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Heterogeneous Agents and Spillovers in Innovation Processes

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Introduction

This work is a collection of papers on innovation, a broad theme that covers several but interconnected issues. Innovation is one of the main determinants of firms' performance in advanced economies and it is also an important driver of growth ((Romer 1990, Aghion and Howitt 1992, Acemoglu 2002, Jones 2002). Firms often invest huge amounts of resources in R&D to improve their production technology (process innovation, aiming to a cost reduction), create new products and increase the quality of the existing ones (product innovation); in this way, firms aim to increase their market shares and profits. Sometimes R&D investment is necessary to enter the market or simply not to exit. Firms' innovative activities contribute to make the surrounding economic system more competitive and stimulate further investment and innovation. At the same time, consumers enjoy the benefits accrued by lower prices, better quality and more variety. Despite of the beneficial effects they bring to the society, innovative activities are often associated with a non competitive market structure (harmful for consumers) and with externalities, meaning that innovation is strictly related to situations that bring to market failures and to not socially desirable outcomes (in terms of prices, quantities produced and R&D effort). These considerations often justify the request of government intervention in terms of subsidies to R&D and patent protection.

The level of innovation of an economic system is affected by the interaction of several agents and also influenced by external factors. Understanding how the different forces at work interact and which factors enhance or prevent innovation is of primary importance from the point of view of policy makers; aware of the possible incentives and obstacles to innovation, they can develop policies aimed to create an environment that favor investment and growth.

In this work I investigate the role of agents' heterogeneity in innovation processes, an issue that has received attention in the literature on innovation only quite recently, tough its importance has been recognized for a long time. I treat this topic from both a theoretical and empirical point of view, though applied to different subjects.

In the theoretical part of the work (Chapter 2 and Chapter 3), I focus on a particular aspect of the issues related to innovation and market failure, namely the spillover externality problem and the use of R&D cooperation agreements (RJV use of the term) as a way to enhance innovation and lead the level of investment closer to its socially optimal level. The positive externality is caused by non-complete appropriability of the results of R&D activity and is responsible for R&D underinvestment. Since d'Aspremont and Jacquemin (1988) and Kamien et al. (1992), the positive effect of R&D cooperation agreements in presence of high spillovers has been widely analyzed. However, most of the previous works only consider symmetric firms, discarding the potential relevant impact of asymmetries on firms' decisions. The empirical literature has emphasized the role of asymmetries in terms of gains from cooperation, that in turn affect decisions about RJV membership (Kogut 1991, Röller, Tombak and Siebert 1998), but these issues have been scarcely taken into account in the theoretical literature, with few exceptions (Baerenss 1999, Atallah 2005). So, in this part of the work I try to fill this gap in the literature taking into account firms' heterogeneity. Firms can be heterogenous in many respects: efficiency level, type of technology, experience, market size etc. Here, firms' heterogeneity regards the efficiency of R&D effort.

In the empirical part, I study a quite different aspect of innovation, namely the link between immigration and innovation. Owing to the size that the phenomenon of immigration has assumed in the advanced countries in the last decades, immigration has been recently at the centre of the political and economic debate. Economists have studied extensively the potential impact of immigration on a variety of economic and social indicators of host countries, such as natives' wages (Borjas 2003; 2005, Ottaviano and Peri 2012) and employment opportunities (Pischke and Velling 1997, Card 2001; 2005), firm productivity (Peri 2012), trade creation (Gould 1994, Rauch and Trinidade 2002, Peri and Requena-Silvente 2010) and crime (Bell et al. 2010, Bianchi et al. 2012), just to take a few examples. Until very recently the effect of immigration on innovation and technical change was instead much less studied. Although new evidence is progressively accumulating, it remains nonetheless mostly limited to the impact of *skilled immigration* in the U.S (Hunt and Gauthier-Loiselle 2010, Stuen et al. 2012, Lewis 2011, Peri 2012).

Immigration can affect local innovation in several ways. First of all, immigration entails an inflow of foreign population into a region, and produces changes (i) in the size of the population; (ii) in the average skill level of the population; (iii) in the age structure of the population. All these variables have been recognized to be powerful predictor of innovation. Immigration has also a direct effect on innovation through cultural diversity (spillovers may arise from complementary abilities and different backgrounds, with a positive effect in the production of new ideas). At the same time, greater difficulties in communication and reduction of social capital can act as obstacles to innovation and growth (these negative effects are more likely to arise in presence of low skilled immigrants). Finally, immigrants flows affect firms' choices concerning technology adoption and investment in physical capital, according to the change in the average skill level they cause in the population.

So, in this part of the work, heterogeneity concerns the greater cultural 'diversity' and the changes in the average skill level of the population induced by large immigration flows.

The thesis has the following structure: Chapeter 1 provides an overview of the way in which the main issues related to innovative activity have been treated in the theoretical literature. Starting from earlier works on innovation, mainly focused on the value attached to innovation in monopolistic and competitive markets, it develops analising the two main fields in the literature on innovation: patent race and spillover externality. The part related to spillovers and R&D cooperation is treated in a more extensive way, since the theoretical models I present in Chapter 2 and Chapter 3 belong to this strand of the literature. This chapter contains also a review of the past literature on incomplete information in R&D models.

In Chapter 2, I extend standard models on R&D competition vs R&D cooperation in a context of non-complete appropriability of the results of R&D activity. In a Cournot duopoly model with R&D investment stage and spillovers, I introduce asymmetries in R&D productivity between firms that may engage in R&D cooperation. Also, with the introduction of a further stage, I analyze the incentive to cooperate in R&D by forming a RJV. While the existent literature focuses on the comparison between two *scenarios* exogenously given, I endogenize the formation process and show that, when spillovers are high, due to firms' asymmetries, RJV is not formed for most of the parameters' values and does not fulfill the aim of stimulating innovation. This contributes to explain the relatively low diffusion of cooperative agreement in R&D and supports some empirical findings about and the determinants of RJVs formation. Also, in line with the theoretical literature, I find that, when spillovers are low, R&D cooperation reduces the total level of investment; in this case allowing this kind of agreements can be harmful, since in some regions of parameters both symmetric and asymmetric firms have incentive to cooperate in order to avoid investment.

Chapter 3 presents a further extension of the model discussed in Chapter 2, namely the introduction of the incomplete information assumption. Here, I investigate the role of R&D cooperation agreements (RJVs) in a context of incomplete information with asymmetric firms, where firms, in addition to set the optimal R&D investment under two *regimes* (R&D competition and RJV), have also to take decisions about RJV membership. Some interesting results arise from this extended model. (i) When firms compete in R&D, incomplete information about rival's R&D productivity leads to inefficient investment choices in some regions of parameters; in particular, when firms are actually symmetric, asymmetric information further reduces the investment, with respect to the complete information setting. (ii) A signaling role of cooperation agreements emerges, in addition to the already recognized role in reducing the inefficiencies arising from free riding problem. Revealing its willingness to participate, the efficient firm to signal its type, thus increasing the investment level (innovation enhancing effect) and improving total welfare. (iii) When firms are asymmetric, for most of the parameters' values, RJV is not formed and does not fulfill the role of stimulating innovation.

Chapter 4 (joint with Massimiliano Bratti[1]) investigates the causal effect of foreign immigration on innovation (patents' applications) in Italian provinces. We provide evidence for a country which was exposed to a very fast and large wave of immigrations during the 2000s, using a very small geographical scale of analysis (NUTS-3 regions), which enables us to better control for differences in institutional and socio-economic factors which are difficult to observe but which may simultaneously contribute to both attracting new immigrants and increase the innovation potential of a region. Moreover, unlike most papers in the literature which only considered the effect of skilled immigration, (i) we first focus on the general impact of immigration, and then (ii) separately look at the effects of low-educated and high-educated immigrants on innovation. Using instrumental variables' estimation (and instruments based on immigrant *enclaves*), we find that the overall stock of immigrants has a significant negative effect on innovation of Italian provinces: rising the share of immigrants by one percent point (p.p.) decreases patenting by 0.064 percent. However, distinguishing the effect between low and high-skilled migrants shows that the aggregate negative effect is driven by the prevalence in Italy of low-educated immigrants. In fact, our estimates suggest that an increase of 1 p.p. in the share of low skilled foreign migrants on the population induces a reduction in patents' applications per 1000 inhabitants in a range between 0.094 and 0.186 percent, according to the method used to classify immigrants by skill level. Instead, presumably due to the extremely low presence of high skilled immigrants in Italy and to the underutilization of their competencies, the impact of high skilled immigrants on innovation is positive, but cannot be precisely estimated.

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Chapter 1

Innovation and Market Failures: a review of the literature

Introduction

One of the features of advanced economies is competition on innovation: the now prevalent view is that firms become industry leaders by conducting research and development (R&D) to improve either their production technology (process innovation, aiming to a cost reduction) or the products they provide (product innovation, usually associated with improved quality). R&D is crucial not only in the analysis of an individual industry, but also form an economy-wide point of view. Solow discovery (1957) that only a small fraction of per-capita growth was associated with an increase in the ratio of capital and labor called economists' attention to the role of technological progress in improving welfare. Innovation is thought to be beneficial for society, since it should lead to more variety, lower prices, better quality, etc. At the same time, innovative activities are often associated with a non competitive market structure (harmful for consumers) and with externalities, meaning that innovation is strictly related to situations that bring to market failures and to not socially desirable outcomes (in terms of prices, quantities produced and R&D effort). These considerations often justify the request of government intervention in terms of subsidies to R&D and patent protection.

It is not surprising that this topic has generated a huge amount of theoretical and empirical works. After early studies on innovation focused on the relationship between market structure and incentive to innovate (Schumpeter, 1943; Arrow, 1962; Dasgupta and Stiglitz, 1980), the analysis of the issues related to innovative activities has developed in several fields. Two main strands can be identified in the literature. The first one is related to the degree of protection of innovation from imitative competition and deals with issues such as the nature of innovation as public good and the potential negative consequences of patent race, among which the waste of resources and the adoption of excessively risky technologies (Dasgupta and Maskin, 1986; Judd, 1985; Klette and De Meza, 1986) and the persistence of monopoly (Gilbert and Newbery, 1982; Dasgupta and Stiglitz, 1980; Lee and Wilde, 1980; Loury, 1979; Reinganum, 1982; Fudenberg et al., 1983). The other field of analysis, instead, focuses on the positive externality caused by non-complete appropriability of the results of R&D activity (spillovers problem), responsible for R&D underinvestment, and on R&D cooperation (RJV) as a way to lead the level of investment closer to its socially optimal level. After the seminal papers of d'Aspremont and Jacquemin (1988), a huge literature on R&D cooperation in presence of spillovers has developed. The basic model has been extended in several ways, assuming endogenous spillovers, asymmetric firms or asymmetries in outcomes. Since these models confirm the result concerning the desirability of R&D cooperation in presence of spillovers (see Kamien et al., 1992, Suzumura, 1992, Amir, 2000, Lambertini and

Rossini, 2009, just to take some examples), over the last twenty years there has been an increasing interest in the role that R&D collaboration agreements might play in helping to overcome some of the market failures associated with R&D and innovation. In recent years, increasing attention has been devoted also to the structure of R&D agreements and to the process of RJV formation and partner selection.

The aim of this chapter is to provide an overview of the way in which the main issues related to innovative activity have been treated in the theoretical literature. Section 2 starts to describe the earlier works on innovation, mainly focused on the value attached to innovation in monopolistic and competitive markets. Section 3 and Section 4 are dedicated to the analysis of the two main fields of the literature in innovation: patent race and spillover externality, respectively. The part related to spillovers and R&D cooperation will be treated in a more extensive way, since the theoretical models I present in Chapter 2 and Chapter 3 belong to this strand of the literature. The aim of Section 5 is to review the past literature on incomplete information in R&D models, since the model presented in Chapter 3 assumes asymmetric information about R&D productivity. Finally, Section 6 briefly discusses the role of firms' asymmetries in RJV formation process, a theme scarcely taken into account in the literature, that inspired the models described in the next two chapters.

1.1 Market structure and incentive to innovate

Early studies on innovation focused on the relationship between market structure and incentive to innovate, mainly analyzing the value attached to innovation. An important issue raised by Schumpeter (1943) concerns the market environment more conductive to R&D activity. In his view, (i) R&D efforts are more likely to be undertaken by large firms and (ii) monopolistic or oligopolistic firms pursue more aggressively innovative activity than firms with little or no market power. According to a report of U.S. Patent and Trademark Office (2000), the top ten companies in terms of the number of patents granted are fairly large companies. However, this does not mean necessarily that large firms do more R&D; instead, it could imply that firms that do more R&D become large. This is a quite complicate issue to analyze since it involves many strategic considerations. In fact, there are different forces at work: innovation may be necessary to stay on (enter) the market, but at the same time the introduction of a new product by a firm undermines the marketability of existing products and the development of a new production process requiring new equipment reduces the value of existing productive capacity (what Schumpeter called "creative destruction"). Arrow (1962) tried to isolate the "pure" incentive to innovate, independent of any strategic considerations of preemptive innovation. Without considering the threat of entry, both competitive and monopolistic firms undervalue the innovation compared to a social planner interested in maximizing total welfare, because they only consider the profit they can earn as a result of the innovation and ignore the additional benefits that innovation can lead to consumers. So, from the point of view of the society as a whole, there is the risk of too few innovation. However, competitive firms value the innovation more than the monopolist. The reason is that a competitive firm is just breaking even prior to adopting the innovation and so it values the innovation at the full additional profits it will generate. By contrast, the monopolist is already earning a monopoly profit with its existing technology and the introduction of the new process undermines that investment (replacement effect)[1]. This result can be reversed introducing a potential entrant along with the assumption that, if entry occurs, the monopolist compete as a high-cost firm in a Cournot duopoly[2]. Gilbert and Newbery (1982) show

[1]This theoretical result is quite general (it holds for drastic and non drastic innovation, for any demand function and for Cournot or Bertrand competition).

[2]This is because the entrant invests in R&D and develops a new technology that allows to lower the marginal cost with respect to the incumbent.

that, in this case, the monopolist has the bigger incentive to innovate. This is because not only the innovation allows to lower the costs and earn higher profits, but also because the monopolist has to take into account the fact that if it does not innovate the entrant will, wiping out the monopolist's dominant position (efficiency effect). However, Reinganum (1983) shows that this conclusion may not hold when the timing of the successful breakthrough is uncertain. The replacement effect induces the incumbent to wait and enjoy its current profit. This effect, instead, does not delay the innovative activity of the potential entrant.

Dasgupta and Stiglitz (1980) develop a model in which the decision to spend on R&D is an explicit part of firms' strategies. They assume an industry composed of n symmetric Cournot firms that choose the level of output and the amount they will spend on R&D, this latter aiming to lower the unit cost of production. They show that an increase in the number of firms in the industry will decrease the amount each firm is willing to spend in R&D and that the share of industry's total sales revenue devoted to R&D is likely to be smaller in less concentrated industries. This supports Schumpeter's basic claim that imperfect competition is good for technical progress.

Empirical evidence suggests that R&D intensity increases along with industry's concentration, but only up to a rather modest value, after which R&D efforts appear to level off or even decline as a fraction of firm revenues.

1.2 Innovation and patents protection

After the first studies concentrated on the relation between market structure and innovation, the analysis of the innovative activities has developed in several fields. One of most studied issues is related to the degree of protection of innovation from imitative competition. Innovation is often considered a public good, the supply of which must be encouraged through a system of patents. An innovation created by one firm provides usable information to the other firms at little or no cost. While all firms stand prepared to use such information none is willing to pay the amount of money (often huge) necessary to produce it without compensation. This compensation is often granted by a patent that gives the innovator temporary monopoly power. The implied trade-off between incentive to innovate and efficient market structure continues to stimulate an intense debate.

The studies on the optimal extension of patents rights have developed along two dimensions: the length of time for which a patent right extends (patents length) and the range of products to which the patent applies (patent breadth). With respect to the first dimension, the issue is to find a balance between the innovator's ability to earn a return on its R&D investment and the benefits that will accrue to consumers once the patent expires and competition emerges. The basic model is due to Nordhaus (1969); according to this model, the optimal patent duration is finite. An initial increase in patent duration induces a greater R&D effort and a greater discounted net surplus to producers and consumers; beyond a given point, however, increases in the duration of the patent reduces the net social surplus, even though they lead to more R&D. This is due to the assumption of diminishing returns of R&D and to the fact that with very long duration of time the present value of consumers' benefits (which arise after the expiration of the patent) will be very small. As for the optimal breadth of patents, it has to be noted that the larger is the required minimal degree of difference from an existing process or good in order for the new one to be patentable, the more difficult it is for the other firms to "invent around" the patent and to make an attempt on inventor's dominant position. Unfortunately, there is not a clear method for measuring patent breadth, so it is very difficult to analyze this point.

Though a patent system is thought to be necessary to correct a market failure and enhance innovation, Bessen and Maskin (2009) argue that, when discoveries are "sequential"[3], patents protection is not as useful for encourag-

[3] meaning that successive inventions build in an essential way on their predecessors.

ing innovation as in a static setting. Indeed, society and even inventors themselves may be better off without such protection.

Some additional problems arise when the market is characterized by competition on innovation protected by patents. In this context, coming first is all that matters since patents awards have a “winner-take-all” feature. This can generate a race to obtain the patent, often associated with non desirable consequences. The point is that patents create a rent in the form of monopoly profit, and every time the market or a regulatory agency engenders a rent, there is competition for it; the effect of this competition is that the rent tends to be partially dissipated by the additional costs incurred in the attempt to appropriate it. In addition, patent races can result in an inefficient amount of R&D investment by the firms involved in the competition (Pepall et al., 2005).

There are also further dangers involved in patent race. The works of Dasgupta and Maskin (1986), Judd (1985) and Klette and De Meza (1986) highlight that patent races lead firms to choose excessively risky R&D technologies (R&D competitors pick technologies that involve a higher “variance” with respect to its social optimal level). Moreover, patent race may affect the market structure itself. Gilbert and Newbery (1982) explain the persistence of monopoly by showing that, whenever innovation by the monopolist can prevent a new firm to enter the market, the monopolist has a large incentive to pursue it, so as to protect its monopoly profit. This effect is strengthened by the patent system because it reinforces the ability of the incumbent to preclude entry. A simple model of patent race is the “memoryless” or “Poisson” patent race, associated to the works of Dasgupta and Stiglitz (1980), Lee and Wilde (1980), Loury (1979) and Reinganum (1982). The research technology is characterized by the assumption that a firm’s probability of making a discovery and obtaining a patent at a given point of time depends only on firm’s current R&D expenditure, and not on its past experience and competitor’s past research program. These models consider patent race between an incumbent and a potential entrant and show that, in case of non drastic innovation, there is a tendency for the monopoly to persist, because the established firm has an higher probability of obtaining a patent. Introducing experience in patent race[4], Fudenberg et al.(1983) show that the leader obtains a monopoly on R&D, even if it enters the race only a shot period of time before the follower: so, competition in R&D may be strongly restricted by first-mover advantages and experience effects.

Another way in which patent protection can affect the industrial structure is through the incentive to create the so called “sleeping patents”. Very often a singe firm holds a large number of patents all related to the same process or product, most of which are not used. The motivation behind a “sleeping patent” is to create a buffer of protection for the monopoly profits generated by the truly valuable patent. By acquiring patents the incumbent strengthens its monopoly position.

1.3 Spillover externality and R&D cooperation

Another field of analysis regards the spillovers generated by the R&D activity. When patent protection is not completely effective and innovation creates spillovers, firms that conduct R&D individually do not internalize the positive externality on their rivals associated with an innovation. They thus tend to underinvest in R&D from an industry and social point of view (Katz, 1986; d’Aspremont and Jaquemin, 1988; Kamien et al., 1992). Jaffe (1986), finds empirical evidence of the presence of spillovers, showing that firms benefit from R&D of rivals. Ornaghi (2006) highlights a gap between private and social rate of returns of R&D, concluding that appropriability problems reduce investment

[4] At each moment of the patent race, the game can be summarized by the vector of experiences for all firms.

in R&D. In this literature, firms' cooperation in R&D is considered a tool to correct the inefficiencies generated by spillovers, through the internalization of the externalities.

In the theoretical literature, a first attempt to analyze an oligopolistic market in terms of R&D cooperation was made by Katz (1986). Katz proposed a multi-stage model of process innovation to examine the formation of a RJV. His analysis shows that industry-wide cooperative agreements usually have socially beneficial effects when the degree of product market competition is low, when there are information spillovers for the non-cooperating firms and when the participating firms are able to share their research results.

However, the most influential paper in this strand of the literature has been that of d'Aspremont and Jacquemin (1988); most of the theoretical works on R&D cooperation in presence of spillovers are based on their model. They develop a 2-stage duopoly model in which, at the first stage, firms decide the amount of R&D effort and in the second stage they choose the quantities to be produced in order to maximize their profit. Undertaking R&D investment, a firm aims to reduce its initial marginal costs (process innovation): however, the rival firm benefits from a fraction (identified by the spillover parameter) of this cost reduction. The output of each firm is an increasing function of its own R&D expenditure, since this expenditure reduces a firm's costs and makes a higher output more profitable. By contrast, the effect of the rival's R&D effort on a firm's production can go either way: it makes the rival a tougher competitor, but at the same time it has an expansionary effect on firm's profit since rival's R&D activity spills over and lower its costs. The net result depends on the extent of the spillovers; the amount of research done by each firm is decreasing in the spillover parameter. When spillovers are low, research expenditures of the two firms are strategic substitutes (firms' output and profit are decreasing functions of the R&D expenditures of their rivals); yet, this gives each firms an incentive to spend aggressively in R&D to avoid being the loser in the war. When spillovers are high, research expenditures are strategic complements; the more one firm spends in R&D, the more the rival is induced to spend. Even if a firm spends only a little in R&D, it knows that this will induce the rival to do a fair bit of research activity, from which it can obtain some benefits. Hence, firms' incentive to invest in R&D can be quite small as each firm seeks to free ride on the other's efforts. d'Aspremont and Jacquemin (1988) claim that, when the spillover problem is severe, R&D cooperation allows to internalize the spillover externality, increasing the total investment and leading it closer to its socially optimal level[5]. Indeed, the authors compare the amount of R&D expenditure under two different scenarios: R&D competition regime, in which firms act non-cooperatively in both stages, and R&D cooperation regime, in which, at the first stage, firms choose research intensity to maximize the joint profit (tough cooperation is not allowed in the production stage). They find that when spillovers are large, cooperation increases R&D expenditure and, as consequence, the produced quantities. This is because the agreement forces each firms to internalize the external benefits that such spending has upon its rival and eliminates the free-riding problem. This means also that the two firms will enjoy a profit at least as great as that earned in absence of cooperation and that consumers will benefit from the the cost reduction induced by a greater R&D effort. This happens because in this case the primary effect of R&D cooperation is to correct a market failure. However, the outcome under the single coordination plan may not necessarily be good for consumers. In particular, consumers are hurt by the technology cooperation when spillovers are small, since in this case the total investment is lower in RJV regime than in R&D competition, and a lower rate of innovation implies higher prices. The policy implication of this model is that, if the spillover problem is relevant, RJV should be encouraged so long as the antitrust authorities can assure that such cooperation on research effort will not also extend to cooperation in production and prices (price fixing cartel).

Kamien et al. (1992) show that this results extends to a n-firms oligopoly, where firms produce differentiated

[5]They find that, with high spillovers, the extent of R&D effort is under the social optimal level in both regimes.

goods. They consider also the possibilities of joint production and of full information sharing (maximum spillovers).

The potential benefits of R&D cooperation in presence of spillover are among the reason why RJVs are not treated as per se violations by the antitrust authorities and are encouraged by policy-makers[6].

Starting from these seminal papers, a huge literature has developed. Several authors extended the basic model to make the spillover parameter endogenous, confirming the beneficial effect of R&D cooperation when spillovers are high. Increasing attention has been devoted also to the structure of R&D agreements and to the processes of RJV formation and partner selection.

1.3.1 Endogenous spillovers

The literature has recognized the possibility that firms may be able to affect the degree of spillovers they send or receive; in this case, the spillovers parameter is considered as a strategic variable set by firms. In fact, the amount of spillovers from one firm to the other depends on two factors: the *absorptive capacity* of a firm (capacity to exploit rival's research outcomes, that may depend on its own R&D effort) and the amount of knowledge a firm is willing to share with the other firms (*information sharing*). When firms act strategically, the incentive to share information depends on the nature of the product market. If firms are in different but complementary industries, spillovers enables the receiving firm to improve its product or technology, attract more consumers and increase its profits; this, in turn, has a beneficial impact also on the profits of the sending firm. If firms are in the same industry, instead, spillovers simply will make the receiving firm more competitive, reducing the profits of the sending firm. When firms act cooperatively, then incentives to share information depend on the nature of the joint profit function.

Katsoulacos and Ulph (1998) endogenize the spillover chosen by the sender (that is the extent of information sharing) and find that that sometimes firms in a RJV decide not to fully share information in order to prevent the market from becoming too competitive.

