with respect to banks: they have information advantages and they are more able to extract value from the liquidation of assets. Fabbri and Menichini (2010) investigate trade credit and obtain interesting results: the type of inputs purchased on credit influences whether firms use trade credit in case of financial constraints or to exploit supplier liquidation advantage. Moreover, a technology biased towards tangible assets is associated with a higher use of trade credit, in particular when creditor protection weakens and financial constraints strengthen. The legal environment is important in determining the optimal financing of firms: the key factors are creditor protection and also a balance between banks and suppliers.

3.3 Corporate law reform

The regulation concerning the penalization of the accounting fraud was modified in April 2002 with the "Decreto delegato d.lgs. n. 61". This decree was the result of a series of initiatives, from the proposal of an enabling act ("Proposta di legge delega") to reform the corporate laws, approved by the Italian council of minister in May 2000, to the enabling act n. 366 approved by the Parliament in October 2001.

The new article 2622 states that:

"The false communication offence is disclosed when in financial statements, reports or other corporate communications are exposed facts that are not true or when there is the omission of information on the economic and financial situation, the disclosure of which is mandated by law. Punishment is, however, excluded in cases that can be defined as less serious, that is, when the false statements or the omissions do not alter significantly the economic situation of the company. It is not, in fact, configured the offence of false corporate communication if:

- The falsifications or the omissions determine a variation of the fiscal year result, before tax, of no more than 5% or a change in the net assets of no more than 1%;
- The offense was the result of estimates that, taken individually, do not differ by more than 10% from the correct one.

Before April 2002 these offences were punished by the article 2621 and the following articles of the civil code. The shareholders and the creditors were protected as well as the all the people that had an interest in knowing the economic situation of a company.

In general, if someone would like to invest his money or to buy shares of a firm, it is obvious that he would like to have complete, exhaustive, clear and true information about the firm. The accounting frauds are not anymore condamned in certain cases with the new regulation: therefore a firm that is making losses and that has a large probability to default can change the financial stetements and present the financial situation in a better way. Banks and investors in this sense are less protected, because they may unconsciously finance firms in bad economic situations and they can incur in problems in case of firms' default or inability to repay the debts.

3.4 Data and empirical approach

3.4.1 Unicredit dataset

Firm data come from the Unicredit survey "Indagine sulle imprese manufatturiere" ("Surveys of Italian Manufacturing Firms") on Italian manufacturing firms with more than 10 employees, published every 3 years. [2] We explore two waves of data: the survey conducted in 2001, that deals with the business activities for the period 1998-2000, and the survey carried out in 2004, that deals with the business activities in the period 2001-2003. The dataset is a repeated cross-section. The variables also include standard balance sheet variables. The data include all Italian firms with more than 500 employees and a selection of smaller firms, obtained using a sampling design stratified by area, industry and firm size. The sample is statistically representative of the Italian firms in the manufacturing sector.

The surveys contain respectively 4680 firms for 2001 wave and 4289 firms for 2004 wave, although for many variables the dataset shows incomplete information.

[2] The surveys considered in this work were carried out by the Research Department of Capitalia Banking group. In 2007 Capitalia was acquired by Unicredit Group.

3.4.2 Quasi-natural experiment

The focus of this paper is to investigate the connections between legal institutions and investors' protection and firms' real decision and Italy provides the perfect environment to run a quasi-natural experiment.

Banks play a key role in the Italian financial system and are fundamental to finance firms. External investors, such as banks, face a risk when they finance a firm and of course they would like to have precise and clear corporate information.

The Italian law on accounting fraud of 2002 increases the asymmetry of information between firms and banks: firms can make their financial accounts more opaque. Therefore banks could become more reluctant and cautious in the decision to finance firms, since they know that the financial situation of a firm can be slightly changed without being punished by the law.

The dataset that we analyse contains detailed information about manufacturing firms before and after the implementation of the accounting fraud law (respectively relative to 2000 and 2003). A Difference-in-Differences approach gives the possibility to investigate the changes in the firm debts and investments before and after the introduction of the law, with the advantage of mitigating endogeneity problems. The dependent variables in scope are bank debts (short, medium and long terms), investments, in plants, tool and machinery or in R&D and trade debts. We would like to see if there have been some changes in these dependent variables for the firms that are more affected by the law implementation in 2003. Next section describes in details the empirical approach used.

3.4.3 Empirical approach: Difference-in-Differences estimator

In our sample, firms observed in the two periods could be different so that those firms in the pre-period that are in the treatment group are observed prior to the treatment but the outcome after the treatment is not available. This suggests us to use a Difference-in-Differences approach, which requires observing a representative sample of the same group of firms before and after the reform.