The endogenous spillover is considered in terms of information sharing also in Poyago-Theotoky (1999); in this model symmetric firms choose full information disclosure (maximal spillover) in RJV regime, where they maximize the joint profit, while firms set the minimum value for the spillover parameter when they act non-cooperatively. Amir et al. (2001) find similar results. Amir et al. (2003) assume that firms participating to a R&D cartel (whose aim is the maximization of the joint profit) choose the level of the spillover parameter in addition to possibly asymmetric levels of the R&D effort. They find that the optimal R&D cartel must be either a RJV with maximal spillover, or else call for all R&D to be conducted by one firm only (in this latter case with minimal spillover).

Some authors (Beath et al., 1998; Baerenss, 1999; Atallah, 2005), simply claim that RJVs participation implies information sharing, then spillovers should be larger when firms decide to cooperate than when they act non-cooperatively; accordingly, in their models, the spillover parameter takes maximum value in RJV regime.

[6]EU and Japan have always had positive and permissive attitude towards cooperation in R&D; EU Commission involvement in the coordination and in the financing of RJVs, and more generally of cooperative research programs, has substantially increased over the years. As for US, in 1984, Congress enacted the National Cooperative Research Act, which was extended to the National Cooperative Research and Production Act in 1993 to include joint production ventures. This act protects R&D joint ventures and certain qualifying joint production ventures from the strict application of antitrust law (Sherman Act, 1890).

1.3.2 RJV contracts and formation process

Another branch of research concerns the structure of R&D cooperation agreements and the participation process. These models mainly focus on the optimal size of RJVs, partner selection, coalition stability and membership rules.

Atallah (2005b) addresses the issue of partner selection in R&D cooperation, taking into account three firms characterized by different level of efficiency. He finds that firms' preferences regarding a potential partner depend on the extent of the spillovers and on cost differences between firms. With low (high) spillovers, a generic firm prefers to cooperate with the most (least) efficient among the remaining firms. However, when spillovers are very high, firms prefer to be excluded from R&D cooperation. As the cost differential between firms increases, efficient (inefficient) firms prefer to cooperate with the most (least) efficient firm. The equilibrium configuration is such that the most efficient firms cooperate for low spillovers, while all firms are willing to cooperate for intermediate spillovers. In presence of high spillovers, all firms cooperate when the cost differential is sufficiently low, but if the cost differential is high, firms' willingness to cooperate depends on the bargaining mechanism.

Poyago-Theotoky (1995) shows that, depending on the magnitude of the spillovers, the market may not provide enough incentive for the optimum degree of cooperation to take place. The equilibrium size of an RJV is usually less than the optimum size, which requires all firms to be part of the RJV. According to the author, the policy implication is that there should be encouragement for firms competing in high-technology industries to form industry-wide cooperative agreements.

Sometimes, RJVs have been found to act as anti-competitive device and strengthen, or even create, dominant positions in the market. Yi (1998) claims that, in some cases, a joint venture could restrict competition with the adoption of exclusionary membership rules. He studies the endogenous formation of joint ventures between symmetric firms under two different access rule: under the open membership rule, the membership of a joint venture is open to all firms, while the coalition unanimity rule allows exclusivity in membership. The results show that the industry-wide joint venture (the socially efficient structure) is the unique stable outcome under the open membership rule, because an outsider always benefits by joining a large joint venture. However, the grand coalition is frequently not the equilibrium outcome under the coalition unanimity rule. While efficiency in production calls for a widespread membership, strategic considerations may lead members of a large joint venture to restrict their membership ranks. By admitting a new member, the existing members gain access to just one more unit of productive assets, but the new member gains access to the total pool of assets of the venture. The new member gains a competitive advantage against the existing members, that may earn lower profits (despite their lower production costs). Hence, the existing members of a large joint venture may want to deny membership to the outsiders if they are allowed to do it. According to this analysis, even though members of a large joint venture remain competitors in the output market, so that they lack classical market power to raise price by restricting their own output, the refusal to expand membership gives exclusionary market power to members of a large joint venture by disadvantaging rivals firms. Creane and Konishi (2009) find that, with free entry, an efficient firm can find profitable to transfer its knowledge to their rivals because such transfers are credible mechanisms to make the market more competitive and have the effect of deter entry or force exit.

Recently, some authors applied the network approach to the analysis of firms' cooperation in oligopolistic markets. This new models provide some insights on the evolution of the market structure deriving from firms' decisions to set up collaborative agreements; indeed, cooperation agreements alter the competitive position of firms, thus influencing market structure and firms' performance. Differently from the coalition approach, network analysis allows to take into account cooperative relations that are not exclusive. An interesting analysis in this field is that conducted by Goyal and Moraga-Gonzales (2001). Noting that a significant proportion of inter-firm collaborations in R&D takes place between firms exhibiting some degree of market rivalry, they study the incentives to cooperate for horizontally related firms, using a strategic model of R&D network. One of the results of their work is that asymmetric networks (which are those observed more frequently), such as the star or the partially connected network, perform quite well from the social as well as the private point of view. They also find that asymmetric forms of collaboration may alter the market structure by causing large disparities between firms, or even leading to the exit of firms, but that this not necessarily detrimental from a social standpoint. Song and Vannetelbosch (2007) reconsider the Goyal and Moraga-Gonzales model of strategic networks in order to analyze how government subsidies affects the stability and the efficiency of networks of R&D collaboration among firms located in different countries (international collaboration). They also allow for coalition deviations in the formation of R&D collaboration networks. In their model, a conflict between stability and efficiency is likely to occur: firms' incentives to form collaborative ties may be excessive with respect to the socially optimal level. However, if the government subsidizes R&D activity, the likelihood of a conflict between stability and efficiency decreases, leading to a better outcome in terms of social welfare. Moreover, with government's intervention, the aggregate level of effective R&D could increase considerably.

1.4 Incomplete information in innovation processes

Some authors have contributed to the theoretical literature on innovation introducing the hypothesis of incomplete information. In most of the cases, incomplete information is related to information disclosure and optimal contract design issues[7].

d'Aspremont, Bhattacharya and Gerard-Varet (1998), in a context of contract arrangements for R&D collaboration agreement, consider a RJV in which adverse selection and moral hazard may arise. Adverse selection concerns information sharing, while moral hazard regards the choice of private development efforts aimed to translate privately acquired and/or shared knowledge into marketable innovations. Brocas (2004) assumes incomplete information about skills in a regulation context and designs the optimal contract to favor efficient sharing of skills and to encourage socially optimal provision of effort. In this model, a regulator offers a cooperation contract entailing the development by part of two firms of a subsied research project; the contract provides incentives to encourage skill-sharing, which results in distorting R&D efforts with respect to the first best level[8]. Cassiman (2000) introduces incomplete information between firms and the regulator in a context of optimal R&D policy. The policy-maker has two tools to implement social welfare maximization: allowing R&D and giving subsidies. The extent to which there exist appropriability problems between firms is private information. Firms have to declare the level of their spillovers (asymmetric spillovers are possible), since their type is unknown to government and potential partner. In this model, asymmetric information turns out to be responsible for the impossibility to implement first best policy.

Pérez-Castrillo and Sandonìs (1996) analyze the effect of asymmetric information on know-how disclosure in RJVs, looking for a policy that favors the sharing of know-how. They consider RJVs facing technological uncertainty, in the sense that the final cost of the projects is unknown when the RJVs are built up and the disclosure of know-how

[7]With some exceptions: Xue and Gong (2006) use asymmetric information in a model of R&D strategic investment; in Zhu and Weyant (2003) incomplete information concerns strategic decisions on new technology adoption; Grishagin, Sergeyev and Silipo (2001) develop a patent race model in which firms do not know their relative position; Kao (2002) assumes private information about firms' R&D progress.

[8]This model differs from the standard Cournot model with spillovers; it entails a generic formulation of the payoff functions and spillovers are not taken into account.

makes the expected cost of the project lower. However, firms compete in other markets, so when a firm discloses its know-how, the partner becomes a stronger competitor in the other markets. Since know-how is soft information, it's very difficult to impose its transfer by contract and this creates a moral hazard problem. They show that there are many cases in which profitable RJVs do not start because of this moral hazard problem. Moreover they find that patent subsidies can help to reduce this problem, whereas cost subsidies are useless or may even go against the objective of solving the moral hazard problem regarding the disclosure of know-how.

Espinosa and Macho-Stadler (2003) study the impact of moral hazard on the equilibrium number and size of firms. They model the formation of competing partnerships as a sequential 2-stage game with moral hazard within coalitions[9]; at the first stage, partners can group into a 'big' firms through a sequential process, while at the second stage players choose their effort level. This model depart from the assumption that members maximize the coalition's payoff: partners decide individually on the effort level, though they are assumed to share the gross profits of the 'big' firm equally. The level of gross profit is verifiable and thus partners can commit to an equal sharing rule in the first stage. However, only the partnership's total output is verifiable, so each firm faces a team incentive problem: a firm's realized output is dependent on the joint efforts of its members, whose effort and performance cannot be individually verified, and this gives rise to the moral hazard problem. The authors show that, when moral hazard is very severe, it can prevent partnership formation and reduce the equilibrium number of coalitions. In terms of industry profits, in presence of moral hazard, too few coalition are formed in equilibrium, as compared to the efficient outcome.

Finally, Cabon-Dhersin and Ramani (2004), in a quite different context with respect those described above, introduce incomplete information to analyze role of trust in the initiation and success of R&D cooperation. They consider two types of firms, opportunistic and non opportunistic, and find that the higher the spillovers, the higher the level of trust required to initiate R&D cooperation for non-opportunists, while the inverse holds for opportunists

1.5 Discussion

The theoretical literature on R&D cooperation in presence of spillovers agrees on the result that RJVs enhance innovation and contribute to increase the total welfare. Also, some empirical works seem to confirm the positive effect of R&D cooperation on innovation (Simonen and McCann (2008)) and on firms' performance (Benfratello and Sembenelli (2002)). R&D cooperation literature may lead to believe that R&D cooperation between firms is quite common and that collaboration, once initiated, is unlikely to fail. However, even in high-tech sectors cooperation at R&D level is still more the exception that the rule. Furthermore, a large number of RJV break down before completion of the project (Kogut, 1989). Empirical literature has emphasized the role of asymmetries in terms of gains from cooperation and decisions on RJV membership. Firms can be asymmetric in many respects: efficiency level, type of technology, experience, market size etc. Petit and Towlinsky (1999) show that the degree of size-related asymmetries between firms influences participation decisions. Kogut (1991) stresses that firms have different "absorptive capacities" of research results, which in turn determine their willingness to form a RJV. The absorptive capacity is determined by factors such as size and past experience. Röller, Tombak and Siebert (1998) show that size symmetry and product complementary between firms enhance the likelihood of RJV formation.

So, asymmetries seems to affect cooperative outcome and participation decisions, but this issue has been scarcely

[9] The quantity produced by a firm is the sum of the effort of all the firms in the coalition to which the firm belongs. In a partnership profits are shared according to a fixed sharing rule

taken into account in the theoretical literature, with few exceptions that confirm its relevance. Baerenss (1999) finds that asymmetric firms, in terms of initial marginal costs, often fail to agree on RJV formation, even if the RJV generates higher industry profits and turns out to be welfare improving. This is because asymmetric equilibria in production and research stage may arise, and the gains from cooperation are distributed unevenly; accordingly, without side-payments, the desire to cooperate does not coincide for a wide range of parameters. Another important result of this model is that, when initial asymmetries are large, R&D cooperation may reduce the welfare, because it reinforces the initial asymmetry in costs, and helps the larger firm maintain its dominant position. Atallah (2005a) analyzes the effect of asymmetric spillovers (that represent different absorptive capacity) on the incentives to cooperate, and finds that, in most of the cases, firms will not agree on cooperation since it reduces the profits of one of them. Atallah (2005b) highlights the relevance of cost asymmetries in the selection of the RJV partner.

I tried to contribute to fill this gap in the literature by extending the model of d'Aspremont and Jacquemin (1988) to take into account asymmetric firms in terms of R&D efficiency *and* their actual incentive to cooperate in R&D activity. As further extension, I also introduced asymmetric information about rival's R&D efficiency to analyze the consequences of this assumption on the level of investment in the market and on firms' willingness to form RJVs. My contribution to the literature is presented in the following chapters.

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Chapter 2

Asymmetric firms, R&D spillovers and the incentives to form RJVs

Introduction

Innovation is one of the main determinants of economic performance in advanced countries and is commonly thought to be beneficial for society. At the same time, innovative activities are often associated with non-competitive market structures and with externalities, meaning that innovation is strictly related to situations that bring to market failures and that often justify government intervention. One of the most studied issues concerns the spillovers problem, that affect the decisions about R&D investments and that can determine an inefficient level of R&D effort. In the theoretical literature, since the seminal paper of d'Aspremont and Jacquemin (1988; AJ thereafter), this problem has been described using a 2-stage Cournot model in which R&D expenditures results in costs reduction. In this model, part of the competitive advantage arising from costs reduction goes to the rival (through the spillover parameter), who becomes a tougher competitor; the incentive to invest in R&D can be quite small as each firm does not internalize the positive externality on its rival and seeks to free ride on the other's efforts. The level of investment in R&D in a *regime* of competition is compared to that arising in a *regime* in which firms cooperate in R&D choosing the R&D effort in order to maximize the joint profit. The equilibria of the AJ model show that, when spillovers are high, cooperation increases R&D expenditure (and, as consequence, industry output), since it allows to internalize the externality caused by knowledge spillovers. This results in a welfare improvement since in the AJ model the extent of R&D effort results to be below the social optimal level in both *regimes*. The policy implication is that RJV should be encouraged as long as the antitrust authorities can assure that such cooperation on research effort will not also extend to production and prices. Since several extensions of the AJ model confirm the result concerning the desirability of R&D cooperation in presence of spillovers (see Kamien et al. (1992), Suzumura (1992), Amir (2000), Lambertini and Rossini (2009) for example), over the last twenty years there has been an increasing interest in the role that R&D collaboration agreements might play in stimulating innovation and this can be a reason why RJVs are not treated as per se violations by the antitrust authorities and are encouraged by policy-makers. The R&D cooperation literature may lead to believe that R&D cooperation between firms is quite common and that collaboration, once initiated, is unlikely to fail. However, even in high-tech sectors, cooperation at the R&D level is still more the exception that the rule. Furthermore, a large number of RJV break down before completion of the project (Kogut, 1989). The empirical literature has emphasized the role of asymmetries (basically in size) in terms of gains from cooperation, that in turn affect decisions about RJV membership. Petit and Towlinsky (1999) show that the degree of size-related asymmetries between firms influences participation decisions. Kogut (1991) stresses that firms have different “absorptive capacities” of research results, which in turn determine their willingness to form a RJV. The absorptive capacity is determined by factors such as size and past experience. Röller, Tombak and Siebert (1998) show that size symmetry and product complementary between firms enhance the likelihood of RJV formation. So, asymmetries seems to affect cooperative outcomes and participation decisions, but these issues have been scarcely taken into account in the theoretical literature, with few exceptions. Almost all these models focus on symmetric firms and just compare their investment decisions under two different *regimes* (R&D competition and R&D cooperation) to derive policy implications, without considering firms' actual incentive to cooperate in R&D when cooperation results to be welfare improving. Asymmetries have mainly been associated to initial marginal costs or to the spillover parameter, interpreted in terms of absorptive capacity. Baerenss (1999) finds that asymmetric firms, in terms of initial marginal costs, often fail to agree on RJV formation, even if the effect on industry profit and welfare would be positive. This is because asymmetric equilibria in production and research stage may arise and the gains from cooperation are distributed unevenly; accordingly, without side-payments, the desire to cooperate does not coincide for a wide range of parameters. Atallah (2005a) analyzes the impact of asymmetric spillovers on the consequences and the incentives for cooperation and finds that in most cases firms will not agree on cooperating, because cooperation reduces the profits of one of them. As for RJVs formation process, studies are mostly related to partner selection (Atallah, 2005b) or coalition stability issues (Goyal et al., 2001; Song and Vannetelbosch, 2007).

In this work I try to contribute to fill this gap by extending the standard AJ model to take into account asymmetric firms in an investment game in which they have also to decide about RJV membership. Differently from previous models, firms are assumed to be asymmetric in the efficiency of R&D investment, that is, in the effective cost reduction obtained from R&D investment. Firms start with identical marginal costs, but these are affected in different way by investment decisions.

My model differs from that of AJ mainly in three aspects, in addition to the introduction of asymmetric firms. First, the investment choice is discrete, that is firms have to decide if invest a fixed amount in R&D or avoid R&D activity[1]. The use of a discrete variable for R&D investment choice implies that results have to be interpreted in terms of regions of parameters' values for the variable under consideration; if, under a certain *regime*, there is a larger region in which an equilibrium with investment does exist, it can be said that in that *regime* the probability to observe investment is higher, so there is more investment. Second, I do not assume joint profit maximization in RJV, since it would imply a system of transfers in presence of asymmetric outcomes (Baerenss (1999), Salant and Shaffer (1998)); I assume that in RJV firms have to coordinate their R&D effort, that is they have to agree on the same investment strategy. Third, To analyze the incentive to form a RJV, I add a further step to the standard game, in which firms' decisions about RJV membership determine the *regime* in which they will end up in the investment stage[2].

I solve the model not only for the case in which firms are asymmetric, but also for the case of symmetric firms; from the comparison of the two cases it can be assessed the relevance of firms' asymmetries in terms of outcomes. Moreover, it will be shown that, in the particular case in which firms are symmetric, my version of the model replicates the results of the standard model, that is there is more (less) investment in RJV *regime* when spillovers are high (low); so, results arising from the extended (modified) model should hold also for standard models.

[1]This choice has been done mainly to make the model tractable; however it turned out to be useful since it allows for possible asymmetric investment choices even in presence of simmetric firms, while in almost all the models where investment variable is continouos only symmetric solutions are taken into account.

[2]The analysis of the incentive to cooperate in R&D is particularly interesting in presence of asymmetric firms; with symmetric firms and joint profit maximization in RJV , firms have always incentive to cooperate, given that outcomes are symmetric (Lambertini and Rossini, 2009).

The paper is organized as follows. Section 2 describes the model; in Section 3 equilibria for each stage of the game and for the whole game are derived for the case of high spillovers, while in Section 4 the case of low spillovers is treated; Section 5 concludes.

2.1 The Model

The model is a modified version of the standard 2-stage investment game with spillovers (AJ model). As said before, equilibrium outcome are computed for the case of asymmetric firms as well as for the case of symmetric firms. The description of the game and the generic formulation of payoffs hold for both symmetric and asymmetric firms, with minor differences.

There are two firms (firm 1 and firm 2) competing on quantities and facing the inverse demand function for an homogeneous good:

$$P = a - Q = a - q_1 - q_2$$

Each firm can decide to invest a fixed amount $K > 0$ in R&D in order to reduce the initial marginal cost c (assumed identical for the two firms) by $t_i (i = 1, 2)$. R&D investment can make firms asymmetric, even if they both invest; in fact, firm 1 and firm 2 could not be equally efficient in R&D activity. When we analyze the case of symmetric firms, we are considering two firms that are equally efficient in their R&D activity: R&D investment leads to the same costs reducion, that is $t_1 = t_2 = t$. In the case of asymmetric firms, firm 2 obtains a lower cost reduction from investment: if it invests K, the costs reduction is $t_2 = \alpha t$, with $\alpha \in (0, 1)$, while $t_1 = t$, provided that firm 1 invests. The investment of a firm also benefits the rival due to the presence of spillovers (non-perfect appropriability of the results of R&D activity); this creates a *positive* externality problem leading to R&D under-investment[3]. In this model firms have the possibility to form a Research Joint Venture (RJV) to jointly determine an investment strategy. In the following for a RJV *regime* coordination is required in order to invest in R&D, that is, we observe investment only if both firms agree on this decision; the choice of no investment by at least one firm in RJV prevents R&D investment. We characterize the RJV in this way because this kind of agreement is considered a mean to internalize the externality arising from the existence of spillovers and to eliminate the 'free riding' problem. The preceding works model RJV as a situation in which symmetric firms make R&D investment choices in order to maximize the joint profit (the variable describing R&D effort/expenditure is continuous) and take symmetric actions. In this model, in which R&D choice is discrete, we assume this kind of coordination in RJV to replace the 'joint profit maximization hypothesis'. Asymmetric firms and discrete R&D choice may lead to asymmetric outcomes and the joint profit maximization would imply a system of side payments (see Baerenss (1999) and Salant and Shaffer (1998)). So, in the RJV *regime* there are only two possible outcomes: either both firm invest or none invests.

Coordination in production is not allowed. The spillover parameter is assumed to be exogenous: it is not a matter of choice for firms (as in Poyago-Thoetoky (1999) and Amir et al. (2003)) and its value does not change when firms are in RJV (in Beath et al. (1998), Atallah (2005), Kamien et al. (1992), Baerenss (1999) and Lambertini and Rossini (2009), under RJV *regime*, the spillover parameter takes value one since it is assumed information sharing in addition to coordination of R&D effort). I follow d'Aspremont and Jacquemin (1988) in keeping the spillover exogenous. With

[3] d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Suzumura (1992), Brocas (2004).

this assumption I don't mean that information disclosure in RJV is not a relevant issue; simply, it could be realistic to think that a firm (that maximizes its own profit in RJV) is not willing to share its knowledge with the other firm (a rival in the production stage). Poyago-Theotoky (1999) show that, when firms can decide about the value of the spillover parameter as measure of information disclosure and maximize their own profit, they will set the minimum level[4]. While R&D expenditure is observable, information disclosure is not a contractible variable, so it makes sense to assume that the extent of knowledge leakage is the same under both *regimes*.

Generic formulation for firm i's profits ($i = 1, 2$) can be written as:

$$\Pi_i = (P - c_i)q_i - K_i$$

where

$K_i \in \{0, K\}$, $K > 0$

$c_i = c - t_i - \beta t_j$, with $j = 1, 2$ and $j \neq i$

$0 \leq \beta \leq 1$ is the spillover parameter

$t_i = 0$ if $K_i = 0$, with ($i = 1, 2$)

$t_1 = t$ if $K_1 = K$

$t_2 = \alpha t$ with $0 < \alpha \leq 1$ if $K_2 = K$[5]

In the special case in which $\alpha = 1$ we are assuming that firms are symmetric. The maximum cost reduction is obtained when the two firms are symmetric, both invest, and the spillover is maximum; so the minimum level of the marginal cost is $(c - 2t)$.

Assumptions:

(i) $t > 0$

(ii) $t \leq \frac{c}{2}$ (non-negative costs)

(iii) $t \leq (a - c) \equiv \theta$ (non-negative quantities)

(i), (ii) and (iii) imply $0 < t \leq min\{\frac{c}{2}, \theta\}$.

Assumptions (i), (ii) and (iii) imply $0 < t \leq min\{\frac{c}{2}, \theta\}$.

Timing

The model is a three-stage game:

1. At the first stage firms have to decide about forming a RJV or not. Each firm chooses between *IN* (if it wants to stay in RJV *regime*) and *OUT* (if it prefers to manage its own R&D strategy in a context of competition). RJV is formed only if both firms agree on RJV formation.

2. At the second stage firms decide about the investment strategy. Two different *regimes* have to be considered: (i) if the RJV has not been formed in the previous stage, firms decide non-cooperatively whether invest or not in R&D (possible actions are $K_i = 0$ and $K_i = K$, $i = 1,2$); (ii) if firms are in RJV *regime*, they have to take symmetric actions: invest or not. So the only possible outcomes are $K_1 = K_2 = K$ or $K_1 = K_2 = 0$.

[4]The spillover parameter, when endogenously determined by firms, takes maximal value if firms maximize the joint profit, under the assumption of symmetric R&D effort. Amir et al. (2001) find similar results.

[5]Remember that firm 2' costs reduction depends on its R&D efficiency.

3. At the third stage firms compete à la Cournot; cooperation in production is not allowed even in the case in which firms have formed a RJV.

At the beginning of each stage, firms observe the outcome of the previous stage (multi-stage game with observed actions). The game is solved backward: equilibrium strategies for symmetric and asymmetric firms are computed for each stage, starting from the last one and moving backward to find the equilibria of the whole game.

In the following, we divide the analysis in two cases treated in separate sections, namely the case of high spillovers ($\beta > \frac{1}{2}$) and the case of low spillovers. ($\beta < \frac{1}{2}$). This distinction is common in the literature, since the value of β larger or smaller than $\frac{1}{2}$ determines the thresholds that will define the regions of parameters and, accordingly, the results. We start by considering the case of high spillovers; this describes a situation in which a firm obtains large benefits from R&D investment of the rival. However, in order to derive some policy implication about the desirability of RJVs, the effects of R&D cooperation when spillovers are low need to be analyzed. Also, the limit case of low spillovers ($\beta \to 0$) represents a situation in which the externality problem does not exist and can be used to infer the consequences of allowing R&D cooperation when the extent of spillovers is very limited.

2.2 The case of high spillovers

2.2.1 Stage 3: Cournot competition

Equilibrium strategies in this stage are given by the quantities that maximize each firm's profits given the choice of the rival. Firm i chooses q_i that maximize

$$\Pi_i = (P - c_i)q_i - K_i$$

given q_j (i, $j = 1$, 2 and $i \neq j$), Since $c_1 = c - t_1 - \beta t_2$ and $c_2 = c - t_2 - \beta t_1$, best responses are

$$q_1 = \frac{a - 2c_1 + c_2}{3} = \frac{\theta + t_1(2-\beta) + t_2(2\beta - 1)}{3} \tag{2.1}$$

$$q_2 = \frac{a - 2c_2 + c_1}{3} = \frac{\theta + t_2(2-\beta) + t_1(2\beta - 1)}{3} \tag{2.2}$$

with $\theta = (a - c)$. The resulting profits (payoffs) are

$$\Pi_1 = \frac{1}{9}\left[\theta + t_1(2-\beta) + t_2(2\beta - 1)\right]^2 - K_1 \tag{2.3}$$

$$\Pi_2 = \frac{1}{9}\left[\theta + t_2(2-\beta) + t_1(2\beta - 1)\right]^2 - K_2 \tag{2.4}$$

This is a generic formulation that holds for both symmetric and asymmetric firms; what makes different the two cases is the value of t_2 when $K_2 = K$ in the second stage[6]. Also, the final value of firms' profits will depend upon

[6]Remember that, after investment, firm 2's cost reduction is t in case of symmetric firms and αt in case of asymmetric firms.

investment's choices made at stage 2, which determine the actual value of K_1, K_2, t_1 and t_2. So, in the preceding stage, firms can anticipate what will be their profits given their own investment strategy and the rival's one.

Note that, when spillovers are high and both firms invest, the optimal quantity produced by firm 1 is lower when it is facing the less efficient firm ($t_2 = \alpha t$): firm 1 is less aggressive when the R&D productivity of the rival is lower and the latter has higher marginal cost. Even if the two firms are asymmetric, the higher is β, the more c_1 and c_2 converge and firm 1 loses its competitive hedge; moreover firm 1's cost reduction is lower with respect to the case in which it faces an equally efficient firm.

2.2.2 Stage 2: Investment strategy

In this stage two possible *regimes* have to be analyzed: if the two firms have not formed the RJV in the first stage, they make simultaneous decisions about R&D investment without coordination, that is, each firm i chooses between $K_i = 0$ and $K_i = K$ ($i = 1, 2$) in order to maximize its final payoff. If the two firms have set up a RJV, they have to coordinate on the same action (invest or not). I assume that in RJV each firm i states its preference between $\Pi_i(K_i = K_j = K)$ and $\Pi_i(K_i = K_j = 0)$, with $j \neq i$; if their preferences are not the same there is no investment in the RJV and no further investment is possible[7]. The analysis of this stage allows comparisons with the literature on R&D competition versus R&D cooperation, where most of the models (designed as two-stages games) just compare the amount of R&D effort/expenditure chosen by firms under the two different *regimes* to derive policy implications. It will be shown that this model generates similar results in case of symmetric firms, confirming the equivalence between discrete and continouos models. In addition, investment strategies under the two regimes can be compared also for the case of symmetric firms.

2.2.2.1 R&D competition *regime*

Let $\bar{s}_i = \{0, K\}$ be the strategy of firm i, $i = 1, 2$, in R&D competition; $\bar{s} = (\bar{s}_1, \bar{s}_2)$ is the strategy profile of the players. The following propositions state equilibrium investment choices when firms do not coordinate their R&D efforts.

Proposition 1. When firm 1 and firm 2 are symmetric and spillovers are high, in R&D competition: (i) if $K < (t/9)(2-\beta)(2\theta + 3\beta t) \equiv \tau$, the SPE is such that both firms invest in R&D, whereas (ii) if $K > \tau$, there is a unique SPE in which none invests.

Proof.

Firms' choices are symmetric. If $\bar{s}_j = K, \bar{s}_i = K$ iff $(\Pi_i|\bar{s}_i = K, \bar{s}_j = K) = \frac{[\theta+t(1+\beta)]^2}{9} - K > \frac{[\theta+t(2\beta-1)]^2}{9} = (\Pi_i|\bar{s}_i = 0, \bar{s}_j = K)$, with $i, j = 1, 2$ and $i \neq j$, that is iff

$$K < \frac{t(2-\beta)[2\theta + 3\beta t]}{9} \equiv \tau \qquad (2.5)$$

If firm j plays 0, firm i will play 0 iff $(\Pi_i|\bar{s}_i = 0, \bar{s}_j = 0) = \frac{\theta^2}{9} > \frac{[\theta+t(2-\beta)]^2}{9} - K = (\Pi_i|\bar{s}_i = K, \bar{s}_j = 0)$, with $i, j = 1, 2$ and $i \neq j$, that is iff

$$K > \frac{t(2-\beta)[2\theta + t(2-\beta)]}{9} \equiv \delta \qquad (2.6)$$

[7]This assumption is justified by the fact that a firm willing to invest can anticipate in the first stage the lack of coordination in RJV and decide to compete in R&D in the second stage (choosing OUT in the first stage).

Given that $\delta < \tau$, if $K < \delta$, the unique SPE is such that both firms invest, and, if $K > \tau$, there is a unique SPE in which none invests. In $\delta < K < \tau$, both types of symmetric equilibrium are possible. Since, in this region, $(\Pi_i|\bar{s}_i = K, \bar{s}_j = K) > (\Pi_i|\bar{s}_i = 0, \bar{s}_j = 0)$, the *Pareto Dominance* concept can be used to select the equilibrium with investment■.

According to *Proposition 1*, symmetric firms adopt symmetric investment strategies: when the cost of investment is under a certain threshold they both invest, while if the cost is above the threshold none invests. This is consistent with the findings in the theoretical literature, where firms have to decide the amount of R&D expenditure (continuous variable) and they are assumed to take symmetric strategies.

Proposition 2. When firm 1 and firm 2 are asymmetric (firm 2 has lower R&D productivity) and spillovers are high, in R&D competition the unique SPE are: (i) if $K < \frac{\alpha t(2-\beta)[2\theta+2t(2\beta-1)+\alpha t(2-\beta)]}{9} \equiv h$, both firms invest in R&D, (ii) if $h < K < \delta$[8], only firm 1 invests; (iii) if $K > \delta$ none invests.

Proof.

If $\bar{s}_1 = K, \bar{s}_2 = K$ iff $(\Pi_2|\bar{s}_2 = K, \bar{s}_1 = K) = \frac{[\theta+\alpha t(2-\beta)+t(2\beta-1)]^2}{9} - K > \frac{[\theta+t(2\beta-1)]^2}{9} = (\Pi_2|\bar{s}_1 = 0, \bar{s}_2 = K)$, that is iff

$$K < \frac{\alpha t(2-\beta)[2\theta + \alpha t(2-\beta) + 2t(2\beta-1)]}{9} \equiv h \tag{2.7}$$

Given $\bar{s}_2 = K, \bar{s}_1 = K$ iff $(\Pi_1|\bar{s}_1 = K, \bar{s}_2 = K) = \frac{[\theta+t(2-\beta)+\alpha t(2\beta-1)]^2}{9} - K > \frac{[\theta+\alpha t(2\beta-1)]^2}{9} = (\Pi_1|\bar{s}_1 = 0, \bar{s}_2 = K)$, that is iff

$$K < \frac{t(2-\beta)[2\theta + 2\alpha t(2\beta-1) + t(2-\beta)]}{9} \equiv g$$

Since $h < g$, $\bar{s} = (K, K)$ is SPE when $K < h$.

If $\bar{s}_1 = 0, \bar{s}_2 = 0$ iff $(\Pi_2|\bar{s}_2 = 0, \bar{s}_1 = 0) = \frac{\theta^2}{9} > \frac{[\theta+\alpha t(2-\beta)]^2}{9} - K = (\Pi_2|\bar{s}_2 = K, \bar{s}_1 = 0)$, that is iff

$$K > \frac{\alpha t(2-\beta)[2\theta + \alpha t(2-\beta)]}{9} \equiv f$$

Given $\bar{s}_2 = 0, \bar{s}_1 = 0$ iff $(\Pi_1|\bar{s}_1 = 0, \bar{s}_2 = 0) = \frac{\theta^2}{9} > \frac{[\theta+t(2-\beta)]^2}{9} - K = (\Pi_1|\bar{s}_1 = K, \bar{s}_2 = 0)$, that is iff $K > \delta$. Since $\delta > f$, $\bar{s} = (0, 0)$ is SPE when $K > \delta$.

If $K > g$, $\bar{s}_1 = 0$ given $\bar{s}_2 = K$; if $\bar{s}_1 = 0, \bar{s}_2 = K$ iff $K < f$. Since $g > f$, $\bar{s} = (0, K)$ cannot be a SPE.

If $\bar{s}_1 = K$ and $K > h$, firm 2 will play $\bar{s}_2 = 0$; when $\bar{s}_2 = 0, \bar{s}_1 = K$ iff $K < \delta$. Given that $h < \delta$, $\bar{s} = (K, 0)$ is SPE when $h < K < \delta$.

Also, given the order of thresholds, equilibria in each interval are unique■.

Differently from the case of symmetric firms, when firms are characterized by different R&D productivity an equilibrium with asymmetric investment choices may arise; there is a region of parameters in which only the more efficient firm invest, whereas the other one exploits the spillover effect to reduce its costs without paying the investment's cost. It will be shown in the following that this asymmetric equilibrium strongly affects the decision to cooperate in R&D.

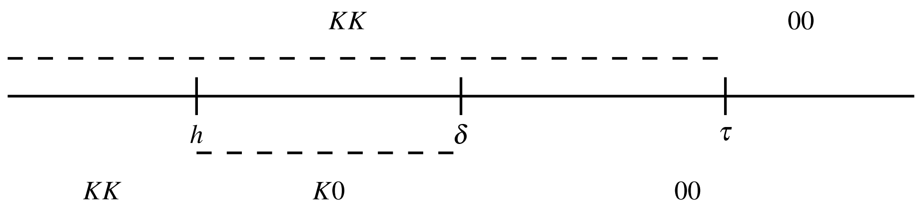
From *Proposition 1* and *Proposition 2* the following corollary can be stated.

Corollary 1. In presence of high spillovers, given that $\delta < \tau$, firm 1 invests in a smaller region of parameters when it faces a firm that is less efficient in R&D activity■.

[8]Where δ is defined in (6)

Figure 1 shows R&D investment choices in R&D competition *regime* for the case of symmetric and asymmetric firms. It is not surprising to observe less investment by part of the less efficient firm, made evident by the region with asymmetric investment choices; however it can be noted that when spillovers are high also firm 1 is less likely to invest if its rival is characterized by lower R&D productivity, with respect to the case in which the other firm is equally efficient.

Figure 2.1: **R&D investment choices in R&D competition *regime* (high spillovers)**



Note: each outcome represents firms' investment choices in an equilibrium of the continuation game started at the beginning of the second stage. The first element refers to the choice of firm 1, the second to the choice of firm 2. Above the solid line is represented the case of symmetric firms; below the solid line there are the outcomes for asymmetric firms.

2.2.2.2 Research Joint Venture *regime*

If the two firms formed a RJV at the first stage, coordination is required to invest in R&D, that is, we observe investment only if both firms agree on this decision. So, in a RJV there are only two possible outcomes: either both firm invest or none invests. I assume that each firm states its preference over 'invest' (to which correspond the profits after $K_1 = K_2 = K$), or 'not invest' (to which correspond the profits after $K_1 = K_2 = 0$); in case of disagreement, no firm can invest. Let $\tilde{s} = (\tilde{s}_1, \tilde{s}_2))$ be the combination of actions taken by the players, with $\tilde{s}_1, \tilde{s}_2 = \{(00), (KK)\}$. Firms' feasible actions are named KK and 00 to indicate that the choice of a player refers to an outcome in which both firms take the same investment strategy.

Proposition 3. If firm 1 and firm 2 are asymmetric and spillovers are high, in RJV *regime* the unique SPE are: (i) the RJV invests if $K < (1/9)[t(2\beta-1)+\alpha t(2-\beta)][2\theta+t(2\beta-1)+\alpha t(2-\beta)] \equiv \rho$, (ii) the RJV does not invest if $K > \rho$.

Proof.

Firm 2 prefers investment in RJV when $(\Pi_2|K_2 = K, K_1 = K) > (\Pi_2|K_2 = 0, K_1 = 0)$, that is if $\frac{[\theta+\alpha t(2-\beta)+t(2\beta-1)]^2}{9} - K > \frac{\theta^2}{9}$, or

$$K < \frac{[t(2\beta-1)+\alpha t(2-\beta)][2\theta+t(2\beta-1)+\alpha t(2-\beta)]}{9} \equiv \rho. \tag{2.8}$$

Firm 1 prefers investment in RJV when $(\Pi_1|K_1 = K, K_2 = K) > (\Pi_1|K_1 = 0, K_2 = 0)$, that is if $\frac{[\theta+t(2-\beta)+\alpha t(2\beta-1)]^2}{9} -$

$K > \frac{\theta^2}{9}$, or

$$K < \frac{[\alpha t(2\beta - 1) + t(2 - \beta)][2\theta + \alpha t(2\beta - 1) + t(2 - \beta)]}{9} \equiv \rho^{'} \tag{2.9}$$

Since $\rho < \rho^{'}$, the RJV invests only if $K < \rho$; in the interval $[\rho, \rho^{'}]$, the preference of firm 2 prevents investment; for $K > \rho^{'}$ both firms prefer not to invest in RJV■.

If α was equal to one, the two thresholds ρ and $\rho^{'}$ would take the same value. This new threshold is named z:

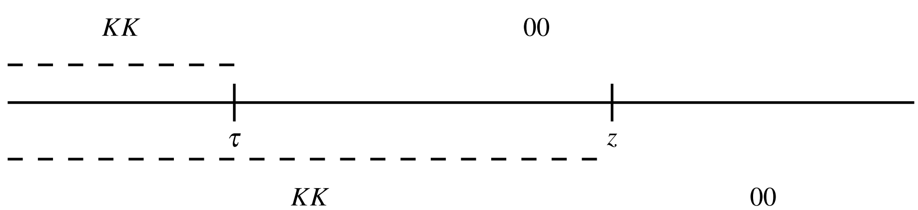
$$z \equiv \frac{t(1+\beta)[2\theta + t(1+\beta)]}{9} \tag{2.10}$$

From *Proposition 3*, simply putting $\alpha = 1$, the following corollary can be derived.

Corollary 2. If firm 1 and firm 2 are symmetric and spillovers are high, in RJV *regime*: (i) if $K < z$, the unique SPE is such the RJV invests, whereas (ii) if $K > z$, there is a unique SPE in which the RJV does not invest.

Ordering on the same line the thresholds that define the regions of parameters for the equilibria in the two *regimes*, it is possible to compare, for each interval, the outcomes under R&D competition and under RJV *regime*. This is the way in which previous models evaluate how the possibility to coordinate R&D efforts changes the outcomes in terms of investment. Figures 2-4 show the comparison of R&D investment decisions under the two *regimes* in case of symmetric and asymmetric firms; given that ρ can be larger of smaller than δ, according to the parameters' values, two different figures are used to describe the case of asymmetric firms.

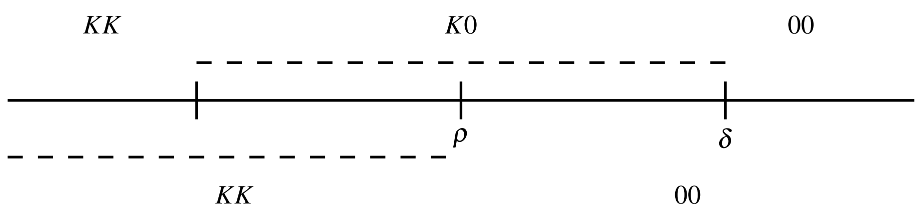
Figure 2.2: **Symmetric firms: comparison of *regimes* (high spillovers)**



Note: equilibria of the continuation game started at the beginning of the second stage. Outcomes above the solid line refer to symmetric firms' investment choices in R&D competition *regime*; below the solid line are represented investment choices in RJV *regime*. The first element refers to firm 1, the second to firm 2.

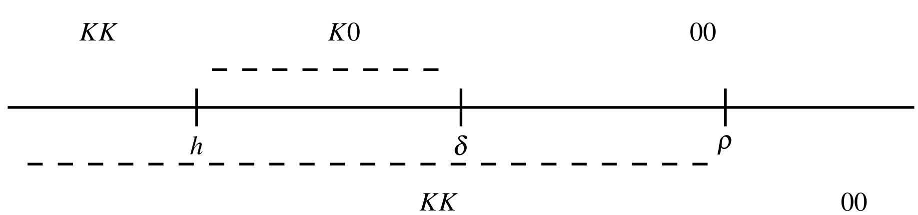
From Figure 2 it can be noted that, when firms are equally efficient in their R&D activity, the region of parameters in which firms invest is larger under RJV *regime* (in the interval $[\tau, z]$ there is no investment in R&D competition), that is, it is more likely to observe higher total investment in RJV *regime*. This is in line with the past theoretical literature, according to which, in presence of high spillovers, RJV enhances investment in R&D through coordination, that allows to internalize the spillovers externality. Figure 3 and Figure 4 highlight consistent results for asymmetric firms: there is more total investment in RJV, given that in the interval $[h, \rho]$ at least one of the two firms does not invest in R&D competition, while in RJV the equilibrium is such that both firms invest.

Figure 2.3: **Asymmetric firms: comparison of *regimes* (high spillovers) -** $\rho < \delta$



Note: equilibria of the continuation game started at the beginning of the second stage. Outcomes above the solid line refer to asymmetric firms' investment choices in R&D competition *regime*; below the solid line are represented investment choices in RJV *regime*. The first element refers to firm 1, the second to firm 2.

Figure 2.4: **Asymmetric firms: comparison of *regimes* (high spillovers) -** $\rho > \delta$



Note: equilibria of the continuation game started at the beginning of the second stage. Outcomes above the solid line refer to asymmetric firms' investment choices in R&D competition *regime*; below the solid line are represented investment choices in RJV *regime*. The first element refers to firm 1, the second to firm 2.

The analysis of the formation process allows to establish whether these beneficial effects can actually emerge, that is if the RJV is going to be formed in the regions of parameters in which it enhances the total investment. This will be done in the following subsection.

2.2.3 Stage 1: RJV formation

At the beginning of the game firms have to decide about the possibility to form a RJV that commit them to coordinate their R&D effort. Let $s = (s_1, s_2)$, with $s_1, s_2 = \{IN, OUT\}$, be a generic combination of actions taken by firm 1 and firm 2 at first stage. Firm i ($i = 1, 2$) plays $s_i = IN$ if it expects an higher profit from cooperation in R&D; it plays $s_i = OUT$ if it prefers to manage its own investment strategy in a context of competition. The RJV is formed if $s_1 = s_2 = IN$.

Since the game is solved backward, in this stage each firm takes its decision about RJV formation comparing the (possibly) different profits it expects to obtain under the two *regimes*. With reference to Figures 2-4, the analysis will be developed only for the intervals in which the outcomes under the two *regimes* are different; in all the other intervals the possibility to coordinate R&D efforts cannot change investment decisions and firms will be indifferent between the two actions.

Proposition 4. When spillovers are high, symmetric firms have incentive to form a RJV in the region of parameters in which this kind of agreement leads to different investment choices with respect to R&D competition. In the interval $[\tau, z]$ the possibility to cooperate in R&D enhance innovation by increasing the total investment. This equilibrium is welfare improving with respect to a situation in which only R&D competition is feasible.

Proof.

In case of symmetric firms, the two *regimes* differs in terms of outcome only in the interval $[\tau, z]$, where both firms invest in RJV and none in R&D competition. It is straightforward that, in this region, firms will form the RJV, since $\Pi_i^{KK} > \Pi_i^{00}$ ($i = 1, 2$) if $K < z$ (see *Proposition 3* and *Corollary 2*). The resulting equilibrium in which both firms invest in RJV increases the total surplus since firms get higher profits and the lower costs induced by R&D activity allow to produced larger quantities and reduce the price, thus increasing also the consumer surplus■.

So, in case of symmetric firms, a region of parameters in which the beneficial effect of RJVs actually materializes always exists. Unfortunately, this is not the case when firms have different R&D productivity. Even if from the simple comparison of *regimes* RJV appeared to boost total investment[9], equilibria of the whole game are such that there is no incentive to cooperate by part of the the less efficient firm when the equilibrium in R&D competition entails asymmetric investment choices. Asymmetric firms can find profitable to set up a RJV to invest only if the cost of investment is such that the equilibrium in R&D competition entails no investment at all, while at the same time profits are higher when both firms invest than when no firm invests. However, this equilibrium with RJV formation between asymmetric firms does not necessarely exist: its existence depends upon parameters' values. *Proposition 5* states these results in a formal way; as before, only the intervals with different outcomes in the two *regimes* are taken into account.

Proposition 5. When spillovers are high and firms are asymmetric (i) for $h < K < \delta$ the RJV is not formed; (ii) if $\rho > \delta$, in the interval $[\delta, \rho]$ the RJV will be formed and leads to more investment and higher total surplus.

Proof.

[9] The threshold below which the RJV invests (ρ) is higher than the threshold below which both firms invest in R&D competition (h).

First of all, remember that the parameter ρ is always larger than h but can be larger or smaller than δ according to the parameters' values.

(i) When $h < K < \delta$, the equilibrium in R&D competition is such that only firm 1 invests; this means that $\Pi_1^{K0} > \Pi_1^{00}$ and $\Pi_2^{K0} > \Pi_2^{KK}$ (see *Proposition 2*). So, whatever the equilibrium in RJV *regime*, one of the two firms will not find profitable the adoption of the same investment strategy by part of both firm and will choose the action OUT.

(ii) If $\rho > \delta$, in the interval $[\delta, \rho]$ there is no investment at all in R&D competition, but equilibrium in RJV *regime* entails investment; this means that $\Pi_i^{KK} > \Pi_i^{00}$ for $i = 1, 2$. Hence both firms have incentive to choose the action *IN* and the equilibrium of the whole game is such that RJV is formed and invests. If this is the case, firms' profits are higher and consumers benefit from the costs reduction (welfare improvement)■.

To sum up, due to the presence of asymmetric equilibria in R&D competition *regime*, for most of the parameters values, a RJV between asymmetric firms is not going to be formed and so has not beneficial effects in terms of enhancing innovation. This is because, in most of the cases, the less efficient firm prefers to exploit the benefits from firm 1's R&D activity (through spillover effect) without paying the cost of investment. As stated above, it might exist a region of parameters in which the possibility to create a RJV between asymmetric firms enhances innovation; this happens only if $\rho > \delta$. It can be shown that the lower is α, the more it is likely that $\rho < \delta$; so, the more firms are different in terms of R&D productivity, the less is likely to observe RJV formation. These results are consistent with the empirical evidence according to which asymmetries between firms negatively influence RJV participation decisions (see for example Petit and Towlinsky (1999) and Röller, Tombak and Siebert (1998)). Also, for a given α, if the spillover parameter tends to its maximum value ($\beta \to 1$), ρ tends to become larger than δ, implying that if the spillover externality is very severe there is a region of parameters in which for the more efficient firm is not profitable to invest when the rival just exploit the spillover effect, but both firms can be better off if, in RJV, they commit themselves to invest.

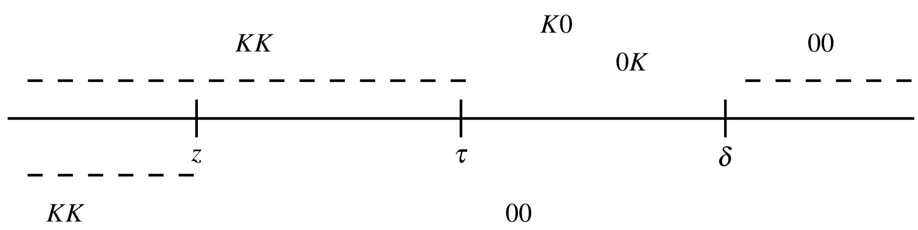
2.3 The case of low spillovers

For the case of low spillovers, I only sketch the equilibria in second and first stage and comment the main findings. The way in which equilibria are derived is the same as for the case of high spillovers; what it is different is just the order of the relevant thresholds and, accordingly, the equilibrium strategies in some regions of parameters.