We use $post = 0$ to denote the pre-period and $post = 1$ to denote the post-period, y_{it} as the outcome (debts or investments) for firm i in period t. A regression-based estimator that just uses the level of the outcome variable is used to estimate the following model:

$$y_{it} = \beta_0 + \beta_1 T_i + \beta_2 post_t + \beta_3 T_i * post_t + \epsilon_{it} \tag{3.1}$$

where T_i is a dummy variable taking the value 1 if the individual is in the treatment group and 0 if they are in the control group, and $post_t$ is a dummy variable taking the value 1 in the post-treatment period and 0 in the pre-treatment period.

The Difference-in-Differences estimator is going to be the estimate of β_3, the coefficient on the interaction between T_i and $post_t$.

3.4.4 Data

The empirical approach specifies the variables of investments and debts vs. bank as a function of several firm-level characteristics using a Difference-in-Differences approach.

The dependent variables used are:

- Debts financed by bank (short, medium and long term) over the total sales in thousand euros;
- Investments in plants, tools and machineries over the total sales and expressed in thousand euros;
- Investments in R&D over the total sales and over the number of employees in R&D;

- Trade debts (with respect to suppliers) over the total sales in hundred euros.

The treatment group is the group that is affected by the changes in the regulation on accounting fraud. We assign to this group firms in which the owner owns 100% of the firm and owns the full control over the business and the owner is not a bank or a financial institution. In this case the owner is free to slightly change the financial statements without having to respond to other people that control or own a part of the firm. Therefore the treatment variable (treat) is equal to 1 for the group of firms in which the owner owns 100% of the firm and also has the full control and the owner is not a bank or a financial institution. The treatment variable is equal to 0 for the control group: this control group is used to show that the effect on dependent variables is not homogeneous across firms.

Table 3.1 shows the distribution of firms in year 2000 and 2003 in the treatment and control group.

Firm level characteristics used in the regression analysis control for differences due to geographical dimension, size, sector of activity and relation with banks. In particular, the variable region of Italy where the firm is located is able to incorporate the differences in the environment due to different locations. One important difference is the quality of judicial enforcement of creditors' rights: when contracts are weakly enforced the incentives to repay could be lower and therefore banks may reduce loans.

Fabbri and Padula (2004) have studied the relationship between the quality of judicial enforcement of creditors' rights and the allocation of credit to households, considering the differences in legal enforcement in the region in Italy. They show that, when enforcement is weak, banks tend to raise interest rates and ration credit and households are more likely to be credit-constrained. In our case we are indirectly considering the differences in the legal enforcement by controlling for the variable region in our model.

Firms belonging to different sectors of activity may have specificities, different sources of technologies and appropriability conditions. To account for these peculiarities, we control for the sector of activity assigned following the Pavitt classification (traditional sectors, scale intensive sectors, specialized sectors, high technology sectors and other sectors). [3]

We also control for firm size, measured in sales in billion euros, that may affect firm's innovativeness and for the number of banks with whom the firm has a business relation.

3.4.5 Empirical specification

The empirical specification used is the following:

$$y_{it} = \beta_0 + \beta_1 T_i + \beta_2 post_t + \beta_3 T_i * post_t + X_i + \epsilon_{it} \tag{3.2}$$

where:

$$y_{it} = \begin{cases} y*, & \text{if } y* > 0 \\ 0, & \text{if } y* <= 0 \end{cases} \tag{3.3}$$

The dependent variables used are the debts vs. banks in the short, medium and long term, investments in plants, tools and machineries or in R&D and trade debts. We use also a Tobit model since the dependent variables are censored from below. [4] In fact we observe the values of firm debts and investments only above or equal to zero. The presence of many zeroes in the dependent variables and in the main explanatory variables prevents us from using a log-log specification. The control variables (X_i) are the region, the sector of activity, sales (in billion euros) and number of banks.

[3]Traditional sectors include textiles, footwear, food and beverages, paper and printing and wood; scale intensive sectors include basic metals and motor-vehicles, trailers and semitrailers; specialized sectors include machinery and equipment, office, accounting and computing machinery and medical, precision, and optical instruments; high technology sectors include chemicals, pharmaceuticals and electronics.

[4]We obtain similar results also using OLS regressions.

3.5 Results

3.5.1 Firm debts and investments

Table 3.2 presents the results of the analysis using firm debts vs. banks (in the short, medium and long term) in thousand euros over employees as dependent variable. The coefficient of interest is the coefficient of the interaction between T and *post*: its value is negative, statistically significant and stable across the various specifications. The negative sign means that firms in the treatment group decrease the amount of debts vs. banks (with respect to the control group) after the new law implementation.