Figure 5 and Figure 6 show the equilibrium strategies in R&D competition and RJV *regime* for symmetric and asymmetric firms. It can be noted from Figure 5 that, differently from the case of high spillovers, in R&D competition there also equilibria that reflect asymmetric investment choices by part of symmetric firms. In the interval $[\tau, \delta]$[10]there are two possible equilibria in which only one of the two firms invests, and no one can be ruled out according to *Pareto dominance criterion*. The threshold below which symmetric firms invest in RJV *regime* (z) is lower than τ when $\beta < \frac{1}{2}$; hence, consistent with the past literature, the total investment is lower in RJV *regime* when spillovers are low (it is more likely to observe investment when firms choose investment strategies non-cooperatively). Qualitatively similar results emerge for asymmetric firms. Figure 6 shows that the order of thresholds that characterize R&D competition is the same as for high spillovers case, but here the value of K that defines the region in which the RJV invests (ρ) is lower than h; so, there is less investment in RJV *regime* also for symmetric firms. These results could be explained by the fact that if firms keep most of the benefits from R&D investment and act non-cooperatively, they are more willing to invest in R&D to avoid being left behind. If this fear disappears, they reduce R&D activity (which means higher

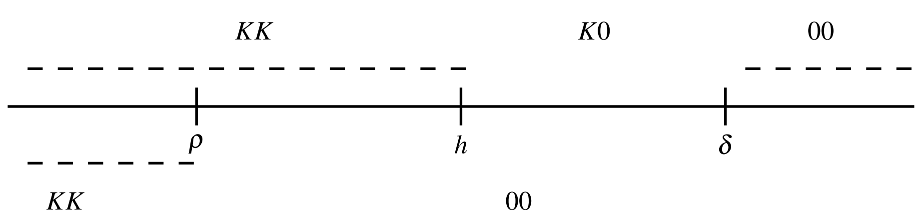
[10]The thresholds τ and δ are defined in (5) and (6) respectively.

Figure 2.5: **Symmetric firms: comparison of *regimes* (low spillovers)**



Note: equilibria of the continuation game started at the beginning of the second stage. Outcomes above the solid line refer to symmetric firms' investment choices in R&D competition *regime*; below the solid line are represented investment choices in RJV *regime*. The first element refers to firm 1, the second to firm 2.

Figure 2.6: **Asymmetric firms: comparison of *regimes* (low spillovers)**



Note: equilibria of the continuation game started at the beginning of the second stage. Outcomes above the solid line refer to asymmetric firms' investment choices in R&D competition *regime*; below the solid line are represented investment choices in RJV *regime*. The first element refers to firm 1, the second to firm 2.

costs and consumer prices).

What is particularly important in this section is to see whether cooperation agreements (leading to less total investment) are actually established. In the following lemmas firms decisions in the first stage are stated for the region of parameters in which the two *regimes* generates different outcomes.

Lemma 1. When firms are symmetric and spillovers are low, a RJV in which firms do not invest is formed for $z < K < \tau$. In the interval $[\tau,\, \delta]$ firms fail to agree on the same investment strategy and end up in R&D competition.

Proof.

The proof is straightforward. In the interval $[z,\, \tau]$ each firm has incentive to stay in RJV, given that the profit it obtains in RJV, where firms jointly decide not to invest, is larger than the profit it get in R&D competition, where both firms invest (Proposition ? show that $\Pi_i^{00} > \Pi_i^{KK}$ for $K > z$, with $i = 1, 2$). For $\tau < K < \delta$ the RJV cannot be formed since in R&D competition two equilibria in which only one firm invests are possible, meaning that each firms prefers an outcome with asymmetric investment choices to one with no investment at all■.

Lemma 2. When spillovers are low, asymmetric firms establish a RJV in which there is no investment in the interval $[\rho,\, h]$. When $h < K < \delta$, the less efficient firm gets an higher profit in R&D competition, so the RJV is not formed.

Proof.

The same arguments discussed in the proof of Lemma 1 for the regions with symmetric and asymmetric outcome in R&D competition hold■.

From *Lemma 1* and *Lemma 2* it follows

Proposition 6. When spillovers are low, it always exist a region of parameters in which firms agree to form a RJV with the aim of avoid investment; this happens irrespective of the fact that firms are symmetric or asymmetric.

According to these findings, when spillovers are low, allowing R&D cooperation agreements can be harmful if the aim is that of enhancing innovation; if the externality is not severe, symmetric and asymmetric firms will have incentive to collude to avoid investment in some regions of parameters.

Conclusions

In the previous sections, I develope a 3-stage duopoly model of R&D investment in the presence of spillovers, to analyze firms' willingness to form cooperative agreements to coordinate R&D efforts, taking into account possible firms' asymmetries in terms of R&D's efficiency. Equilibrium choices at the first stage determines the *regime* under which the two firms will define their R&D investment strategies: R&D competition or RJV. Analyzing the formation process allows to go beyond a simple comparison of investment choices under the two *regimes* and establish whether the outcomes under RJV *regime* can actually emerge.The analysis considered both the case of high and low spillovers.

When the externality arising from non complete appropriability of the results of R&D efforts is large and a firm obtains large benefits from R&D investment of the rival (high spillovers case), RJV enhances investment when firms are symmetric. It always exists a region of parameters in which firms agree to form a RJV and the resulting coordination effect leads to more total investment and higher profits (welfare improvement). When firms are asymmetric, instead, R&D cooperation is not likely to fulfill the aim of stimulating innovation. In RJV *regime* there are larger regions of parameters with equilibria entailing more total investment irrespective of possible asymmetries between the two firms. However, for most of the parameters' values, a RJV with investment is never formed when firms are asymmetric and the alleged beneficial coordination effect does not actually emerge. This is due to the presence of equilibria with asymmetric investment choices in R&D competition *regime*; for values of the cost of investment such that this kind of equilibria arises, the less efficient firm can exploit the spillover effect to become more efficient at no cost, so it has no incentive to commit itself to invest. The larger the difference in terms of R&D productivity, the less is likely to observe RJV formation. These results are consistent with the empirical evidence according to which asymmetries between firms negatively influence RJV participation decisions (see for example Petit and Towlinsky (1999) and Röller, Tombak and Siebert (1998)).

The possibility to create a RJV can even be harmful, if it is meant to increase total investment, when the extent of spillovers is very limited; when spillovers are low, not only the total investment is lower in RJV *regime*, but also it always exist a region of parameters in which firms agree to form a RJV with the aim of avoid investment. This result holds in case of both symmetric and asymmetric firms.

So, RJVs can be a useful tool to overcome the problem of under-investment in R&D in presence of externality only when the extent of this latter is large. Also, the innovation enhancing effect can be guaranteed just in case of symmetric firms; the formation of a RJV aiming to invest is much less likely when firms are not equally efficient, and does not even need to arise. If the externality is not severe, competition remains the better way to stimulate investment and promote innovation.

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[53] Yi S., 1998, Endogenous formation of joint ventures with efficiency gains, RAND Journal of Economics vol.29, n.3, 610-631. Asymmetric information in a duopoly with spillovers: new findings on the effects of RJVs

Chapter 3

Asymmetric information in a duopoly with spillovers: new findings on the effects of RJVs

Introduction

Innovation is one of the main determinants of economic performance in advanced countries. R&D, one of the key driver of successful innovation, is crucial not only in the analysis of an individual industry, but also from an economy-wide point of view. One of the main features of advanced economies is competition in innovation: the now prevalent view is that firms become industry leaders by conducting R&D activity to improve either their production technology (process innovation, aiming to a cost reduction) or the products they provide (product innovation, usually associated with improved quality). Innovation is thought to be beneficial for society, since it should lead to more variety, lower prices, better quality, etc. At the same time, innovative activities are often associated with a non competitive market structure and with externalities, meaning that innovation is strictly related to situations that bring to market failures and to not socially desirable outcomes. These considerations often justify the request of government intervention in the form of subsidies to R&D activity or patents' protection. It is not surprising that this argument, related to several different but interconnected issues, generated a huge amount of theoretical and empirical works. One of the most studied issues concerns the existence of spillovers, that affects the decisions about R&D investments and that can determine an inefficient level of R&D effort. When patent protection is not completely effective and innovation creates spillovers, firms that conduct R&D individually do not internalize the positive externality on their rivals associated with an innovation. They thus tend to underinvest in R&D from an industry and social point of view (Katz, 1986; d'Aspremont and Jaquemin, 1988; Kamien et al., 1992). Jaffe (1986), finds empirical evidence of the presence of spillovers, showing that firms benefit from R&D of their rivals. Ornaghi (2006) highlights a gap between private and social rate of returns of R&D, concluding that insufficient appropriability reduces investments in R&D. In the theoretical literature, starting from the seminal paper by d'Aspremont and Jacquemin (1988), this problem has been described using a 2-stage Cournot model in which R&D expenditure results in cost reduction. Part of the competitive advantage from the resulting costs reduction goes to the rival (spillover problem), that becomes a tougher competitor; the incentive to invest in R&D can be quite small as each firm seeks to free ride on the other's efforts. In d'Aspremont and Jacquemin's model, cooperation in R&D (RJV), requiring firms to choose the R&D effort in order to maximize the joint profit, increases R&D spending when spillovers are high, since it allows to internalize the externality caused by knowledge spillovers. The policy implication is that RJV should be encouraged as long as the antitrust authorities can assure that such cooperation on research effort will not also extend to cooperation in production and prices (price fixing cartel).

Since several extensions of this model confirm the result concerning the desirability of R&D cooperation in presence of spillovers (Kamien et al., 1992; Suzumura, 1992; Amir, 2000; Lambertini and Rossini, 2009), over the last twenty years there has been an increasing interest in the role that R&D collaboration agreements might play in helping overcome the discussed market failure. This potential benefit can be a reason why RJVs are not treated as per se violations by antitrust authorities and are encouraged by policy-makers. EU and Japan have always had positive and permissive attitude towards cooperation in R&D; EU Commission involvement in the coordination and in the financing of RJVs, and more generally of cooperative research programs, has substantially increased over the years. As for US, in 1984, Congress enacted the National Cooperative Research Act, which was extended to the National Cooperative Research and Production Act in 1993 to include joint production ventures. This act protects R&D joint ventures and certain qualifying joint production ventures from the strict application of antitrust law (Sherman Act, 1890). Empirical works confirm the positive effect of R&D cooperation on innovation (Simonen and McCann, 2008) and on firms' performance (Benfratello and Sembenelli, 2002). R&D cooperation literature may lead to believe that R&D cooperation between firms is quite common and that collaboration, once initiated, is unlikely to fail. However, even in high-tech sectors cooperation at R&D level is still more the exception than the rule. The empirical literature has emphasized the role of asymmetries (basically in size) in terms of gains from cooperation and decisions on RJV membership. Petit and Towlinsky (1999) show that the degree of size-related asymmetries between firms influences participation decisions. Kogut (1991) stresses that firms have different "absorptive capacities" of research results, which in turn determine their willingness to form a RJV. The absorptive capacity is determined by factors such as size and past experience. Röller, Tombak and Siebert (1998) show that size symmetry and product complementary between firms enhance the likelihood of RJV formation. Therefore, asymmetries seems to affect cooperative outcomes and participation decisions, but they have been scarcely taken into account in the theoretical literature, with few exceptions. Asymmetries have been mainly associated to initial marginal costs (Baerenss, 1999) or to the spillover parameter, interpreted in terms of absorptive capacity (Atallah, 2005a). As for RJVs formation process, past studies are mostly related to partner selection (Atallah, 2005b) or coalition stability issues (Goyal et al., 2001; Song and Vannetelbosch, 2007).

Here I will start by imposing an asymmetry in the ability to do R&D and then I will introduce incomplete information. In particular, I extend the Cournot-duopoly model with investment and spillovers of d'Aspremont and Jacquemin (1988) to allow for incomplete information in an investment game in which firms have also to decide about RJV membership. Differently from the original model, the investment choice is discrete, that is firms have to decide if invest a fixed amount in R&D or avoid R&D activity; this allows for possible asymmetric outcome. Also, I do not assume joint profit maximization in RJV, since it would imply a system of transfers in presence of asymmetric outcomes (Baerenss, 1999; Salant and Shaffer, 1998). I assume that in RJV firms have to coordinate their R&D effort, that is, RJV creation implies investment by part of both firms. The fact that I use a discrete variable for R&D investment choice implies that results have to be interpreted in terms of regions of parameters values for the variable under consideration; if, under a certain *regime*, there is a larger region in which an equilibrium with investment does exist, it can be said that in that *regime* the probability to observe investment is higher, so there is more investment. It will be shown that, in the particular case in which information is complete and firms are symmetric, results are in line with the literature, that is there is more investment in RJV *regime* when spillovers are high.

Incomplete information in R&D literature is mainly related to contract arrangements (d'Aspremont, Bhattacharya and Gerard-Varet,1998; Pastor and Sandonis, 2000; Brocas, 2004), knowledge disclosure (d'Aspremont, Bhattacharya and Gerard-Varet, 2000), relative position in patent race (Grishagin, Sergeyev and Silipo, 2001; Kao, 2002) and new technology adoption (Zhu and Weyant, 2003). Cassiman (2000) assumes asymmetric information between firms and regulator about spillovers, while Cabon-Dhersin and Ramani (2004) considers two types of firms (private information) to study the role of trust in R&D cooperation. Here incomplete information is about the efficiency of R&D investment, that is the effective cost reduction obtained from a fixed R&D investment; this assumption implies that firms can become asymmetric after the investment stage (they starts with identical marginal costs). It turns out that a less efficient firm is more likely to free-ride, avoiding investment and exploiting spillovers from the rival firm. I assume that only one of the two firms has private information; this assumption can be justified by the fact that R&D productivity may be not directly observable, especially if a firm is "new" in the market (plausible in high-tech sectors). The hypothesis of asymmetric information generates additional adverse effects in R&D competition. For example, in case of symmetric firms, the under-investment in R&D competition *regime* is worsened by the presence of asymmetric information; also, in some regions of parameters, the firm with incomplete information chooses an investment strategy that makes it worse off with respect to the case in which it has complete information (in some sense incomplete information leads to inefficient investment choices for the firm that has not private information).

To analyze the incentive to form a RJV, I add a further step to the standard game, in which firms' decisions about RJV membership determine the *regime* under which the will operate. At the beginning of the game one firm can propose an agreement (RJV) involving commitment on R&D investment; the other firm will accept if it thinks that the agreement will lead to higher profits than those attainable in R&D competition. Most of the previous models just compare the outcomes under the two different *regimes* to derive policy implications, without considering whether firms have incentive to cooperate when cooperation results to be welfare improving. This is particularly important in presence of asymmetric firms; with symmetric firms and joint profit maximization in RJV, firms have always incentive to cooperate, given that outcomes are symmetric (Lambertini and Rossini, 2009).

It is common in the literature to distinguish the case of high and low spillovers, since different values of the spillover parameter can lead to different results. In this paper I focus only the case of high spillovers, which is the most interesting case since under-investment and need for policy intervention arise when the spillover problem is severe[1].

Results contribute to support previous findings about the desirability of a positive attitude towards R&D cooperation agreements by policy-makers: RJVs can increase the level of investment of efficient firms not only through the internalization of the externality caused by spillovers, but also through their signaling effect. This model contributes also to explain empirical findings about the determinants of RJV formation.

The structure of the paper is as follows. Section 2 describes the model; in Sections 3 equilibria in R&D competition *regime* are described, while Section 4 defines firms' strategies regarding RJV formation and summarizes the results; Section 5 concludes.

[1] However, I did all the computation also for the case of low spillovers; in the particular case in which information is complete and firms are symmetric, results are consistent with the past theoretical literature. With asymmetric information, firms have no incentive to form the RJV and the possibility to coopearate in R&D simply does not change anything with respect to the case in which only R&D competition is feasible. So, given the positive effect of RJV when spillovers are high, it can be said that allowing RJVs cannot be harmful, even if the regulator does not know the extent of the spillovers.

3.1 The model

3.1.1 The set up

Two firms (firm 1 and firm 2) compete on quantities and face the inverse demand function for an homogeneous good: $P = a - Q = a - q_1 - q_2$

Each firm can decide to invest a fixed amount K in R&D in order to reduce the initial unit (marginal) cost c (assumed identical for the two firms) by $t_i (i = 1, 2)$. R&D investment can make firms asymmetric, even if they both invest; in fact, firm 1 and firm 2 could not be equally efficient in R&D activity. The investment of a firm also benefits the rival due to the presence of spillovers (non-perfect appropriability of the results of R&D activity); this creates a positive externality problem leading to R&D under-investment[2]. Firms have the possibility to form a Research Joint Venture (RJV) to coordinate their investment strategies: in RJV they commit to invest. I characterize the RJV in this way because this kind of agreement is considered a tool to internalize the externality arising from the existence of spillovers and to eliminate the "free riding" problem. In the literature on this issue, RJV is seen as a situation in which symmetric firms make R&D investment choices in order to maximize the joint profit (the variable describing R&D effort/expenditure is continuous) and take symmetric solutions. In this model, in which R&D choice is discrete, I assume this kind of coordination to replace the "joint profit maximization hypothesis"[3]. Also, in this model, this latter hypothesis could require asymmetric R&D efforts by the 2 firms and/or generate outcomes (in particular when firms are asymmetric) that could be not optimal for a firm that is willing to maximize its own profit. This, in turn, would require a system of transfers to compensate the firm that finds itself worse off (see Baerenss, 1999 and Salant and Shaffer, 1998). So, in my model, agreement on RJV formation implies investment by both firms. Coordination in production is not allowed. The spillover parameter is assumed to be exogenous: it is not a matter of choice for firms (as in Poyago-Thoetoky, 1999 and Amir et al., 2003) and its value does not change when firms are in RJV[4]. I follow d'Aspremont and Jacquemin (1988) in keeping the spillover exogenous. With this assumption I don't mean that information disclosure in RJV is not a relevant issue; simply, it could be realistic to think that a firm (that maximizes its own profit in RJV) is not willing to share its knowledge with the other firm (a rival in the production stage). Poyago-Theotoky (1999) show that, when firms can decide about the value of the spillover parameter as measure of information disclosure and maximize their own profit, they will set the minimum level[5]. While R&D expenditure is observable, information disclosure is not a contractible variable, so it makes sense to assume that the extent of knowledge leakage is the same under both *regimes*.

I only analyze the case of high spillovers; this describes a situation in which a firm obtains large benefits from R&D investment of the rival. This is the more interesting case, since this literature is focused on R&D cooperation as a way to handle the externality arising from non complete appropriability of R&D output, and this problem is more serious the more the spillover is high.

The model is characterized by asymmetric information: firm 1 has incomplete information about the level of R&D productivity of firm 2, that is it does not know the extent of cost reduction that the rival can obtain from R&D investment, while firm 2 knows that when firm 1 invests K, its cost reduction is equal to t. We can think of firm 1 as

[2] See d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Suzumura (1992), Brocas (2004).

[3] This leads to equivalent results with respect to the previous models in case of symmetric firms and complete information.

[4] In the works of Beath et al., 1998, Atallah, 2005, Kamien et al.,1992, Baerenss, 1999 and Lambertini and Rossini, 2009, under RJV *regime*, the spillover parameter takes value one since it is assumed information sharing in addition to coordination of R&D effort.

[5] The spillover parameter, when endogenously determined by firms, takes maximal value if firms maximize the joint profit, under the assumption of symmetric R&D effort. Amir et al. (2001) find similar results.

the "incumbent" firm, established in the market, whose productivity level is known; firm 2 could be a "new" firm, just entered the market, so its productivity is still to be proved.

Let $\alpha > 0$ denote the productivity of firm 2's R&D investment[6]; then, firm 2 can be of two types, α_L or α_H, with equal prior probability. If firm 2 is of type α_L (low R&D productivity), the cost reduction generated by investing K is $t_2 = t\alpha_L$, with $\alpha_L < 1$, that is, it is less efficient than firm 1 once they have invested in R&D. If firm 2 is of type α_H, (high R&D productivity) the cost reduction is $t_2 = t\alpha_H$ with $\alpha_H = 1$; in this case firm 1 and firm 2 turn out to be symmetric ($t_2 = t$).

The generic formulation for firm i's profits, with $i = 1, 2$, can be written as: $\Pi_i = (P - c_i)q_i - K_i$, where

- $K_i \in \{0, K\}$, $K > 0$
- $c_1 = c - t_1 - \beta t_2(\alpha)$ and $c_2 = c - t_2(\alpha) - \beta t_1$ with $\alpha \in \{\alpha_L, \alpha_H\}$
- $t_i = 0$ if $K_i = 0$
- $t_1 = t$ if $K_1 = K$, $t_2(\alpha) = \{\alpha_L t, t\}$ if $K_2 = K$
- β is the spillover parameter.

The maximum cost reduction is obtained when the two firms are symmetric, both invest, and the spillover is maximum; so the minimum level of the marginal cost is $(c - 2t)$.

3.1.2 Timing and assumptions

The following assumpions are stated:
(i) $0 < t \leq \frac{c}{2}$ (non-negative costs)
(ii) $t \leq (a - c) \equiv \theta$ (non-negative quantities)
(iii) $\alpha_H = 1$ and $\alpha_L \in [0.2, 0.6]$
(iv) $Prob(\alpha = \alpha_H) = Prob(\alpha = \alpha_L) = \frac{1}{2}$ (*prior probabilities*)
(v) $\frac{1}{2} \leq \beta \leq 1$[7]

The model is a three-stage game:

1st stage: RJV formation. Firm 1 (the "incumbent") can propose to firm 2 to form a RJV; the agreement implies that both firms commit themselves to invest K in the following stage (once RJV is formed, investment is observable and no firm can deviate from the decision to invest). Obviously, it will make the proposal only if it expects that in this way an higher profit is attainable; otherwise it will do nothing and firms go directly to R&D competition *regime*. Possible actions of firm 1 are defined by "*RJV*" (that means that it is willing to form RJV) and "*nothing*". If firm 1 makes the proposal, firm 2 can accept (ending in RJV *regime* in the following stage) or not (R&D competition in 2nd stage); its actions are called "*accept*" and "*not accept*".

2nd stage: Investment. In this stage two different *regimes* are taken into account. If the RJV has not been formed in the first stage, firms decide non-cooperatively and simultaneously whether invest or not in R&D (actions are $K_i = 0$

[6]The parameter α is a measure of cost reduction and is private information.
[7]In general the spillover parameter belongs to the interval $[0, 1]$ and the threshold $\beta = \frac{1}{2}$ separate low spillovers from high spillovers.

or $K_i = K$, $i = 1,2$). If firms are in RJV, this means that they agreed on investing ($K_1 = K_2 = K$); accordingly, there is no strategic interaction in this part of the game.

3rd stage: Cournot competition. Firms act non-cooperatively (coordination in production is not allowed) and set the quantities to be produced in order to maximize their (expected) profit given the strategy of the rival.

At the beginning of each stage, firms observe the outcome of the previous stage (multi-stage game with observed actions). The game is solved backward.

To arrive to the solution of the game I proceed in this way. First, I determine in separate subsections R&D competition equilibria in case of complete and incomplete information. This allows to identify the consequences of incomplete information assumption in a context in which cooperation in R&D is not possible; also, to solve the game, we need to know equilibria arising in case of complete information since the payoffs obtained by the firms under this assumption are the relevant ones following separating strategies (beliefs updating). Then, I determine firms' equilibrium strategies regarding RJV membership comparing the payoffs attainable in RJV *regime* with those (expected to be) earned in R&D competition, and summarize the results of the whole game.

3.2 Equilibria under R&D competition *regime*

3.2.1 The case of complete information

In the game with incomplete information firm 2 can be of two different types: it could be as efficient in R&D productivity as firm 1 or it can be less efficient. So, looking for equilibria under complete information, I consider separately the case in which firms are symmetric and the case in which they are asymmetric. Since the game is solved backward, we first compute equilibrium strategies in last stage (Cournot competition), where the strategic variable is the quantity to be prodeced in order to maximize profits. These quantities allow to define a generic formulation of firms' profits (payoffs), used to find the optimal actions in the previous stage. In the second stage, firm i's strategy ($i = 1$, 2) in R&D competition is denoted by $\bar{s}_i = \{0, K\}$; $\bar{s} = (\bar{s}_1, \bar{s}_2)$ is the strategy profile of the players.

In the last stage, equilibrium quantities are those of Cournot competition, with the difference that here $c_1 = c - t_1 - \beta t_2$ and $c_2 = c - t_2 - \beta t_1$. So, best responses are

$$q_1(\alpha_H) = \frac{a - 2c_1 + c_2}{3} = \frac{\theta + t_1(2-\beta) + t_2(2\beta - 1)}{3} \tag{3.1}$$

$$q_2 = \frac{a - 2c_2 + c_1}{3} = \frac{\theta + t_2(2-\beta) + t_1(2\beta - 1)}{3} \tag{3.2}$$

and the resulting profits are, for i, $j = 1$, 2 and $i \neq j$,

$$\Pi_i = \frac{1}{9}\left[\theta + t_i(2-\beta) + t_j(2\beta - 1)\right]^2 - K_i \tag{3.3}$$

Remember that $K_i = K$ or $K_i = 0$ according to the investment choice made in the previous stage, and this in turn determines the value of the (possible) cost reduction. So, the expression that define the profits can assume different shape according to both firms' investment strategies. Given the equilibrium strategies in the last stage, outcomes of the strategic interaction in the investment stage are stated in Proposition 1.

Proposition 1. Under complete information, if firm 1 and firm 2 are symmetric, in R&D competition: (i) if $K < (t/9)(2-\beta)[2\theta + 3\beta t \equiv \tau$, both firms invest in R&D, whereas (ii) if $K > \tau$, there is a unique SPE in which none invests.

Proof.

Firms' choices are symmetric. If firm j plays K, firm i will play K iff $(\Pi_i|\bar{s}_i = K, \bar{s}_j = K) = \frac{[\theta+t(1+\beta)]^2}{9} - K > \frac{[\theta+t(2\beta-1)]^2}{9} = (\Pi_i|\bar{s}_i = 0, \bar{s}_j = K)$, with $i, j = 1, 2$ and $i \neq j$, that is iff

$$K < \frac{t(2-\beta)[2\theta + 3\beta t]}{9} \equiv \tau \tag{3.4}$$

If firm j plays 0, firm i will play 0 iff $(\Pi_i|\bar{s}_i = 0, \bar{s}_j = 0) = \frac{\theta^2}{9} > \frac{[\theta+t(2-\beta)]^2}{9} - K = (\Pi_i|\bar{s}_i = K, \bar{s}_j = 0)$, that is iff

$$K > \frac{t(2-\beta)[2\theta + t(2-\beta)]}{9} \equiv \delta \tag{3.5}$$

Given that $\delta < \tau$, if $K < \delta$, the unique SPE is such that both firms invest, and, if $K > \tau$, we have a unique SPE in which none invests. In $\delta < K < \tau$, both symmetric equilibria are possible. Since, in this region, $(\Pi_i|\bar{s}_i = K, \bar{s}_j = K) > (\Pi_i|\bar{s}_i = 0, \bar{s}_j = 0)$, *Pareto Dominance* concept is used to select the equilibrium with investment■.

Note that in this case there are only symmetric equilibria: either both firms invest or none invest, depending on the value of K. Moreover, there is a region of parameters' values in which both firms would be better off investing (and this would be also welfare improving), but this outcome does not arise because of the incentive to free-ride. Infact, provided that

$$K < z \equiv \frac{t(1+\beta)[2\theta + t(1+\beta)]}{9} \tag{3.6}$$

$(\Pi_i|\bar{s}_i = K, \bar{s}_j = K) > (\Pi_i|\bar{s}_i = 0, \bar{s}_j = 0)$; given that $z > \tau$, if firms could coordinate their R&D efforts, they will reach a better outcome in the interval $[\tau, z]$ for the parameter K, and this is what will happen if they could form a RJV. As stated before, this is in line with the standard results in the literature where investment choice is continuous and symmetric firms maximize the joint profit in RJV.

When firm 2 is less efficient in R&D activity than firm 1, the costs structures are such that $c_1 = c - t_1 - \beta(\alpha_L t_2)$ and $c_2 = c - \alpha_L t_2 - \beta t_1$, so at the last stage firms will produce

$$q_1(\alpha_L) = \frac{\theta + t_1(2-\beta) + \alpha_L t_2(2\beta - 1)}{3} \tag{3.7}$$

$$q_2(\alpha_L) = \frac{\theta + \alpha_L t_2(2-\beta) + t_1(2\beta - 1)}{3} \tag{3.8}$$

and their profits, given the values of t_i and K_i $(i = 1, 2)$, are

$$\Pi_1 = \frac{1}{9}[\theta + t_1(2-\beta) + \alpha_L t_2(2\beta - 1)]^2 - K_1 \tag{3.9}$$

$$\Pi_2 = \frac{1}{9}[\theta + \alpha_L t_2(2-\beta) + t_1(2\beta - 1)]^2 - K_2 \tag{3.10}$$

Equilibrium investment strategies are described in the following Proposition.

Proposition 2. When information is complete and firm 1 and firm 2 are asymmetric (firm 2 has lower R&D productivity), in R&D competition the unique SPE are: (i) if $K < (\alpha_L t/9)(2-\beta)[2\theta + 2t(2\beta - 1) + \alpha_L t(2-\beta)] \equiv h$, both firms invest in R&D, (ii) if $h < K < \delta$, only firm 1 invests; (iii) if $K > \delta$ none invests.

Proof.

If $\bar{s}_1 = K$, $\bar{s}_2 = K$ iff $(\Pi_2|\bar{s}_2 = K, \bar{s}_1 = K) = \frac{[\theta+\alpha_L t(2-\beta)+t(2\beta-1)]^2}{9} - K > \frac{[\theta+t(2\beta-1)]^2}{9} = (\Pi_2|\bar{s}_1 = 0, \bar{s}_2 = K)$, that is iff

$$K < \frac{\alpha_L t(2-\beta)[2\theta + \alpha_L t(2-\beta) + 2t(2\beta-1)]}{9} \equiv h \tag{3.11}$$

Given $\bar{s}_2 = K$, $\bar{s}_1 = K$ iff $(\Pi_1|\bar{s}_1 = K, \bar{s}_2 = K) = \frac{[\theta+t(2-\beta)+\alpha_L t(2\beta-1)]^2}{9} - K > \frac{[\theta+\alpha_L t(2\beta-1)]^2}{9} = (\Pi_1|\bar{s}_1 = 0, \bar{s}_2 = K)$, that is iff

$$K < \frac{t(2-\beta)[2\theta + 2\alpha_L t(2\beta-1) + t(2-\beta)]}{9} \equiv g$$

Since $h < g$, $\bar{s} = (K, K)$ is SPE when $K < h$.

If $\bar{s}_1 = 0$, $\bar{s}_2 = 0$ iff $(\Pi_2|\bar{s}_2 = 0, \bar{s}_1 = 0) = \frac{\theta^2}{9} > \frac{[\theta+\alpha_L t(2-\beta)]^2}{9} - K = (\Pi_2|\bar{s}_2 = K, \bar{s}_1 = 0)$, that is iff

$$K > \frac{\alpha_L t(2-\beta)[2\theta + \alpha_L t(2-\beta)]}{9} \equiv f$$

Given $\bar{s}_2 = 0$, $\bar{s}_1 = 0$ iff $(\Pi_1|\bar{s}_1 = 0, \bar{s}_2 = 0) = \frac{\theta^2}{9} > \frac{[\theta+t(2-\beta)]^2}{9} - K = (\Pi_1|\bar{s}_1 = K, \bar{s}_2 = 0)$, that is iff $K > \delta$, (δ is defined in (5)). Since $\delta > f$, $\bar{s} = (0, 0)$ is SPE when $K > \delta$. This proves part (i) and (iii).

If $K > g$, $\bar{s}_1 = 0$ given $\bar{s}_2 = K$; if $\bar{s}_1 = 0$, $\bar{s}_2 = K$ iff $K < f$. Since $g > f$, $\bar{s} = (0, K)$ can never be a SPE.

If $\bar{s}_1 = K$ and $K > h$, firm 2 will play $\bar{s}_2 = 0$; when $\bar{s}_2 = 0$, $\bar{s}_1 = K$ iff $K < \delta$. Given that $h < \delta$, $\bar{s} = (K, 0)$ is SPE when $h < K < \delta$ (part (ii)).

Also, given the order of thresholds, equilibria in each interval are unique■.

Before leaving the complete information setting, it is important to highlight two facts. First, differently form the case of symmetric firms, here there is an interval for the values of K in which we observe asymmetric investment choices: only the efficient firm invests and the less efficient one prefers to save on investments costs and exploit the benefit of cost reduction through the spillover effect. Second, when both firms invest, the optimal quantity produced by firm 1 when it is facing the less efficient firm is lower than firm 1's optimal quantity when its rival is equally efficient (firm 1 is less aggressive when the R&D productivity of the rival is lower and the latter has higher marginal cost). These two facts drive the main results under incomplete information.

3.2.2 The case of incomplete information

3.2.2.1 Quantity stage

We first look for the quantities that maximize each firm's profits given the choice of the rival, when in the last stage firm 1 cannot distinguish the types of firm 2 (BNE)[8]. Firm 2 has complete information (firm 1 can be of only one type); it maximizes its profit with respect to q_2, given q_1. Its best reply is given by

$$BR_2(q_1) = q_2 = \frac{a - b_1 - c_2}{2}$$

Firm 1 has incomplete information and maximizes its *expected profit* with respect to q_1, given the expected value of q_2. Its best reply is

$$BR_1(q_2^e) = q_1 = \frac{a - bq_2^e - c_1^e}{2}$$

Note that, since firm 2's cost reduction (that is private information) affects also firm 1's costs through the spillover, incomplete information makes firm 1's costs random. The NE is given by the intersection of firm 1's reaction function and firm 2's expected reaction function

$$\begin{cases} q_1^* = \frac{a - bq_2^e - c_1^e}{2} \\ q_2^e = \frac{a - bq_1^* - c_2^e}{2} \end{cases}$$

Let μ indicate the belief held by firm 1, namely $\mu = Prob(\alpha = \alpha_H)$. Then,
$c_1^e = c - t_1 - \beta t_2 \alpha(\mu)$
$c_2^e = c - t_2 \alpha(\mu) - \beta t_1$
with $\alpha(\mu) = \mu + (1 - \mu)\alpha_L$.
Accordingly, the equilibrium quantities (best responses) are

$$q_1^{\mu} = \frac{\theta + t_1(2 - \beta) + t_2\alpha(\mu)(2\beta - 1)}{3} \tag{3.12}$$

$$q_2^{\alpha L} = \frac{2\theta + (2t_1 - t_2\alpha(\mu))(2\beta - 1) + 3t_2\alpha_L}{6} \tag{3.13}$$

$$q_2^{\alpha H} = \frac{2\theta + (2t_1 - t_2\alpha(\mu))(2\beta - 1) + 3t_2}{6} \tag{3.14}$$

where $\theta = (a - c)$
The final payoffs under incomplete information are then

$$\begin{aligned} \Pi_1(\alpha_2) \quad = \quad & \frac{1}{18}[2\theta + 2t_1(2 - \beta) + t_2(2\beta - 1)(3\alpha_2 - \alpha(\mu))] \cdot \\ & [\theta + t_1(2 - \beta) + t_2\alpha(\mu)(2\beta - 1)] - K_1 \end{aligned} \tag{3.15}$$

$$\Pi_2(\alpha_2) = \frac{1}{36}[2\theta + 2t_1(2\beta - 1) + t_2(3\alpha_2 - \alpha(\mu)(2\beta - 1))]^2 - K_2 \tag{3.16}$$

with $\alpha_2 = \alpha_L$, 1. Therefore, when firm 1 is not able to distinguish between the two types of firm 2, its expected profit is

[8]If in previous stages the two types of firm 2 chose different actions (separating strategy) we have to consider the equilibrium quantities of the complete information case. A separating equilibrium requires beliefs updating by part of firm 1, that is, it will be able to recognize the type of firm 2 after observing its action.

$$E(\Pi_1) = \frac{1}{9}[\theta + t_1(2-\beta) + t_2\alpha(\mu)(2\beta-1)]^2 - K_1 \tag{3.17}$$

Comparing equilibrium quantities in case of complete and incomplete information, it can be noted that, when there is investment by part of both firms, type α_H is better off under incomplete information, since $q_1^{(\mu)} < q_1(\alpha_H)$; the opposite holds for type α_L.

3.2.2.2 Investment in R&D stage

Consider now firms' strategies when, at the second stage, they have to decide if invest or not in R&D. Let $s_1 = K_1 = \{0, K\}$ be the action chosen by firm 1 and $s_2 = (K_{2\alpha L}, K_{2\alpha H})$, be the strategy of firm 2, where the first element identifies the action chosen by type α_L and the second one the action selected by type α_H; again, each type chooses between 0 and K. Then, define $s = (s_1, s_2)$ as the combination of actions taken by players at the second stage. Firm 2 knows its type, so it takes the action that leads to the higher profit, given the strategy of firm 1. Firm 1 cannot distinguish between the two types, so it makes its decision to maximize its expected profit given the strategy of firm 2, i.e. given the four possible combination of actions taken by the two types ($s_2 = \{(0,0), (0,K), (K,0), (K,K)\}$). The probabilities it assigns to each type are derived by the prior probabilities according to Bayes' rule, when applicable; when firm 1 has incomplete information at stage 2 (no beliefs updating[9]) the probabilities assigned to each type are the same as prior beliefs, that is $Prob(\alpha = \alpha_H) = \mu = \frac{1}{2}$.

There are 8 possible combination of actions (s_1, s_2): I analyze each one separately to check if it can be an equilibrium in the continuation of the game and for which values of the parameter K.

Before analysing the possible configurations of equilibria, it is useful to fix the regions of parameters in which the different types of firm 2 have a *dominated* strategy; this allows in some cases for a correct updating of beliefs in the following stage and for the elimination of some strategies of firm 2. An action is dominated for player 2 at stage j if it does not lead to higher profit for all possible beliefs held by firm 1 and any continuation satisfying sequential rationality.

Consider type α_L. Under some conditions, type α_L will never invest.

Lemma 1. $K_{2\alpha L} = K$ is dominated (strictly) if

$$K > \frac{t\alpha_L(2-\beta)[2\theta + 2t(2\beta-1) + t\alpha_L(2-\beta)]}{9} \equiv a \tag{3.18}$$

Proof.

(In Appendix)

Consider now type α_H. Under some conditions, type α_H will always invest.

Lemma 2. $K_{2\alpha H} = 0$ is dominated (strictly) if

$$K < \frac{t(2-\beta)[2\theta + t(2-\beta)]}{9} \equiv \delta$$

Proof.

If firm 1 plays $K_1 = 0$, firm 2, when its type is α_H, prefers $K_{2\alpha H} = K$ if

[9]Firm 1 would have posterior probabilities different from prior probability if, in the first stage, it proposes RJV and the two types give different answers.

$$(\Pi_{2\alpha H}|K_1 = 0, K_{2\alpha H} = 0, \mu) > (\Pi_{2\alpha H}|K_1 = 0, K_{2\alpha H} = K, \mu)$$

that is, if

$$\frac{\theta^2}{9} < \frac{[2\theta + t(3-\alpha(\mu)(2\beta-1))]^2}{36} - K$$

namely

$$K < \frac{t(3-\alpha(\mu)(2\beta-1))[4\theta + t(3-\alpha(\mu)(2\beta-1))]}{36}$$

This threshold is decreasing in μ and takes its minimal value for $\mu = 1$; so, substituting $\mu = 1$ in the above inequality it turns out that if $K < \delta$, where δ is defined in (5), type α_H chooses $K_{2\alpha H} = K$ when $K_1 = 0$ for any μ. In the same way, when $K_1 = K$ and $K < \tau$, with τ defined in (4), type α_H chooses $K_{2\alpha H} = K$ when $K_1 = K$ for any μ. For $K < min\{\delta, \tau\}$ type α_H never chooses $K_{2\alpha H} = 0$. Since, for $\beta > \frac{1}{2}$, $\delta < \tau$, $K_{2\alpha H} = 0$ is a dominated strategy for type α_H when $K < \delta$■.

These results allow to eliminate the combinations $s = (0, (K, 0))$ and $s = (K, (K, 0))$ as part of possible equilibria. Indeed we can prove

Lemma 3. If a separating equilibrium exists, it has to be such that type α_L does not invest and type α_H invests, that is $s_2 = (0, K)$.

Proof.

From the results stated in *Lemma 1* and *Lemma 2*, and given that $\delta > a$[10], we can never have a situation in which $K_{2\alpha H} = 0$ *and* $K_{2\alpha L} = K$■.

It follows that possible separating equilibria are only $s = (K, (0, K))$ and $s = (0, (0, K))$. It has to be checked if, and for which values of K, they are actually sustainable as part of an equilibrium strategy.

When the two types of firm 2 choose different actions, at the last stage firm 1 has complete information once it has observed the investment choice of the rival (perfect updating). When firm 1 observes $K_2 = 0$, it knows that it is competing with type α_L, whereas when it observes $K_2 = K$, it knows that it is competing with type α_H[11]: then, the final payoff are those computed for the complete information case. However, when firm 1 has to make the investment choice (second stage), it doesn't know the type of the rival and uses the prior beliefs to compute its expected profits given $s_2 = (0, K)$.

Let $\hat{s_2}$ be the separating strategy of firm 2 at stage 2, namely $\hat{s_2} = (0, K)$. Given this strategy

$E(\Pi_1|K_1 = 0, \hat{s_2}) = \frac{1}{2}\left\{\frac{\theta^2}{9}\right\} + \frac{1}{2}\left\{\frac{[\theta+t(2\beta-1)]^2}{9}\right\} = \frac{\left\{\theta^2+[\theta+t(2\beta-1)]^2\right\}}{18}$

$E(\Pi_1|K_1 = K, \hat{s_2}) = \frac{1}{2}\left\{\frac{[\theta+t(2-\beta)]^2}{9} - K\right\} + \frac{1}{2}\left\{\frac{[\theta+t(1+\beta)]^2}{9} - K\right\}$

Hence, firm 1 plays $K_1 = K$ if

$$E(\Pi_1|K_1 = K, \hat{s_2}) > E(\Pi_1|K_1 = 0, \hat{s_2})$$

that is, if

[10] By assumptions, $\alpha_L \in [0.2, 0.6]$ and $t \leq \theta$.

[11] Posterior beliefs in the third stage will be $(\mu||K_2 = 0) = 0$ and $(\mu|K_2 = K) = 1$. Accordingly, $BR_1(after\, K = 0) = q_1^C(q_2^{\alpha L}) = \frac{a-2c_1+c_2^{\alpha L}}{3} = \frac{\theta+t_1(2-\beta)}{3}$ and $BR_1(after\, K = K) = q_1^C(q_2^{\alpha H}) = \frac{a-2c_1+c_2^{\alpha H}}{3} = \frac{\theta+t_1(2-\beta)+t(2\beta-1)}{3}$, $t_1 = \{0, t\}$.

$$K < \frac{t(2-\beta)[2\theta + t(1+\beta)]}{9} \equiv \gamma \tag{3.19}$$

while it plays $K_1 = 0$ if $K > \gamma$. If $K = \gamma$, it is indifferent. For $s = (K, (0, K))$ and $s = (0, (0, K))$ to be part of an equilibrium, it has to be checked that each type of firm 2 has no incentive to deviate (choosing the action played by the other type, or any other mixed strategy), given updated beliefs of firm 1.

Lemma 4. The combination of actions $s = (K, (0, K))$ is part of a *separating PBE* in the continuation game started at the second period, if $\nu < K < \gamma$, with $\nu \equiv (t/36)(3\alpha_L + 1 - 2\beta)[4\theta + 3t(3\alpha_L + 2\beta - 1)]$.

Proof.

(In Appendix)

Lemma 5. When spillovers are high, an equilibrium in which $s_1 = 0$ and $s_2 = (0, K)$ cannot exist.

Proof.

(In Appendix)

From *Lemma 4* and *Lemma 5*, it follows

Proposition 3. If RJV is not allowed, or, equivalently, firms end up in R&D competition without beliefs updating, the only possible *separating equilibrium* entails $s = (K, (0, K))$ at the second stage. If $K \notin [\nu, \gamma]$, a *separating equilibrium* cannot obtain.

The following step is the analysis of *pooling PBE*, in which the two types of firm 2 choose the same action, hence $s_2 = (0, 0)$ or $s_2 = (K, K)$. We can have two types of pooling, namely $s = (0, (0, 0))$ and $s = (K, (K, K))$, as it will be shortly shown below.

In this case, firm 1 cannot distinguish between the two types when, at the beginning of the third stage, it observes the investment choice of the rival; this means that it cannot update its beliefs and the posterior beliefs are the same as prior beliefs along the equilibrium path (final payoff are those of incomplete information).

Consider first $s_2 = (0, 0)$[12]. The expected profits that firm 1 compares are $E(\Pi_1|(0, (0, 0))) = \frac{1}{9}\theta^2$ and $E(\Pi_1|(K, (0, 0))) = \frac{1}{9}[\theta + t(2-\beta)]^2 - K$. It follows that, for $K > \frac{t(2-\beta)[2\theta + t(2-\beta)]}{9} = \delta$[13], $K_1 = 0$ when $s_2 = (0, 0)$.

Lemma 6. The only possible *pooling equilibrium* in which both types of firm 2 do not invest is such that $s = (0, (0, 0))$.

Proof.

Given $s_2 = (0, 0)$, $K_1 = K$ if $K < \delta$. As stated in *Lemma 2*, for $K < \delta$, $K_{2\alpha H} = K$ is a dominant strategy for type α_H; accordingly, it never plays $K_{2\alpha H} = 0$ in this region and the pooling equilibrium with $s = (K, (0, 0))$ can be ruled out ■.

Proposition 4. A *pooling equilibrium* where no firm invests can exist only if $K > \delta$.

Proof.

Given $s_2 = (0, 0)$, $K_1 = 0$ only if $K > \delta$. In this interval, type α_L has no incentive to deviate from $K_{2\alpha L} = 0$ since $\delta > a$ and for $K > a$ will never play $K_{2\alpha L} = K$ (see *Lemma 1*). Therefore, firm 1's beliefs after observing $K_2 = K$, are such that $(\mu|K_2 = K) = 1$. Type α_H does not deviate if $\Pi_{2\alpha H}(K_1 = K_2 = 0, \mu = \frac{1}{2}) \geq \Pi_{2\alpha H}(K_1 = 0, K_2 = K, \mu = 1)$, that is if

[12] In this case, $(\mu|K_2 = 0) = ((1-\mu)|K_2 = 0) = \frac{1}{2}$ and $BR_1(after\, K_2 = 0) = BR_1(q_2^e) = \frac{a - 2c_1^e + c_2^e}{3} = \frac{\theta + t_1(2-\beta)}{3}$ with $t_1 \in \{0, K\}$.

[13] δ is defined in (5).

$$\frac{1}{9}\theta^2 \geq \frac{1}{9}[\theta + t(2-\beta)]^2 - K$$

Since this inequality is satisfied for $K > \delta$, we can conclude that a pooling equilibrium with $s = (0, (0, 0))$ may exist for $K > \delta$■.

Consider now $s_2 = (K, K)$[14]. Firm 1 will play $K_1 = K$ if

$$E(\Pi_1|(K, (K, K))) > E(\Pi_1|(0, (K, K)))$$

that is, if

$$\frac{[\theta + t(2-\beta) + t\alpha(\mu)(2\beta-1)]^2}{9} - K > \frac{[\theta + t\alpha(\mu)(2\beta-1)]^2}{9}$$

that, with $\mu = \frac{1}{2}$, is equivalent to

$$K < \frac{t(2-\beta)[2\theta + t(2-\beta) + t(1+\alpha_L)(2\beta-1)]}{9} = \kappa' \quad (3.20)$$

Lemma 7. A *pooling equilibrium* such that $s_1 = 0$ and $s_2 = (K, K)$ cannot exist. If a *pooling equilibrium* with $s_2 = (K, K)$ exists, it has to be such that $s = (K, (K, K))$ at second stage.

Proof.

Given $s_2 = (K, K)$, $K_1 = 0$ if $K > \kappa'$, where κ' is defined in (23). The strategy $s_2 = (K, K)$ can be taken into account only for the interval $[0, a]$, where $a = \frac{t\alpha_L(2-\beta)[2\theta+2t(2\beta-1)+t\alpha_L(2-\beta)]}{9}$[15], because, for $K > a$, type α_L never plays K. Since $\kappa' > a$, it cannot exist an interval in which the conditions that allow $s = (0, (K, K))$ to be part of an equilibrium are satisfied at the same time. So, we can delete $s = (0, (K, K))$ as part of a possible pooling equilibrium■.

The following Proposition identifies the region of parameters in which the *pooling equilibrium* with investment does exist.

Proposition 5. A *pooling equilibrium* where both firms invest can exist only if $K \leq \kappa''_{\alpha L}$, with

$$\kappa''_{\alpha L} \equiv \frac{t(3\alpha_L - (\frac{1+\alpha_L}{2})(2\beta-1))[4\theta + 4t(2\beta-1) + t(3\alpha_L - (\frac{1+\alpha_L}{2})(2\beta-1))]}{36} \quad (3.21)$$

Proof.

(In Appendix)

To sum up, the following investment choices can be sustainable as part of equilibria in the continuation game starting in R&D competition *regime* with incomplete information:

- $s = (K, (0, K))\, for\, \nu < K < \gamma$
- $s = (0, (0, 0))\, for\, K > \delta$
- $s = (K, (K, K))\, for\, K < \kappa''_{\alpha L}$.

[14] Best reply after observing $K_2 = K$ will be $BR_1(after\, K_2 = K) = BR_1(q_2^e) = \frac{a-2c_1^e+c_2^e}{3} = \frac{\theta+t_1(2-\beta)+t\frac{1}{2}(1+\alpha)(2\beta-1)}{3}$ with $t_1 = \{0, K\}$.

[15] See *Lemma 1*.