This result confirm the idea that firms in the treatment group get less credit from the bank after the change in the law. The hypothesis behind is that after the introduction of the new regulation, banks are more cautious in lending money to firms in which the owner has 100% of the firm and owns the full control over the business. In this case the owner can slightly change the financial statements (according to the new regulation) and he does not incur in penalization. As a consequence banks can not rely on firms' balance sheet information. A likely consequence of this opacity of financial information provided by firms is that banks are more reluctant to extend credit to firms.

To the extent that financial frictions also affect investment choices, we investigate how the new regulation impacts the asset side of firms' balance sheets. In particular, we study the effect on investments in plants, tools and machineries and R&D. Table 3.3 reports the results of the specification with investments in plants, tools and machineries.

The coefficient of the interaction between T and *post* is negative and statistically significant. Furthermore, it is stable across specifications. The negative sign indicates that firms in the treatment group reduce the amount of investments in plants, tools and machinery after the regulation changes.

Table 3.4 reports the results of the analysis using investments in R&D. The coefficient of the interaction between T and *post* is negative, statistically significant and stable across many specifications. Firms in the treatment group reduce the investments in R&D after the change in the law.

A reduction of the R&D expenses is not surprisingly, since R&D investments are inherently risky and usually cannot be pledged as collateral. It is more striking and alarming the decrease in the investments in assets, which can be used as a collateral.

Therefore, after a reduction of the credit line coming from banks as a consequence of the new regulation, the firms in the treatment group react by reducing investments in plants, tools, machinery and in R&D. This is likely to have adverse effects on growth and innovativeness of firms.

3.5.2 Trade debts

Trade credit is a widely used source of credit for Italian firms. It consists of delaying payments to suppliers. Suppliers have an information advantage with respect to banks or financial institutions and they are also more able to exploit the liquidation assets of a default firm. In view of the special role of trade credit, we study how the change in regulation affects the firms' decision to rely on credit from suppliers. In Italy trade debts is largely used: for example in 2011 trade debts correspond to more than 40% of firm financial debts (Banca d'Italia, 2006-2011)

The results of the analysis in terms of trade debts before and after the implementation of the new law are reported in Table 3.5.

In contrast with the previous findings, the coefficient of the interaction between T and *post* is not statistically significant. The reliance on trade credit does not seem to differ between firms affected and unaffected by the reform.

This result confirms the idea that banks are more cautious with respect to firms in the treatment group after the new law. Banks reduce the credit line towards these firms to protect themselves from the opacity of balance sheet information. On the other hand, suppliers have an information and liquidation advantage with respect to banks and therefore do not have to reduce credits to firms.

3.6 Conclusion

The aim of this paper is to investigate the connections between legal institutions, investors' protection and firms' investment behaviour. The implementation of the new accounting fraud regulation in 2002 in Italy offers an ideal setting to test our ideas. This law has allowed firms to slightly falsificate the financial statements, under certain conditions described in section 3, without incurring in punishments and may contribute to weaken the protection of creditors and shareholders. Our analysis has used a dataset of Italian firms before and after the introduction of the new law and has focused on the effect of the new law on the asset and liability sides of firms' balance sheets.

The treatment group is the group that is affected by the changes in the regulation on accounting fraud. We consider that this group is made by firms in which the owner owns 100% of the firm, owns the full control over the business. In this case the owner is free to slightly change the balance sheet without having to respond to other people that control or own a part of the firm. The control group is made of the remaining firms and allows us to implement a Difference-in-Differences approach.

The results show that firms affected by this law experience a reduction in bank loans and investments in plants, tools, machinery and in R&D. The intuition behind this result is that, with the introduction of the new regulation, banks are likely to be more reluctant to extend credit to firms due to the possible opacity of their financial statements. The consequence is that banks do not completely rely on the information provided and reduce the line of credit for these firms with respect to the control group.

Firms affected by the contraction of credit react by reducing the investments in plants, tools, machinery and R&D. On the other hand, the credit coming from suppliers is not reduced for the firms in the treatment group. This happens because suppliers have an information and liquidation advantage with respect to financial institutions.