It is easy to show that $\nu < \kappa''_{\alpha L} < \delta < \gamma$, so we can identify five regions with the corresponding equilibria as follows:

- $K < \nu$ entails $s = (K, (K, K))$
- $\nu < K < \kappa''_{\alpha L}$ entails $s = (K, (K, K))$ *and* $s = (K, (0, K))$
- $\kappa''_{\alpha L} < K < \delta$ entails $s = (K, (0, K))$
- $\delta < K < \gamma$ entails $s = (K, (0, K))$ *and* $s = (0, (0, 0))$
- $K > \gamma$ entails $s = (0, (0, 0))$.

Equilibrium selection

There are two regions of parameters in which two different equilibria exist, namely the interval $[\nu, \kappa''_{\alpha L}]$ (where both $s = (K, (K, K))$ and $s = (K, (0, K))$ are possible), and the interval $[\delta, \gamma]$ (where both $s = (K, (0, K))$ and $s = (0, (0, 0))$ are possible). In what follows, I'm going to take into account only $s = (K, (K, K))$ in $[\nu, \kappa''_{\alpha L}]$ and $s = (K, (0, K))$ in $[\delta, \gamma]$ (equilibria with more total investment). This choice can be justified using the concept of *"Interim Pareto Dominance"*[16] to select equilibria. Another reason to focus on these equilibria is that, in this literature, object of interest is the possibility to increase the amount of R&D investment through coordination of R&D effort; so, I concentrate on the comparison between RJV outcome and the best outcome (in terms of total investment) under R&D competition *regime*.

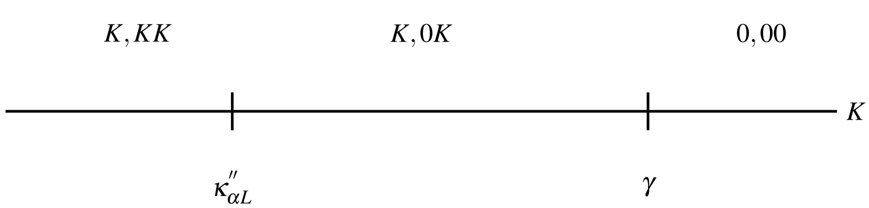
Proposition 6. (i) The combination of actions $s = (K, (K, K))$ *interim Pareto dominates* $s = (K, (0, K))$ in $[\nu, \kappa''_{\alpha L}]$; (ii) $s = (K, (0, K))$ *interim Pareto dominates* $s = (0, (0, 0))$ in $[\delta, \gamma]$.

Proof.

(In Appendix)

Taking into account the selection of equilibria, firms' investment choices in R&D competition are summarized in Figure 1.

Figure 3.1: **R&D investment's choices in R&D competition *regime***



Note: each outcome represents the choices of each agents in an equilibrium of the continuation game started at the beginning of the second stage. In particular the first element refers to the choice of firm 1, the second to the choice of firm 2 (type α_L) and the third to the choice of firm 2 (type α_H).

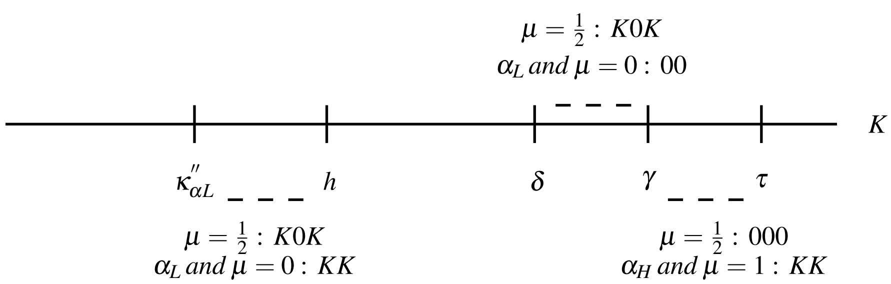
[16] See Holmström and Myerson (1983)

3.2.3 Effects of incomplete information on R&D investment decisions.

Figure 2 displays on the same line the thresholds that define the equilibria in R&D competition under complete and incomplete information and gives some insights about the consequences of incomplete information on investment choices. Consider the case in which firms are actually symmetric. When information is complete, the equilibrium is such that both firms invest when $K < \tau$ and none invests when $K > \tau$; when information is incomplete, instead, both firms invest when $K < \gamma$ and none invests when $K > \gamma$[17]. Given that $\gamma < \tau$, the region of parameters in which an equilibrium with investment is sustainable is larger when information is complete, that is, there is a region, namely $[\gamma, \tau]$, where incomplete information leads to an equilibrium with no investment. Here, firm 1 does not invest when it considers the possibility that its rival is less efficient, and, given the choice of firm 1, the best reply of firm 2 is to adopt a symmetric action. So, asymmetric information about rival's R&D productivity intensifies the problem of sub-optimal investment; if informational asymmetry could be eliminated, in the above mentioned region of parameters symmetric firms would invest and obtain higher profits.

As for the case in which firms are asymmetric, the order of the relevant thresholds is such that $\kappa''_{\alpha L} < h < \delta < \gamma$. It can be noted that incomplete information increases the region of parameters in which we have an asymmetric outcome (that is where only firm 1 invests): this outcome arises in $[\kappa''_{\alpha L}, \gamma]$ under incomplete information and in $[h, \delta]$ under complete information. In the regions of parameters where asymmetric information generates different outcomes with respect to the complete information setting, the more efficient firm (firm 1) is worse off. In the interval $[\kappa''_{\alpha L}, h]$ the less efficient firm (type α_L) does not invest since, if it did it, firm 1 would not distinguish between the two types of firm 2 in the last stage and would produce a larger quantity than in case of complete information; so investing is no more a best reply for the less efficient firm, and firm 1 cannot exploit the cost reduction from rival's investment. In this region, both firms are worse off when information is asymmetric, and the total investment is lower. In the interval $[\delta, \gamma]$, incomplete information leads to a non-efficient (*ex post*) investment choice by part of firm 1; this latter invests because of the positive probability to face the efficient firm (that would invest), but, given that this is not the case, firm 1 would be (*ex post*) better off avoiding investment. On the contrary, the less efficient firm is better off under incomplete information.

Figure 3.2: **Effects of incomplete information in R&D competition *regime***



5.5 To sum up, this kind of informational asymmetry damages efficient firms (firm 1 and type α_H of firm 2), while, for some parameters' values, it allows the less efficient firm to exploit the spillover effect and to reduce its costs, without bearing the cost of investment.

[17] As in the case of complete information, in incomplete information setting two firms equally efficient will make symmetric investment choice at equilibrium

3.3 RJV formation

In this section we study firms' equilibrium decisions regarding RJV membership (first stage). This allow to analyze the actual incentives to form R&D cooperation agreements and to see in which way this can change the outcomes with respect to those arising in R&D competition *regime*.

Firms act sequentially and have to decide about the possibility to form a RJV that commit them to coordinate their R&D effort. The first mover is firm 1: it can propose or not the agreement to firm 2. Firm 1's actions are defined by $\hat{s_1} = \{RJV, nothing\}$. If it plays "*nothing*", firms end up directly in R&D competition *regime,* with the outcomes defined in the previous section. If it plays "*RJV*", firm 2 chooses between "*accept*" (ending up in RJV regime) and *not accept* (ending up in R&D competition); so, firm 2's possible actions are defined as $\hat{s_2} = (\hat{s}_{2\alpha L}, \hat{s}_{2\alpha H}) = \{accept, not\, accept\}$. A generic combination of actions taken by firm 1 and the two types of firm 2 is denoted by $\hat{s} = (\hat{s_1}, \hat{s_2})$. To evaluate firms' best replies I analyze separately the intervals that define the equilibrium outcomes in R&D competition *regime*. First, I find firm 2's best reply to firm 1 (possible) proposal and then I check whether firm 1 has actually incentive to propose the agreement, anticipating firm 2's reaction. Each firm, in order to take its decision, will compare the payoff that it is going to obtain in a certain interval in R&D competition *regime* with the payoff generated by the joint decision to invest; payoffs arising under complete or incomplete information setting will be taken into account according to, respectively, separating or pooling strategies by part of firm 2 after firm 1's proposal.

Remember that there are three intervals with different equilibria in the continuation game starting at stage 2 under R&D competition (see Figure 1). Let us start by considering what happens for $K < \kappa''_{\alpha L}$. Results are stated in the following lemma.

Lemma 8. When $K < \kappa''_{\alpha L}$, equilibria involving separating strategies at the first stage cannot be attained. Each combination of actions such that the two types of firm 2 take the same action can be part of a *pooling equilibrium*. In particular, there are three possible equilibrium strategies in the first stage that are outcome equivalent, involving investment by part of all firms, irrespective of RJV formation: (i) Firm 1 plays $\hat{s_1} = nothing$ and firms end up in R&D competition, whatever the pooling strategy of firm 2; (ii) Firm 1 plays $\hat{s_1} = RJV$ and firm 2 choose $\hat{s_2} = (\hat{s}_{2\alpha L}, \hat{s}_{2\alpha H}) = (not\, accept, not\, accept)$, preventing RJV formation; (iii) Firm 1 plays $\hat{s_1} = RJV$ and firm 2 choose $\hat{s_2} = (\hat{s}_{2\alpha L}, \hat{s}_{2\alpha H}) = (accept, accept)$; RJV is formed but total investment and profits are the same as in R&D competion.

Proof.

(In Appendix)

Lemma 8 makes clear that, for $K < \kappa''_{\alpha L}$, the possibility to form a RJV does not change the outcomes arising when only R&D competition *regime* is feasible. It states that no equilibrium such that firm 1 is able to distinguish between the two types of firm 2 does exist. Since in R&D competition investing is the best strategy for all firms given investment by part of the rival, whatever the beliefs, and given that the RJV option entails the same investment strategy, type α_H will always have incentive to mimic the action of type α_L because when $\mu = 0$ the quantity produced by firm 1 is lower and type α_H would obtain a higher profit[18]. From this result, it follows that all the possible pooling equilibria entail investment by part of all firms, and, without beliefs updating, profits will be those of incomplete information; this is exactly the outcome that arises in R&D competition *regime*.

The second interval to be analyzed is $[\kappa''_{\alpha L}, \gamma]$. Remember that, when R&D competition starts with incomplete information $s = (K, (0, K))$ is the equilibrium strategy in the second stage.

[18]Remember that, when each player invests, $\Pi_{2\alpha H}$ under incomplete information is decreasing in $\alpha(\mu)$, so it is higher when $\mu = 0$, since, due to spillover effect, q_1 is lower when firm 1 competes with the less efficient firm.

Lemma 9. If $\kappa''_{\alpha L} < K < \gamma$, no *pooling equilibrium* such that the two types of firm 2 choose the same action after firm 1's proposal can exist.

Proof.

(In Appendix)

From *Lemma 9*, it follows that possible equilibria in $[\kappa''_{\alpha L}, \gamma]$ involve separating strategies by part of firm 2, after firm 1's proposal. It has to be noted that, due to beliefs updating, this interval has to be further divided in sub-intervals corresponding to the regions that identify the equilibria arising with complete information. The same consideration holds to check the possible existence of separating equilibria for $K > \gamma$.

For $\kappa''_{\alpha L} < K < \gamma$, the sub-intervals pertain complete information equilibria for asymmetric firms[19]. We stated before that the order of the relevant thresholds is such that $\kappa''_{\alpha L} < h < \delta < \gamma$. Possible separating equilibria are searched in each sub-intervals; the following lemmas show the results.

Lemma 10. If $\kappa''_{\alpha L} < K < h$, an equilibrium in which firm 2 plays a separating strategy after firm 1's proposal cannot exist. In this interval the only possible equilibrium is such that firm 1 plays $\hat{s_1} = nothing$ and the game ends up with the outcomes of R&D competition *regime*, namely firm 1 and type α_H of firm 2 invest, while type α_L does not.

Proof.

(In Appendix)

Lemma 11. If $h < K < \delta$, the only possible equilibrium following $\hat{s_1} = RJV$ entails $\hat{s_2} = (\hat{s}_{2\alpha L}, \hat{s}_{2\alpha H}) = (not\, accept, accept)$; firm 1 and type α_H will invest in RJV ($\mu = 1$) while, if $\alpha = \alpha_L$, the RJV is not formed and in R&D competition only firm 1 invests ($\mu = 0$). There is another possible equilibrium in which firm 1 plays $\hat{s_1} = nothing$ and R&D competition starts with incomplete information. The two equilibria are outcome equivalent.

Proof.

(In Appendix)

Lemma 12. In the interval $\delta < K < \gamma$, if

$$\gamma > \phi \equiv \frac{t(2\beta - 1 + 3\alpha_L)[4\theta + t(2\beta - 1 + 3\alpha_L)]}{36} \tag{3.22}$$

for $max\{\delta, \phi\} < K < \gamma$ the equilibrium is such that $\hat{s_1} = RJV$ and $\hat{s_2} = (\hat{s}_{2\alpha L}, \hat{s}_{2\alpha H}) = (not\, accept, accept)$. In all the other cases, the only possible equilibrium entails $\hat{s_1} = nothing$ and, accordingly, nothing changes with respect to a situation in which only R&D competition is feasible.

Proof.

(In Appendix)

When the equilibrium with $\hat{s_1} = RJV$ arises in $[\delta, \gamma]$, the possibility to create a RJV allows to restore the complete information setting before the investment stage. If $\alpha = \alpha_H$, the two equally efficient firms will invest in RJV *regime* and $\mu = 1$ (nothing changes with respect to the outcome in R&D competition), while, if $\alpha = \alpha_L$, in R&D competition $\mu = 0$ and no firm invests. In this latter case, without the possibility to propose the cooperation agreement, firm 1, under incomplete information, would have made an inefficient investment decision ($K_1 = K$) and get a lower profit.

As for the last interval to be analyzed, namely the values of K such that $K > \gamma$, it will be shown the existence of separating equilibria that allow type α_H to signal its type at no cost by accepting the cooperation agreement. This turns

[19] In this interval, symmetric firms with complete information will invest since $\tau > \gamma$.

out to be welfare improving: we will observe more total investment and higher profits, provided that the two firms are actually symmetric.

Lemma 13. (i) When $max\{\phi, \gamma\} < K < z$, with z defined in (6), a *separating equilibrium* entailing $\hat{s_1} = RJV$ and $\hat{s_2} = (\hat{s}_{2\alpha L}, \hat{s}_{2\alpha H}) = (not\,accept, accept)$ in the first stage exists and is welfare improving. (ii) For some parameters' values such that

$$\gamma < \eta^{''}_{\alpha L} \equiv \frac{[2t(2\beta-1)+t(3\alpha_L-\alpha(\mu)(2\beta-1))]}{36} \cdot \frac{[4\theta+2t(2\beta-1)+t(3\alpha_L-\alpha(\mu)(2\beta-1))]}{36} \quad (3.23)$$

a *pooling equilibrium* in which firm 1 proposes the cooperation agreement and both type of firm 2 accept may arise for $\gamma < K < \eta^{''}_{\alpha L}$; this equilibrium is welfare improving. (iii) All the other possible equilibria in the region defined by $K > \gamma$ lead to the same outcome as if only R&D competition *regime* was feasible. (iv) Where equilibria defined in (i) and (ii) do exist, they *interim Pareto dominate* all the other possible equilibria.

Proof.

(In Appendix)

In the welfare improving separating equilibrium, firm 1 is able to distinguish between the two types of firm 2, given that only type α_H will accept the proposed agreement. So, RJV is formed between the two equally efficient firms and investing in R&D makes them better off (in addition to be beneficial for consumers). When $\alpha = \alpha_L$, nothing changes with respect to the subgame starting with R&D competition. Remember that in R&D competition *regime* the unique equilibrium in this region is such that no firm invests. As for the welfare improving pooling equilibrium (that does not need to arise), RJV formation leads to more investment and higher profits for all firms.

Relevant results from *Lemmas 8-13* are summarized in *Proposition 7*, which states the effects of the possibility to form R&D cooperation agreements. Only the intervals in which the possibility to create a RJV changes the outcomes with respect to R&D competition are considered.

Proposition 7. (i) For $max\{\phi, \gamma\} < K < z$, the possibility of create a RJV enhances investment in R&D and increases welfare at least when firms are equally efficient through a) coordination and b) the possibility for the more efficient type of firm 2 to signal its type. In the interval $[max\{\phi, \gamma\}, \tau]$, with $max\{\phi, \gamma\} < \tau < z$, RJV formation between two equally efficient firms restores the complete information setting and solves the inefficiency generated in R&D competition *regime* by incomplete information. For $\tau < K < z$ more total investment and higher profits for the efficient firms in RJV are due to spillovers internalization. (ii) A pooling equilibrium in which RJV is formed whatever the type of firm 2, generating more total investment and higher profits for all firms and types, may arise. This happens for $\gamma < K < \eta^{''}_{\alpha L}$, if parameters' values are such that $\gamma < \eta^{''}_{\alpha L}$. (iii) The signaling effect could also allow firm 1 to make efficient investment decisions when it faces the less efficient firm. This can be observed if the separating equilibrium with $\hat{s_1} = RJV$ arises in $[\delta, \gamma]$. In this case, the inefficient firm cannot exploit incomplete information of firm 1 to get beneficial effect from rival's investment.

It has been shown that different equilibria can arise according to parameters' values; in any case, where the possibility to cooperate in R&D leads to different outcomes with respect to those existing in R&D competition *regime*, the effects of this kind of agreement turn out to be positive, especially when firms are equally efficient. Note that the

Figure 3.3: **Equilibrium outcomes -** $\eta''_{\alpha L} < \gamma$

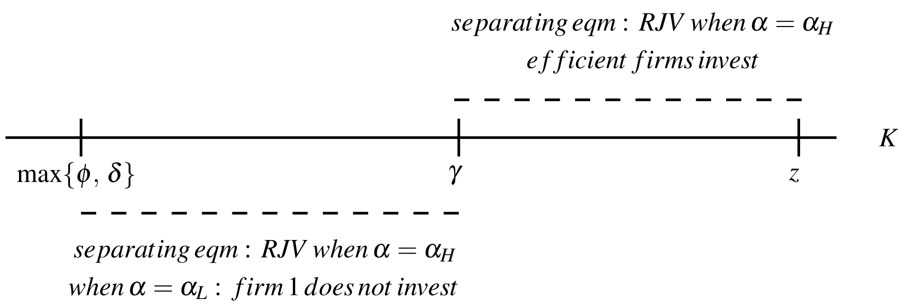
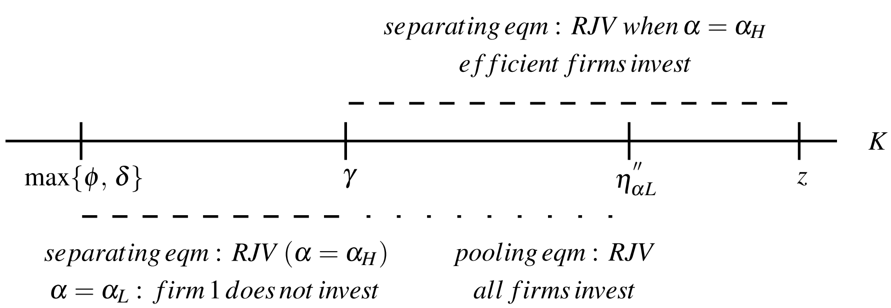


Figure 3.4: **Equilibrium outcomes -** $\eta''_{\alpha L} < \gamma$ **and** $\phi < \gamma$

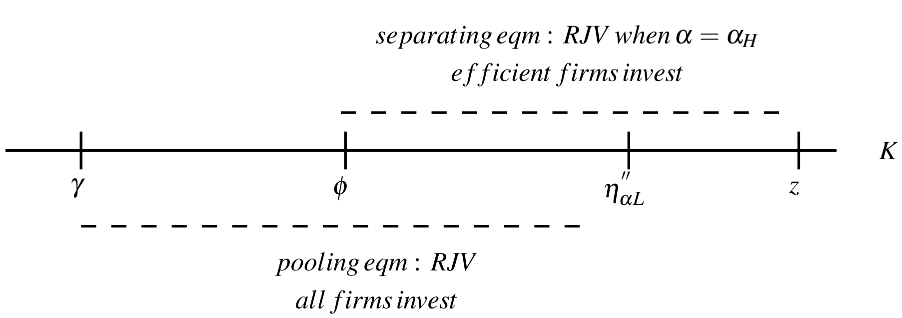


5.5 separating equilibrium entailing RJV formation between symmetric firm exists for all parameters' values. Figures 3-5 show all possible orders of thresholds with the corresponding equilibria.

Conclusions

I developed a 3-stage model to analyze firms' willingness to form cooperative agreements to coordinate R&D effort and the resulting investment choices in a framework of incomplete information. Incomplete information concerns the efficiency of firms' R&D activity, and R&D cooperation entails committment to invest by the firms taking part to the agreement (RJV). The analysis has focused on the case of high spillovers, since it turns out to be the more interesting one.

Figure 3.5: **Equilibrium outcomes -** $\eta''_{\alpha L} < \gamma$ **and** $\phi > \gamma$



The innovation enhancing effects of R&D cooperation are confirmed, at least for the case in which firms are equally efficient. Coordination of R&D efforts allows to internalize the externality generated by spillovers and overcome free-riding problem. Moreover, a new beneficial effect of RJVs has been identified: there is a region of parameters in which the formation process allows the efficient type of firm 2 to signal its type, thus increasing the level of investment and welfare. When firms are symmetric and compete in R&D, incomplete information reduces the region of parameters in which an equilibrium with investment can be sustained; in some sense, the possibility to create a RJV tends to solve this inefficiency, by revealing information. So, not only RJV formation allows investment (and higher profits) in a larger region of parameters, but also it restores the complete information setting as for the level of investment. In other words, the possibility to create a RJV leads to the same outcome as if information was complete. In this region, investment never occurs between asymmetric firms; though, they are not worse off with respect to the outcome under R&D competition *regime* (they get the same payoff). So, allowing RJV formation may lead to a Pareto-improvement, by eliminating information asymmetry. In the other regions, for symmetric firms, the outcome in terms of investment, is the same as if only R&D competition was feasible.

The signaling role of RJV may also help firm 1 to avoid inefficient investment choices; there is a region in which, as long as information remains incomplete, in R&D competition firm 1 invests, and this guarantees a larger profit to the less efficient type, thanks to the spillover effect, but firm 1's choice is (*ex post*) not efficient. Cooperation proposal may generate a separating equilibrium such that, once in R&D competition, firm 1 can recognize the less efficient type and make optimal investment choices.

Finally, it turns out that for most of the parameters' values, a RJV is never formed when firms are actually asymmetric, so the alleged coordination effect does not actually emerge. This is due to the presence of asymmetric equilibrium in R&D competition; in the region of parameters where this equilibrium arises, type α_L prefers to exploit the benefit from firm 1's investment without paying the cost. This result is in line with those of Baerenss (1999), Atallah (2005a) and Röller, Tombak and Siebert (1998).

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Appendix

Proof of Lemma 1.

Let $\mu \in [0, 1]$ be a generic probability that firm 1 assigns to type α_H. When firm 1 plays $K_1 = 0$, firm 2, when its type is α_L, prefers $K_{2\alpha L} = 0$ if

$$(\Pi_{2\alpha L}|K_1 = 0, K_{2\alpha L} = 0, \mu) > (\Pi_{2\alpha L}|K_1 = 0, K_{2\alpha L} = K, \mu)$$

that is

$$\frac{\theta^2}{9} > \frac{[2\theta + t(3\alpha_L - \alpha(\mu)(2\beta - 1))]^2}{36} - K$$

namely

$$K > \frac{t(3\alpha_L - \alpha(\mu)(2\beta - 1))[4\theta + t(3\alpha_L - \alpha(\mu)(2\beta - 1))]}{36}$$

with $\alpha(\mu) = \mu + (1 - \mu)\alpha_L$. This threshold is decreasing in μ and takes its maximal value for $\mu = 0$; so, if

$$K > \frac{t\alpha_L(2 - \beta)[2\theta + t\alpha_L(2 - \beta)]}{9}$$

then the action $K_{2\alpha L} = K$ is never a best reply to $K_1 = 0$, so type α_L will choose $K_{2\alpha L} = 0$ when $K_1 = 0$ for any μ.

When firm 1 plays $K_1 = K$, type α_L prefers $K_{2\alpha L} = 0$ if

$$(\Pi_{2\alpha L}|K_1 = K, K_{2\alpha L} = 0, \mu) > (\Pi_{2\alpha L}|K_1 = K, K_{2\alpha L} = K, \mu)$$

that is, if

$$\frac{[\theta + t(2\beta - 1)]^2}{9} > \frac{[2\theta + 2t(2\beta - 1) + t(3\alpha_L - \alpha(\mu)(2\beta - 1))]^2}{36} - K$$

namely

$$K > \frac{t(3\alpha_L - \alpha(\mu)(2\beta - 1))[4\theta + 4t(2\beta - 1) + t(3\alpha_L - \alpha(\mu)(2\beta - 1))]}{36}$$

The threshold takes maximal value for $\mu = 0$; so, when

$$K > \frac{t\alpha_L(2 - \beta)[2\theta + 2t(2\beta - 1) + t\alpha_L(2 - \beta)]}{9}$$

the action $K_{2\alpha L} = K$ is never a best reply against $K_1 = K$, so type α_L will choose $K_{2\alpha L} = 0$ when $K_1 = K$ for any μ.

Since

$$\frac{t\alpha_L(2 - \beta)[2\theta + 2t(2\beta - 1) + t\alpha_L(2 - \beta)]}{9} > \frac{t\alpha_L(2 - \beta)[2\theta + t\alpha_L(2 - \beta)]}{9}$$

when $K > (t\alpha_L/9)(2 - \beta)[2\theta + 2t(2\beta - 1) + t\alpha_L(2 - \beta)]$, $K_{2\alpha L} = K$ is never a best reply for type α_L, for any action taken by firm 1 and any belief. Hence, $K_{2\alpha L} = K$ is a dominated strategy for type α_L for

$$K > \frac{t\alpha_L(2-\beta)[2\theta+2t(2\beta-1)+t\alpha_L(2-\beta)]}{9} \equiv a \blacksquare.$$

Proof of Lemma 4.

If $K < \gamma$, only $s = (K, (0, K))$ is possible as separating strategy profile; for it to be part of an equilibrium, it remains to be checked that each type of firm 2 has no incentive to deviate (choosing the action played by the other type, or any other mixed strategy), given updated beliefs of firm 1.

Let's start with type α_L. Its payoff, if it follows the "equilibrium" strategy, is $\Pi_{2\alpha_L}(K_1 = K, K_{2\alpha_L} = 0, \mu_{\alpha L} = 1) = \frac{1}{9}[\theta + t(2\beta-1)]^2$.

If α_L deviates (choosing $K_2 = K$), firm 1, in the last stage, will think to compete with α_H and it will produce $q_1 = q_1^C(q_2^{\alpha H}) = \frac{a-2c_1+c_2^{\alpha H}}{3} = \frac{\theta+t_1(2-\beta)+t_2(2\beta-1)}{3}$, that is the equilibrium quantity for firm 1 in Cournot competition when the two firms are symmetric.

Given $q_1^C(q_2^{\alpha H})$, type α_L chooses the quantity that maximizes its profit, namely the expression

$$[a - \frac{\theta+t_1(2-\beta)+t_2(2\beta-1)}{3} - q_2 - (c - \alpha_L t_2 - \beta t_1)]q_2 - K_2$$

The optimal quantity after deviation is

$$q_{2\alpha L}^D = \frac{2\theta + 2t_1(2\beta-1) - t_2(2\beta-1) + 3\alpha_L t_2}{6}$$

and the profit from deviation is, therefore,

$$\Pi_{2\alpha L}^D = \frac{1}{36}[2\theta + 2t_1(2\beta-1) - t_2(2\beta-1) + 3\alpha_L t_2]^2 - K_2$$

In this case, $t_1 = t_2 = t$ (since $K_1 = K_2 = K$), so

$$\Pi_{2\alpha L}^D = \frac{1}{36}[2\theta + t(2\beta-1) + 3\alpha_L t]^2 - K$$

Let $\Pi_2^{K0} = (\Pi_2 | K_1 = K, K_2 = 0)$ and $\Pi_2^{KK} = (\Pi_2 | K_1 = K, K_2 = K)$. Then, type α_L has no incentive to deviate if

$$(\Pi_2^{K0} | \alpha = \alpha_L, \mu = 0) \geq (\Pi_2^{KK} | \alpha = \alpha_L, \mu = 1) = \Pi_{2\alpha L}^D(K_1 = K_2 = K)$$

The inequality is satisfied when

$$K \geq \frac{t(3\alpha_L + 1 - 2\beta)[4\theta + 3t(3\alpha_L + 2\beta - 1)]}{36} \equiv \nu$$

Given that $\nu < \gamma$, in the interval $[\nu, \gamma]$ type α_L will not deviate[20].

Now, we proceed with a similar check for type α_H. Its payoff, if it follows the "equilibrium" strategy, is $\Pi_{2\alpha H}(K_1 = K, K_{2\alpha H} = K, \mu = 1) = \frac{1}{9}[\theta + t(1+\beta)]^2 - K$. If type α_H deviates (choosing $K_{2\alpha H} = 0$), firm 1, at the last stage, will think to compete with type α_L and it will produce $q_1 = q_1^C(q_2^{\alpha L}) = \frac{a-2c_1+c_2^{\alpha L}}{3} = \frac{\theta+t_1(2-\beta)+\alpha_L t_2(2\beta-1)}{3}$.

Given $q_1^C(q_2^{\alpha L})$, type α_H chooses the quantity that maximizes its profit, namely, it chooses q_2 to maximize

$$[a - \frac{\theta+t_1(2-\beta)+\alpha_L t_2(2\beta-1)}{3} - q_2 - (c - t_2 - \beta t_1)]q_2 - K_2$$

[20] It will not assign a positive probability to the play of $s_{2\alpha L} = K$ in any mixed strategy at equilibrium.

The optimal quantity after deviation is

$$q^D_{2\alpha H} = \frac{2\theta + 2t_1(2\beta - 1) - \alpha_L t_2(2\beta - 1) + 3t_2}{6}$$

and the profit from deviation is

$$\Pi^D_{2\alpha H} = \frac{1}{36}[2\theta + 2t_1(2\beta - 1) + t_2(3 - \alpha_L(2\beta - 1))]^2 - K_2$$

Given $K_1 = K$ and $K_2 = 0$,

$$\Pi^D_{2\alpha H} = \frac{1}{9}[\theta + t(2\beta - 1)]^2$$

Type α_H has no incentive to deviate if

$$(\Pi^{KK}_2 | \alpha = \alpha_H,\, \mu = 1) \geq (\Pi^{K0}_2 | \alpha = \alpha_H,\, \mu = 0) = \Pi^{D(K0)}_{2\alpha H}$$

and this condition is satisfied for $K < \tau$, where τ is defined in (4).

Since $\tau > \gamma$ for $\beta > \frac{1}{2}$, in the interval $[\nu,\, \gamma]$ type α_H will not deviate and $s = (K,\, (0,\, K))$ is sustainable as part of a *separating PBE* in the continuation game started at the second period.

Proof of Lemma 5.

The action $s_1 = 0$ is a best reply to $\hat{s}_2 = (0,\, K)$ only if $K > \gamma$. Type α_L has no incentive to deviate in this region since the action $K_{2\alpha L} = K$ is dominated $(a < \gamma)$. However, type α_H has incentive to deviate (choosing $K_{2\alpha H} = 0$) since $\Pi_{2\alpha H}(K_1 = 0,\, K_2 = K | \mu = 1) = \frac{1}{9}[\theta + t(2 - \beta)]^2 - K < \frac{1}{9}\theta^2 = \Pi^D_2(K_1 = 0,\, K_2 = 0 | \mu = 0)$ when $K > \frac{t(2-\beta)[2\theta + t(2-\beta)]}{9} = \delta$, and $\delta < \gamma$ if $\beta > \frac{1}{2}$. Then, $s = (0,\, (0,\, K))$ cannot be part of any possible separating equilibrium.

Proof of Proposition 5.

Given $s_2 = (K, K)$, $K_1 = K$ only if

$$K < \frac{t(2 - \beta)[2\theta + t(2 - \beta) + t(1 + \alpha_L)(2\beta - 1)]}{9} = \kappa'$$

If $K_1 = K$, type α_L has no incentive to deviate from the pooling strategy $s_2 = (K, K)$ if

$$\Pi_{2\alpha L}(K_1 = K_2 = K,\, \mu = \frac{1}{2}) \geq \Pi_{2\alpha L}(K = K,\, K_2 = 0,\, \mu = \frac{1}{2})$$

namely,

$$\frac{1}{36}[2\theta + 2t(2\beta - 1) + t(3\alpha_L - (\frac{1 + \alpha_L}{2})(2\beta - 1))]^2 - K \geq \frac{1}{9}[\theta + t(2\beta - 1)]^2$$

or

$$K \leq \frac{t(3\alpha_L - (\frac{1+\alpha_L}{2})(2\beta - 1))[4\theta + 4t(2\beta - 1) + t(3\alpha_L - (\frac{1+\alpha_L}{2})(2\beta - 1))]}{36} = \kappa''_{\alpha L}$$

In a similar way, type α_H does not deviate if

$$\Pi_{2\alpha H}(K_1 = K_2 = K,\, \mu = \frac{1}{2}) \geq \Pi_{2\alpha H}(K = K,\, K_2 = 0,\, \mu = \frac{1}{2})$$

that is, if

$$K \leq \frac{t(3-(\frac{1+\alpha_L}{2})(2\beta-1))[4\theta+4t(2\beta-1)+t(3-(\frac{1+\alpha_L}{2})(2\beta-1))]}{36} = \kappa''_{\alpha H}$$

Given that $\kappa''_{\alpha L} < \kappa' < \kappa''_{\alpha H}$, $s = (s_1, s_2) = (K, (K, K))$ can be part of a pooling PBE only if $K < \kappa''_{\alpha L}$■.

Proof of Proposition 6.

Let s a generic combination of actions in some point of the game. An equilibrium entailing s' *interim Pareto dominates* an equilibrium entailing s'' if, given the available information at the time in which s' and s'' are chosen, the payoffs following s' are such that no player is worse off and at least one player is better off, with respect to the payoffs following s''.

Given that, in $[\nu, \kappa''_{\alpha L}]$,

(i) for type α_L

$$(\Pi_{2\alpha L}|s = (K, (K, K))) > (\Pi_{2\alpha L}|s = (K, (0, K)))$$

since

$$\frac{1}{36}[2\theta + 2t(2\beta-1) + t(3\alpha_L - \bar{\alpha}(2\beta-1))]^2 - K > \frac{1}{9}[\theta + t(2\beta-1)]^2$$

when $K < \kappa''_{\alpha L}$,

(ii) for type α_H

$$\begin{aligned}(\Pi_{2\alpha H}|s \quad &= \quad (K, (K, K))) = \frac{1}{36}[2\theta + 2t(2\beta-1) + t(3-\alpha(\mu)(2\beta-1))]^2 - K > \\ &\frac{1}{9}[\theta + t(1+\beta)]^2 - K = (\Pi_{2\alpha H}|s = (K, (0, K)))\end{aligned}$$

since, when spillovers are high, the profit of type α_H increases as $\alpha(\mu) \to \alpha_L$, and

(iii) for firm 1

$$\begin{aligned}E(\Pi_1|s \quad &= \quad (K, (K, K))) = \frac{1}{9}[\theta + t(2-\beta) + t\alpha(\mu)(2\beta-1)]^2 - K > \\ &\frac{1}{18}\{[\theta + t(2-\beta)]^2 + [\theta + t(1+\beta)]^2\} - K = E(\Pi_1|s = (K, (0, K)))\end{aligned}$$

it follows that, for $\nu < K < \kappa''_{\alpha L}$, an equilibrium with $s = (K, (K, K))$ at second stage *interim Pareto dominates* an equilibrium with $s = (K, (0, K))$.

In the same way, it can be demonstrated that an equilibrium with $s = (K, (0, K))$ *interim Pareto dominates* an equilibrium with $s = (0, (0, 0))$ in $[\delta, \gamma]$■.

Proof of Lemma 8.

Let us first demonstrate that for $K < \kappa''_{\alpha L}$, equilibria involving separating strategies at the first stage do not exist. A possible separating equilibrium has to be such that either $\hat{s}'_2 = (not\,accept, accept)$ or $\hat{s}'_2 = (accept, not\,accept)$ after $\hat{s}_1 = RJV$.

Consider first $\hat{s}_2' = (not\,accept,\, accept)$. Given this strategy, at the beginning of the second stage, $(\mu|\hat{s}_2' = not\,accept) = 0$ and $(\mu|\hat{s}_2' = accept) = 1$. So, type α_H would obtain, in RJV *regime*

$$(\Pi_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K,\, \mu = 1) = \frac{[\theta + t(2\beta - 1) + t(2-\beta)]^2}{9} - K$$

If type α_H deviates, playing $\hat{s}_{2\alpha H}' = not\,accept$, in R&D competition firm 1 will think to face the less efficient firm. Under complete information, the outcome with asymmetric firms under complete information is such that both firms invest, since $\kappa_{\alpha L}'' < h$[21]; by deviating, type α_H can get[22]

$$(\Pi^D_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K,\, \mu = 0) = \frac{[2\theta + 2t(2\beta - 1) + t(3 - \alpha_L(2\beta - 1))]^2}{36} - K$$

Given that

$$\frac{[2\theta + 2t(2\beta - 1) + t(3 - \alpha_L(2\beta - 1))]^2}{36} - K > \frac{[\theta + t(2\beta - 1) + t(2-\beta)]^2}{9} - K$$

type α_H has incentive to deviate, hence an equilibrium with $\hat{s}_2' = (not\,accept,\, accept)$ following $\hat{s}_1 = RJV$ can never exist.

The same argument holds to prove that $\hat{s}_2' = (accept,\, not\,accept)$ cannot be part of an equilibrium. Indeed, in R&D competition *regime*, type α_H's profit would be $(\Pi_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K,\, \mu = 1)$[23], while, by deviating, it could obtain $(\Pi^D_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K,\, \mu = 0)$.

Let us consider now possible equilibria entailing pooling strategies at the first stage.

Consider first the pooling strategy in which no type of firm 2 accepts the (possible) RJV proposal by firm 1. No type has incentive to deviate from $\hat{s}_2' = (not\,accept,\, not\,accept)$ since in R&D competition under incomplete information the outcome is such that each firm and each type invest (see *Proposition 5* and *Proposition 6*) and in RJV *regime* the two types would obtain the same profit. Given $\hat{s}_2' = (not\,accept,\, not\,accept)$, firm 1 is indifferent between *RJV* and *nothing*: it will end up in R&D competition *regime* under incomplete information, whatever its choice. So, both $\hat{s}_1 = RJV$ followed by $\hat{s}_2' = (not\,accept,\, not\,accept)$ and $\hat{s}_1 = nothing$ followed by $\hat{s}_2' = (not\,accept,\, not\,accept)$ are sustainable as part of a pooling equilibrium. This proves (ii) and part of (i).

Consider now $\hat{s}_2' = (accept,\, accept)$ after $\hat{s}_1 = RJV$; the outcome following these strategies is such that each firm and each type invest in RJV *regime*. Given that the outcome arising in R&D competition under incomplete information is the same as in RJV *regime*, no type of firm 2 has incentive to deviate and firm 1 is indifferent between *RJV* and *nothing*, given $\hat{s}_2' = (accept,\, accept)$. So, both $\hat{s}_1 = RJV$ followed by $\hat{s}_2' = (accept,\, accept)$ and $\hat{s}_1 = nothing$ followed by $\hat{s}_2' = (accept,\, accept)$ are sustainable as part of a pooling equilibrium. This proves (iii) and the remaining part of (i)■.

Proof of Lemma 9.

Consider first $\hat{s}_2' = (accept,\, accept)$. This pooling strategy cannot be part of an equilibrium since type α_L can get an higher profit in R&D competition *regime*. Indeed, in the interval $[\kappa_{\alpha L}'',\, \gamma]$, the outcome in R&D competition under incomplete information entails $s = (K,\, (0,\, K))$ and so $(\Pi_{2\alpha L}|K_1 = K,\, K_{2\alpha L} = 0,\, \mu = \frac{1}{2}) = (1/9)[\theta + t(2\beta - 1)]^2$; in RJV *regime*, type α_L' profits would be $(\Pi_{2\alpha L}|K_1 = K,\, K_{2\alpha L} = 0,\, \mu = \frac{1}{2}) = (1/36)[2\theta + 2t(2\beta - 1) + t(3\alpha_L - \alpha(\mu)(2\beta - 1))]^2 - K$. Given that

[21] See *Proposition 2*.

[22] See proof of *Lemma 4*.

[23] Both firms invest under complete information since $\kappa_{\alpha L}'' < \tau$ (See *Proposition 1*).

$$\frac{[\theta+t(2\beta-1)]^2}{9} > \frac{[2\theta+2t(2\beta-1)+t(3\alpha_L-\alpha(\mu)(2\beta-1))]^2}{36} - K$$

when $K > \kappa''_{\alpha L}$ (see proof of *Proposition 5*), type α_L has incentive to deviate from $\hat{s}'_2 = (accept, accept)$, so a pooling equilibrium with RJV formation cannot obtain in $[\kappa''_{\alpha L}, \gamma]$.

Consider now $\hat{s}'_2 = (not\,accept, not\,accept)$. Following this strategy, type α_H, in R&D competition, gets $(\Pi_{2\alpha H}|K_1 = K, K_{2\alpha H} = K, \mu = 1)$, while, by deviating, it can obtain $(\Pi_{2\alpha H}|K_1 = K, K_{2\alpha H} = K, \mu = \frac{1}{2})$; given that $(\Pi_{2\alpha H}|K_1 = K, K_{2\alpha H} = K)$ is decreasing in μ (see equation (16)), type α_H has incentive to deviate, so a pooling equilibrium in which both types of firm 2 reject firm 1's proposal to cooperate in R&D does not exist■.

Proof of Lemma 10.

The same arguments for which separating strategies after firm 1's proposal cannot be part of an equilibrium for $K < \kappa''_{\alpha L}$ (see proof of *Lemma 8*) hold also in the interval we are considering, namely $[\kappa''_{\alpha L}, h]$. Given that, in this interval, also pooling strategies after $\hat{s}_1 = RJV$ are not possible (see *Lemma 9*), here I demonstrate that an equilibrium entailing $\hat{s}_1 = nothing$ at the first stage and $s = (K, (0, K))$ at the second stage does exist.

Since a separating strategy of firm 2 at first stage following $\hat{s}_1 = RJV$ cannot be part of an equilibrium, firm 1 will not be able to distinguish between the two types of firm 2 after a possible cooperation proposal, so assume that, after $\hat{s}_1 = RJV$, beliefs are such that $\mu = \frac{1}{2}$ (out of the equilibrium path beliefs could be whatever) and $\hat{s}'_2 = (not\,accept, accept)$ (consistent strategy with $\mu = \frac{1}{2}$). Given this, firm 1 has no incentive to deviate from $\hat{s}_1 = nothing$ since its expected profit in R&D competition *regime,* namely

$$E(\Pi_1|\hat{s}_1 = nothing) = \frac{1}{2}\{\frac{[\theta+t(2-\beta)]^2}{9}\} + \frac{1}{2}\{\frac{[\theta+t(2\beta-1)+t(2-\beta)]^2}{9} - K\}$$

is larger than its expected profit by deviation, (that leads firm 1 in R&D competition *regime* with type α_L with probability $\frac{1}{2}$ and in RJV *regime* with type α_H with the same probability), that is

$$E(\Pi_1|\hat{s}_1 = RJV) = \frac{1}{2}\{\frac{[\theta+t(2-\beta)]^2}{9}\} + \frac{1}{2}\{\frac{[\theta+\alpha(\mu)t(2\beta-1)+t(2-\beta)]^2}{9} - K\}$$

Therefore, in the interval $[\kappa''_{\alpha L}, h]$ it does exist an equilibrium such that firm 1 plays $\hat{s}_1 = nothing$ and the game ends up with the outcomes of R&D competition *regime.*

Proof of Lemma 11.

According to Lemma 9, pooling strategies by firm 2 at the first stage after $\hat{s}_1 = RJV$ cannot be part of an equilibrium, so it has to be checked if $\hat{s}_2 = (accept, not\ accept)$ and $\hat{s}_2 = (not\,accept, accept)$ can be sustainable as equilibrium strategies following firm 1's cooperation proposal.

It is easy to show first that $\hat{s}_2 = (accept, not\ accept)$ can never be an equilibrium strategy. Infact, type α_L has incentive to deviate since its profit in RJV *regime* with beliefs updating (following the strategy $\hat{s}_{2\alpha L} = accept$) is lower than the profit it would obtain by deviation (in R&D competition firm 1 invests and the less efficient firm finds optimal do not invest, so revealing its type in the last stage):

$$\begin{aligned}(\Pi_{2\alpha L}|K_1 &= K, K_{2\alpha L} = K, \mu = 0) = \frac{1}{9}[\theta+\alpha_L t(2-\beta)+t(2\beta-1)]^2 - K < \\ &\frac{1}{9}[\theta+t(2\beta-1))]^2 = (\Pi_{2\alpha L}|K_1 = K, K_{2\alpha L} = 0, \mu)\end{aligned}$$

when $K > h$. Therefore, $\hat{s_2} = (accept, not\,accept)$ can be ruled out as possible equilibrium strategy.

Consider now $\hat{s_2} = (not\,accept, accept)$. I demonstrate first that no type of firm 2 has incentive to deviate and then that, given $\hat{s_2} = (not\,accept, accept)$, firm 1 has no incentive to deviate from $\hat{s_1} = RJV$. If type α_L follows $\hat{s_2} = (not\,accept, accept)$, it will end up in R&D competition and its profit will be $(\Pi_{2\alpha L}|K_1 = K,\, K_{2\alpha L} = 0,\, \mu = 0) = \frac{1}{9}\left[\theta + t(2\beta - 1)\right]^2$; if type α_L deviates, playing $\hat{s}_{2\alpha L} = accept$, in RJV it would get $(\Pi^D_{2\alpha L}|K_1 = K,\, K_{2\alpha L} = K,\, \mu = 1) = \frac{1}{36}\left[2\theta + t(2\beta - 1) + 3t\alpha_L)\right]^2 - K$. Given that

$$\frac{1}{9}\left[\theta + t(2\beta - 1)\right]^2 > \frac{1}{36}\left[2\theta + t(2\beta - 1) + 3t\alpha_L)\right]^2 - K$$

when $K > \nu$ (where ν is defined in (21)) and that $\nu < h$, type α_L will not deviate.

As for type α_H, if it follows $\hat{s_2} = (not\,accept, accept)$, its profit in RJV *regime* will be $(\Pi_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K,\, \mu = 1) = \frac{1}{9}\left[\theta + t(2-\beta) + t(2\beta - 1)\right]^2 - K$. If type α_H deviates, the second stage in R&D competition *regime* starts with $\mu = 0$. Given that $K_1 = K$, if type α_H mimics the less efficient firm, the profit of type α_H will be $(\Pi_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = 0,\, \mu = 0) = \frac{1}{9}\left[\theta + t(2\beta - 1)\right]^2$, that is lower than $(\Pi_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K,\, \mu = 1)$ since

$$\frac{1}{9}\left[\theta + t(2\beta - 1)\right]^2 < \frac{1}{9}\left[\theta + t(2-\beta) + t(2\beta - 1)\right]^2 - K$$

when $K < \tau$, and and $\tau > \delta$. If, in R&D competition, type α_H plays $K_{2\alpha H} = K$, it will obtain the same profit as following $\hat{s_2} = (not\,accept, accept)$ (firm 1 updates its beliefs at the last stage). Hence, type α_H has no incentive to deviate from $\hat{s_2} = (not\,accept, accept)$, that turns out to be the unique possible equilibrium of firm 2 following $\hat{s_1} = RJV$.

It remains to be checked whether firm 1 can have incentive to deviate from $\hat{s_1} = RJV$. Note that firm 1's expected profit when it plays $\hat{s_1} = RJV$ is the same as after playing $\hat{s_1} = nothing$. The RJV is going to be formed only when $\alpha = \alpha_H$, leading to the some outcome arising when R&D competition starts with incomplete information (where $s = (K,\, (0,\, K))$).

It follows that, for $h < K < \delta$, there are only two possible equilibrium strategies at the first stage, namely $\hat{s_1} = RJV$ followed by $\hat{s_2} = (not\,accept, accept)$ and $\hat{s_1} = nothing$, after which R&D competition starts under incomplete information. The two equilibria are outcome equivalent: the two efficient firms invest, while the less efficient firm does not and there is perfect updating at the beginning of the last stage, irrespective of the possibility to form a RJV■.

Proof of Lemma 12.

Looking for possible equilibria entailing $\hat{s_1} = RJV$ in the interval $[\delta,\, \gamma]$, we focus only on separating strategies by firm 2, since no pooling strategies after firm 1's cooperation proposal are sustainable as part of an equilibrium (see *Lemma 9*).

Consider$\hat{s_2} = (accept, not\,accept)$. In the interval under consideration, the equilibrium arising in R&D competition implies investment by firm 1 and type α_H with beliefs updating ($\mu = 1$); in terms of investment choices, the equilibrium in RJV *regime* leads to the same outcome as for the two efficient firms, but, if type α_H deviates from $\hat{s_2} = (accept, not\,accept)$, in RJV *regime* $\mu = 0$. Given that $(\Pi_{2\alpha H}|K_1 = K,\, K_{2\alpha H} = K)$ is decreasing in μ (see equation (16)), $\hat{s_2} = (accept, not\,accept)$ has to be ruled out as possible equilibrium strategies after $\hat{s_1} = RJV$ since type α_H would have incentive to deviate.