3.7 Tables

Table 3.1: Distribution of firms in the treatment and control group by year

Year	Control group	Treatment group	All
2000	4036	428	4464
	90%	10%	
2003	3452	603	4055
	85%	15%	
Total	7488	1031	8519
	88%	12%	

Table 3.2: Debts vs. banks in the short, medium and long term

VARIABLES	Debts vs. banks	Debts vs. banks	Debts vs. banks
Post	0.10***	0.10***	0.10***
	(0.004)	(0.004)	(0.004)
T	0.02*	0.02*	0.02*
	(0.008)	(0.008)	(0.008)
Post * T	-0.03**	-0.03**	-0.04**
	(0.011)	(0.011)	(0.011)
Sales			0.01
			(0.019)
Region dummies	No	Yes	Yes
Sector dummies	No	Yes	Yes
Constant	-0.09***	-0.05***	-0.05***
	(0.003)	(0.010)	(0.010)
Sigma constant	0.13***	0.13***	0.13***
	(0.002)	(0.002)	(0.002)
Observations	6,890	6,887	6,887

Standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Note: Debts vs. banks are divided by the total sales in thousand euros and Sales are expressed in billion euros

Table 3.3: Investments in plants, tools and machinery

VARIABLES	Investments	Investments	Investments
Post	-0.03*	-0.02*	-0.03*
	(0.012)	(0.012)	(0.012)
T	0.10***	0.11***	0.11***
	(0.026)	(0.026)	(0.026)
Post * T	-0.09**	-0.09**	-0.09**
	(0.035)	(0.035)	(0.035)
Sales			0.03
			(0.048)
Region dummies	No	Yes	Yes
Sector dummies	No	Yes	Yes
Constant	-0.01	-0.03	-0.03
	(0.008)	(0.035)	(0.035)
Sigma constant	0.47***	0.47***	0.47***
	(0.004)	(0.004)	(0.004)
Observations	6,947	6,943	6,943

Standard errors in parentheses
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$
Note: Investments are divided by the total sales and are expressed in thousand euros and Sales are expressed in billion euros

Table 3.4: R&D expenses

VARIABLES	R&D exp.	R&D exp.	R&D exp.
Post	-0.00	-0.00	-0.00
	(0.005)	(0.005)	(0.005)
T	0.04***	0.03***	0.03***
	(0.010)	(0.010)	(0.010)
Post * T	-0.04**	-0.03*	-0.03*
	(0.013)	(0.013)	(0.013)
Region dummies	No	Yes	Yes
Sector dummies	No	Yes	Yes
Sales			-0.00
			(0.017)
Constant	0.01	0.00	0.00
	(0.003)	(0.017)	(0.017)
Sigma constant	0.12***	0.12***	0.12***
	(0.002)	(0.002)	(0.002)
Observations	2,736	2,734	2,734

Standard errors in parentheses
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$
Note: R&D expenses are divided by the total sales and by the number of employees in R&D and Sales are expressed in billion euros

Table 3.5: Trade debts in the short term vs. supplier

VARIABLES	Trade debts	Trade debts
Post	-0.95***	-0.95***
	(0.230)	(0.239)
T	2.18***	2.03***
	(0.345)	(0.362)
Post * T	-0.97	-0.96
	(0.515)	(0.548)
Sales	2.17**	2.02*
	(0.731)	(0.841)
Bank number		0.21***
		(0.021)
Region dummies	Yes	Yes
Sector dummies	Yes	Yes
Constant	-6.10***	-7.30***
	(0.642)	(0.692)
Sigma constant	3.86***	3.87***
	(0.162)	(0.166)
Observations	6,887	6,802

Standard errors in parentheses

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Note: Trade debts over the total sales in hundred euros and Sales are expressed in billion euros

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Estratto per riassunto della tesi di dottorato

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Titolo della tesi: Empirical models of firms' innovation, diversity and behaviour

Abstract: This dissertation focuses on firms' innovation, diversity and behaviour. The first chapter highlights how the relation between competition and innovation can additionally be shaped by the structure, distribution and heterogeneity of knowledge across competing innovators. We provide panel data evidence using data on the evolution of multi-dimensional features and attributes of smartphones. The second chapter explores the implications of the diversity of R&D sources on firm innovativeness, focusing on the different impact on financially constrained and unconstrained firms. Finally, the third chapter deals with the impact of legal institutions on creditor's protection, firms' innovation and access to credit in Italy.

Estratto: Questa tesi è dedicata al tema dell'innovazione delle imprese e si articola in tre capitoli. Il primo capitolo studia l'effetto della struttura, della distribuzione e dell'eterogeneità delle conoscenze sulla relazione tra concorrenza e innovazione. Il secondo capitolo analizza le implicazioni della diversità delle fonti di ricerca e sviluppo sull'innovazione delle aziende, evidenziando il ruolo dei vincoli di liquidità. Infine, il terzo capitolo riguarda l'effetto delle istituzioni giuridiche sulla protezione dei creditori, sugli investimenti delle aziende e sull'accesso al credito in Italia.