Therefore if an equilibrium with a separating strategy by firm 2 after firm 1's cooperation proposal exists, it has to be such that $\hat{s_2} = (not\,accept, accept)$. If $\hat{s_2} = (not\,accept, accept)$, firm 1 would have no incentive to deviate from $\hat{s_1} = RJV$ since

$$E(\Pi_1|\hat{s_1} = RJV) = \frac{1}{2}\{\frac{\theta^2}{9}\} + \frac{1}{2}\{\frac{1}{9}[\theta + t(1+\beta)]^2 - K\} >$$
$$\frac{1}{2}\{\frac{1}{9}[\theta + t(2-\beta)]^2 - K\} + \frac{1}{2}\{\frac{1}{9}[\theta + t(1+\beta)]^2 - K\} = E(\Pi_1|\hat{s_1} = nothing)$$

when $K > \delta$. It has to be checked if the two types of firm 2 have incentive to deviate from $\hat{s_2} = (not\,accept, accept)$.

Consider type α_H first. If it follows $\hat{s_2} = (not\,accept, accept)$, in RJV it gets $(\Pi_{2\alpha H}|K_1 = K, K_{2\alpha H} = K, \mu = 1) = \frac{1}{9}[\theta + t(1+\beta)]^2 - K$. It it deviates, R&D competition starts with $\mu = 0$ and firm 1 would not invest (see *Proposition 2*); given $K_1 = 0$, type α_H's best reply will be $K_{2\alpha H} = 0$, leading to $(\Pi_{2\alpha H}|K_1 = K_{2\alpha H} = 0) = \frac{\theta^2}{9}$ (see *Proposition 1*). Given that

$$\frac{1}{9}[\theta + t(1+\beta)]^2 - K > \frac{\theta^2}{9}$$

when $K < z$, with z defined in (6), and that $z > \gamma$, type α_H will not deviate.

Consider now type α_L. Following $\hat{s_2} = (not\,accept, accept)$, type α_L obtains $(\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = 0) = \frac{\theta^2}{9}$ in R&D competition, while, it it deviates, in RJV regime $\mu = 1$ and type α_L's profit will be $(\Pi^D_{2\alpha L}|K_1 = K_{2\alpha L} = K, \mu = 1) = \frac{1}{36}[2\theta + t(2\beta - 1) + 3t\alpha_L]^2 - K$. So, type α_L has incentive to deviate if

$$K < \frac{t(2\beta - 1 + 3\alpha_L)[4\theta + t(2\beta - 1 + 3\alpha_L)]}{36} \equiv \phi$$

According to the parameters' values, the threshold ϕcan be higher or lower than δ and γ, so we analyse three possible cases.

Case 1: $\delta < \gamma < \phi$

In this case, an equilibrium with $\hat{s_1} = RJV$ followed by $\hat{s_2} = (not\,accept, accept)$ does not exist since type α_L has incentive to deviate.

Case 2: $\phi < \delta < \gamma$

In this case, type α_L has no incentive to deviate, so an equilibrium such that the RJV is formed only if $\alpha = \alpha_H$ obtains.

Case 3: $\delta < \phi < \gamma$

The same result as in *Case 1* holds in the interval $[\phi, \gamma]$, while in $[\delta, \phi]$ we have the same result as in *Case 2*.

Summing up the three case, it turns out that an equilibrium with $\hat{s_1} = RJV$ and $\hat{s_2} = (not\,accept, accept)$ may exist only if the parameters' values are such that $\phi < \gamma$, for $max\{\delta, \phi\} < K < \gamma$. Where this equilibrium cannot obtain, the only possible equilibrium entails $\hat{s_1} = nothing$; given $\hat{s_2} = (not\,accept, accept)$ and $\mu = \frac{1}{2}$ after $\hat{s_1} = RJV$ (out of the equilibrium path), firm 1 has no incentive to deviate from $\hat{s_1} = nothing$.

Proof of Lemma 13.

Consider the region of parameters in which $K > \gamma$; here the equilibrium arising when only R&D competition *regime* is feasible is such that no firm invests. Let us start by analyzing possible equilibria with separating strategies of firm 2 at stage 1.

We check first if $\hat{s_2} = (accept, not\,accept)$ after $\hat{s_1} = RJV$ can be part of an equilibrium strategy.

Consider type α_H. If it follows the strategy $\hat{s_2} = (accept, not\,accept)$, in R&D competition it gets $(\Pi_{2\alpha L}|K_1 = K_{2\alpha H} = K, \mu = 1) = \frac{1}{9}[\theta + t(2-\beta) + t(2\beta - 1)]^2 - K$ in the interval $[\gamma, \tau]$ and $(\Pi_{2\alpha L}|K_1 = K_{2\alpha H} = 0, \mu = 1) = \frac{\theta^2}{9}$

for $K > \tau$. In the interval $[\gamma, \tau]$, type α_H has incentive to deviate since $(\Pi_{2\alpha H}|K_1 = K_{2\alpha H} = K, \mu = 1) < (\Pi^D_{2\alpha H}|K_1 = K_{2\alpha H} = K, \mu = 0)$. For $K > \tau$, type α_H will not deviate if

$$\begin{aligned}(\Pi_{2\alpha H}|K_1 &= K_{2\alpha H} = 0, \mu = 1) = \frac{\theta^2}{9} > \\ &\frac{1}{36}[2\theta + 2t(2\beta-1) + t(3-\alpha_L(2\beta-1))]^2 - K = (\Pi^D_{2\alpha H}|K_1 = K_{2\alpha H} = K, \mu = 0)\end{aligned}$$

that is if

$$K > \frac{1}{36}[2t(2\beta-1) + t(3-\alpha_L(2\beta-1))][4\theta + 2t(2\beta-1) + t(3-\alpha_L(2\beta-1))] \equiv \xi$$

Consider now type α_L. If it follows the strategy $\hat{s_2} = (accept, not\, accept)$ it gets $(\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = K, \mu = 0) = \frac{1}{9}[\theta + \alpha_L t(2-\beta) + t(2\beta-1)]^2 - K$. If type α_L deviates, at the investment stage in R&D competition firm 1 will play $K_1 = K$ if $K < \tau$ and $K_1 = 0$ if $K > \tau$, given that $\mu = 1$. We do not take into account the region in which $K < \tau$ since here type α_L deviates, so the equilibrium breaks down. When $K > \tau$, type α_L will not deviate if

$$\begin{aligned}(\Pi_{2\alpha L}|K_1 &= K_{2\alpha L} = K, \mu = 0) = \frac{1}{9}[\theta + \alpha_L t(2-\beta) + t(2\beta-1)]^2 - K > \\ &\frac{\theta^2}{9} = (\Pi^D_{2\alpha L}|K_1 = K_{2\alpha L} = 0\, \mu = 1)\end{aligned}$$

that is if

$$K < \frac{1}{9}[t(2\beta-1) + \alpha_L t(2-\beta))][2\theta + t(2\beta-1) + \alpha_L t(2-\beta))] \equiv \rho$$

Given that $\rho < \xi$, it does not exist a region for $K > \gamma$ in which no type of firm 2 has no incentive to deviate from $\hat{s_2} = (accept, not\, accept)$, that can be ruled out as possible equilibrium strategy after $\hat{s_1} = RJV$.

Let us proceed with the other separating strategy, namely $\hat{s_2} = (not\, accept, accept)$. Following this strategy, type α_H's profit in RJV is $(\Pi_{2\alpha H}|K_1 = K_{2\alpha H} = K, \mu = 1) = \frac{1}{9}[\theta + t(1+\beta)]^2 - K$; if it deviates, in R&D competition, it gets $(\Pi_{2\alpha H}|K_1 = K_{2\alpha H} = 0, \mu = 0) = \frac{\theta^2}{9}$. Hence, type α_H will not deviate if

$$K < \frac{t(1+\beta)[2\theta + t(1+\beta)]}{9} \equiv z$$

Type α_L has no incentive to deviate if $(\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = K, \mu = 0) > (\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = K, \mu = 1)$, that is if

$$K > \frac{t(2\beta - 1 + 3\alpha_L)[4\theta + t(2\beta - 1 + 3\alpha_L)]}{36} \equiv \phi$$

Since ϕ can be higher or lower than γ, according to the parameters' values, we define the region of parameters in which no type has incentive to deviate from $\hat{s_2} = (not\, accept, accept)$ as $max\{\phi, \gamma\} < K < z$. It remains to check is $\hat{s_1} = RJV$ is actually an equilibrium strategy in this interval. Given $\hat{s_2} = (not\, accept, accept)$, firm 1 will not deviate if

$$E(\Pi_1|\hat{s_1} = RJV) = \frac{1}{2}\{\frac{\theta^2}{9}\} + \frac{1}{2}\{\frac{t(1+\beta)[2\theta + t(1+\beta)]}{9}\} >$$
$$\frac{1}{2}\{\frac{\theta^2}{9}\} + \frac{1}{2}\{\frac{\theta^2}{9}\} = E(\Pi_1|\hat{s}_1 = nothing)$$

that is if $K < z$. Therefore, $\hat{s_1} = RJV$ followed by $\hat{s_2} = (not\,accept, accept)$ can be part of an equilibrium for $max\{\phi, \gamma\} < K < z$. With respect to the outcome arising when only RJV *regime* is feasible (no investment at all), this equilibrium is welfare improving since, when $\alpha = \alpha_L$ nothing changes with the possibility to form a RJV, but, $\alpha = \alpha_H$ the efficient firms makes higher profits and the total investment increases. This proves part (i).

Let consider now possible equilibria with pooling strategies of firm 2 at stage 1, starting with $\hat{s_2} = (accept, accept)$. Type α_L has no incentive to deviate if

$$(\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = K, \mu = \frac{1}{2}) = \frac{1}{36}[2\theta + 2t(2\beta-1) + t(3\alpha_L - \alpha(\mu)(2\beta-1))]^2 - K > (\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = K, \mu = 1)$$
$$\frac{\theta^2}{9} = (\Pi_{2\alpha L}|K_1 = K_{2\alpha L} = 0, \mu = \frac{1}{2})$$

that is if

$$K < \frac{[2t(2\beta-1) + t(3\alpha_L - \alpha(\mu)(2\beta-1))]}{36} \cdot \frac{[4\theta + 2t(2\beta-1) + t(3\alpha_L - \alpha(\mu)(2\beta-1))]}{36} \equiv \eta''_{\alpha L}$$

The threshold $\eta''_{\alpha L}$ can be higher or lower than γ, according to the parameters' values.

If $\eta''_{\alpha L} > \gamma$, for $\gamma < K < \eta''_{\alpha L}$, type α_L will not deviate from $\hat{s_2} = (accept, accept)$. Similarly, type α_H does not deviate if

$$K < \frac{[2t(2\beta-1) + t(3 - \alpha(\mu)(2\beta-1))]}{36} \cdot \frac{[4\theta + 2t(2\beta-1) + t(3 - \alpha(\mu)(2\beta-1))]}{36} \equiv \eta''_{\alpha H}$$

Since $\eta''_{\alpha L} < \eta''_{\alpha H}$, for $\gamma < K < \eta''_{\alpha L}$, no type has incentive to deviate from $\hat{s_2} = (accept, accept)$. Given this strategy of firm 2, firm 1 will play $\hat{s_1} = RJV$ since

$$E(\Pi_1|K_1 = K_{2\alpha L} = K_{2\alpha H} = K, \mu = \frac{1}{2}) = \frac{1}{9}[\theta + t(2-\beta) + t\alpha(\mu)(2\beta-1)]^2 - K >$$
$$\frac{\theta^2}{9} = E(\Pi_1|K_1 = K_{2\alpha L} = K_{2\alpha H} = 0, \mu = \frac{1}{2})$$

when

$$K < \frac{[t(2-\beta)+t\alpha(\mu)(2\beta-1)][2\theta+t(2-\beta)+t\alpha(\mu)(2\beta-1)]}{9} = \eta^{'}$$

and $\eta^{'} > \eta^{''}_{\alpha L}$. So, if $\eta^{''}_{\alpha L} > \gamma$, for $\gamma < K < \eta^{''}_{\alpha L}$, and equilibrium with $\hat{s_1} = RJV$ followed by $\hat{s_2} = (accept, accept)$ exists. The RJV is formed whatever the type of firm 2 and leads to a welfare improvement with respect to a situation in which only R&D competition is feasible (where no firm invests) since each firm gets an higher profit and the total investment increases. This proves part (ii).

If $\eta^{''}_{\alpha L} < \gamma$, a pooling equilibrium such that the RJV is formed whatever the type of firm 2 can never exist. In this case, firm 1 plays $\hat{s_1} = nothing$ and the outcome is the same as if only R&D competition is feasible.

All the other possible equilibria for $K > \gamma$ would entail $\hat{s_2} = (not\,accept, not\,accept)$, leading to the same outcome as that arising when there is no possibility to cooperate in R&D. This proves part (iii).

It remains to demonstrate that the separating equilibrium in which the RJV is formed between the two efficient firms and the pooling equilibrium with RJV formation (provided that it exist), *interim Pareto dominate* all the other possible equilibria. The proof is straightforward for the pooling equilibrium, since it does exist because each firm expects higher profits with respect to the profits obtainable in R&D competition, and these latter are equal to those arising from possible equilibria other than the equilibria defined in (i) and (ii). As for the separating equilibrium defined in (i), simply note that

$$(\Pi_{2\alpha L}|\hat{s_1} = RJV, \hat{s_2} = (not\,accept, accept)) = \frac{\theta^2}{9}$$

$$(\Pi_{2\alpha H}|\hat{s_1} = RJV, \hat{s_2} = (not\,accept, accept)) = \frac{[\theta+t(1+\beta)]^2}{9} - K > \frac{\theta^2}{9}$$

$$E(\Pi_1|\hat{s_1} = RJV, \hat{s_2} = (not\,accept, accept)) = \frac{1}{2}\{\frac{\theta^2}{9}\} + \frac{1}{2}\{\frac{[\theta+t(1+\beta)]^2}{9} - K\} > \frac{\theta^2}{9}$$

where the r.h.s represents the payoffs delivered by any equilibrium different from those defined in (i) and (ii). This complete the proof of part (iv)■.

Chapter 4

Immigration, Population Diversity and Innovation of Italian regions[1]

Introduction

At the turn of the century, 4.6% of world population was born in a different country from the one where it currently lived. In the OECD countries this share rises to 8.9%. 31.4 million of immigrants were living in the U.S.; 7.8 million in Germany; 5.6 million in France; 5.3 million in Canada; 2 million in Italy. Several non-OECD countries also had very large foreign-born populations. 11 million live in Russia; 6 million in India; 1.8 million in Israel. In relative terms, high shares of immigrants were recorded in several OECD countries in 2000 (in Luxembourg 37% of the population was foreign-born; in Australia 27%), but also among non-OECD countries (Singapore: 23%, Estonia: 22%, Belize: 21%, and Latvia: 21%).

Owing to the size of the phenomenon, immigration has been recently at the centre of the political and economic debate. Economists have studied extensively the potential impact of immigration on a variety of economic and social indicators of host countries, such as natives' wages (Borjas 2003; 2005, Ottaviano and Peri 2012) and employment opportunities (Pischke and Velling 1997, Card 2001; 2005), firm productivity [Peri(2012)], trade creation (Gould 1994, Rauch and Trinidade 2002, Peri and Requena-Silvente 2010) and crime [Bell et al.(2010)Bell, Machin, and Fasani, Bianchi et al.(2012)Bianchi, Buonanno, and Pinotti], just to take a few examples. Until very recently the effect of immigration on innovation and technical change was instead much less studied. Yet innovation is surely one of the key factors for a country's economic growth (Romer 1990, Aghion and Howitt 1992, Acemoglu 2002, Jones 2002).

Although new evidence is progressively accumulating, it remains nonetheless mostly limited to the impact of *skilled immigration* in the U.S. In recent work [Hunt and Gauthier-Loiselle(2010)] and [Stuen et al.(2012)Stuen, Mobarak, and Maskus], for instance, focus on skilled immigration —immigrant college population and doctoral students respectively— and find positive effects on U.S. innovation, measured by the count of patents or publications, and the citations they received.[2] Evidence that immigration may drive the direction of technological change is provided

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[2] Other studies for the U.S. obtain similar findings. [Chellaraj et al.(2008)Chellaraj, Maskus, and Mattoo] find a positive effect of foreign students on patent applications using time-series data. [Hunt(2011)] finds that immigrants who entered the U.S. with certain types of visas —related to training, study, and temporary work— patent more innovation than natives. [Kerr and Lincoln(2010)] exploit the 1990 Immigration act and show that the increase in patenting from Chinese and Indian immigrants is positively correlated with H-1B type visas ('specialty occupations' requiring at least a bachelor's degree).

for the U.S. by [Lewis(2011)] who shows that plants in areas rich in immigrants adopted during the 80s and the 90s significantly less machinery, because of the relative abundance of less-skilled labour force. Consistent evidence is also reported for the same country by [Peri(2012)].

A related stream of literature expressely focuses on a specific aspect of immigration, the greater *cultural diversity* that it produces in the population. [Ottaviano and Peri(2006)] do not expressely focus on innovation, but on wages and rents; however, from the positive effect of immigrants' diversity on both variables they infer a positive effect on productivity of U.S. cities. A more direct focus of cultural diversity on innovation is provided by [Niebuhr(2009)] who analyzes German regions. She reports significant positive effects of cultural diversity in both total and high-skilled immigrants working in R&D — hence, the focus is again on skilled immigration — on patents percapita using instrumental variables (IVs, hereafter), but not including region fixed effects. Except for the U.S. and Germany, published work for other countries is almost non-existent.

In this paper we make an attempt to contribute to this important stream of literature. In addition to providing evidence for a country which was exposed to a very fast and large wave of immigrations during the 2000s —Italy (see section 4)—, we also use a very small geographical scale of analysis —Italian provinces corresponding to NUTS-3 regions — , which presumably enables us to better control for differences in institutional and socio-economic factors which are difficult to observe but which may simultaneously contribute to both attracting new immigrants and increase the innovation potential of a region. Moreover, unlike most papers in the literature which only considered the effect of skilled immigration, (i) we first focus on the general impact of immigration, and then (ii) separately look at the effects of low-educated and high-educated immigrants on innovation.

The structure of the paper is as follows. Section 4 sets the conceptual framework for our analysis. The existing work on the effect of immigration on innovation is surveyed in Section 4. Section 4 describes the Italian context and the main features of Italy's immigration, and Section 4 the data used in the empirical analysis. The main results on the effect of immigration on patents' applications are included in Sections 4 and 4, reporting OLS and IVs estimates, respectively. Section 4 extends the analysis by separately considering the differential effects of low-educated and high-educated immigrants. The last section summarizes our main findings, and concludes.

4.1 Immigration and innovation: Theory and empirics

4.1.1 Theory and conceptual framework

There are several reasons why immigration may have an effect on innovation. Immigration entails an inflow of foreign population into a region, and produces changes (i) in the size of the population; (ii) in the average skill level of the population; (iii) in the age structure of the population, as immigrants tend to be of working age. The direction of the first two changes is unknown *apriori*, as new immigrants could increase the size of the population or decrease it in case natives abandon a region owing to the high concentration of immigrants, the so-called 'native flight' (on this specific point see Card and DiNardo 2000). The change in the average skill level in the population depends instead on the average levels of human capital of immigrants compared to that of natives. Both population and human capital are powerful predictors of innovation. Population is likely to spur innovation through the advantages produced by the agglomeration of economic activities [Becker et al.(1999)Becker, Glaeser, and Murphy, Glaeser(1999)] and market size [Acemoglu and Linn(2004)]. Human capital is considered theoretically [Romer(1990)] and found empirically

(Faggian and McCann 2009, Andersson et al. 2009, Zinovyeva and Cowan 2012) an important input into the production of new ideas, and therefore innovation. Thus, population's size and average skill level are key *mediating factors* for the effect of immigration on innovation. The same can be said for the age structure of the population, from which we expect younger individuals to be more creative and innovative[3]. Since changes in these mediating variables due to immigrants' inflow are almost 'mechanical', i.e. they do not require economic agents (individuals, firms) to change their behavior, we expect their effect to be relevant also in the short and medium run.

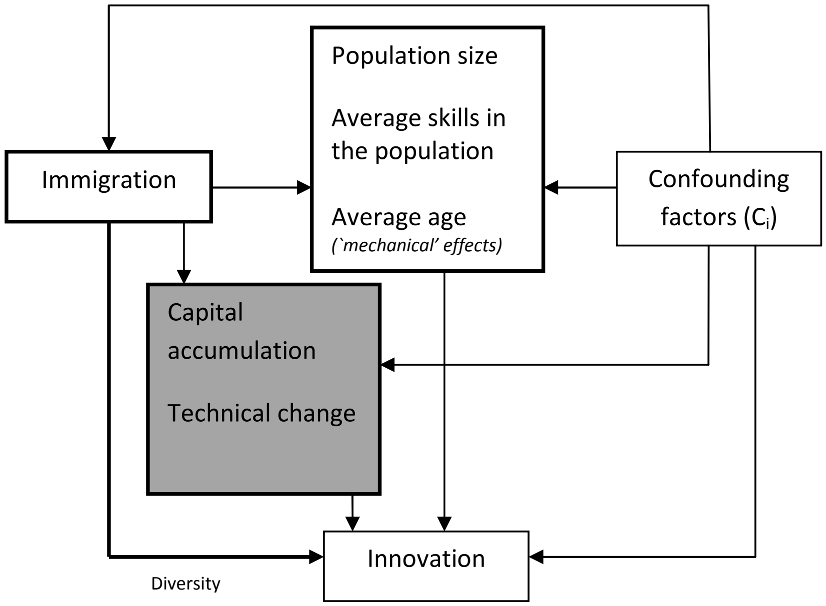
One aspect of immigration on which most of previous articles have focused is the fact that it produces a more culturally diverse population. Individuals coming from different countries usually have different, complementary skills with respect to natives, and the production of new ideas may be positively influenced by contacts and interchanges between culturally diverse individuals [Jacobs(1969)]. Moreover, a more 'diverse' cultural environment may attract more creative individuals [Florida(2002)]. Diversity is not necessarily an advantage though. Cultural diversity could also entail difficulties in communication, especially when immigrants and natives do not share the same language (as it is likely to be the case for low skill immigrants in Italy), reduce social capital, and act as an obstacle to innovation and growth [Alesina and La Ferrara(2005)]. Positive effects on innovation are expected mainly by diversity in the skilled population, and many studies have focused accordigly on skilled immigration only (see section 4).

However, there are other mechanisms through which one may expect negative effects of immigration on innovation. A large inflow of low-skilled immigration within a region may affect firms' choices concerning technology adoption and investments in physical capital. [Lewis(2011)] focus on U.S. metro areas, and finds 'that plants added technlogy more slowly between 1988 and 1993 where immigration induced the ratio of high school dropouts to graduates to grown more quickly' (p. 1031). [Lewis(2011)] also finds that the increases in the relative supply of low-skill workers are associated with slower growth in capital-labor and capital-output ratios. On the grounds of this recent evidence, we will not focus on skilled immigration only, but we will consider in our study both the effect of overall immigration, and the separate effects of skilled and unskilled immigrants. This work is likely to operate especially in the medium and long run, as it is related to technological change and physical capital accumulation.

Hence, when considering the causal effect of immigration on innovation there are many potential pathways to be considered, some of which have opposite effects. The conceptual framework which will represent the starting point for our analysis is depicted in Figure 4.1. As we already pointed out, immigrants have an indirect effect on innovation through various mediating factors. These factors have been distinguished in two groups. 'Mechanical' factors are collected in the white box, while factors which requires economic agents to change their behavior in the grey box. Immigration also has a direct effect on innovation through cultural diversity. A first complication with this framework is that the variables in the two boxes of Figure 4.1 may also be affected by *confounding factors*. This happens if they depend on a 'third variable' which is also a determinant of immigration. An immediate consequence for the analysis is that although a common modelling approach to assessing the causal effect of immigration on innovation would be to omit *mediating factors* (i.e. post-treatment variables), this may generate an omitted variables bias in case they also are confounding factors. Just to take an example, immigrants may settle in large cities as they offer better employment opportunities, but these cities also benefit from agglomeration economies (the 'third variable'), which have in turn a positive impact on innovation. Omitting population from the analysis may then generate a spurious correlation between immigration and innovation, which is only driven by 'agglomeration economies'. Another example may be represented by positive shocks to the demand of low-skilled workers, which both change the product mix of a region, driving it towards more labour-intensive production processes, and the stock of low skilled workers in the region

[3] In fact, studies on the effect of population ageing on innovation are almost non-existent, while there is some evidence that older populations are less productive [Lindh and Malmberg(1999), Feyrer(2008)].

Figure 4.1: Conceptual framework: Effect of immigrants on innovation



through immigrants' inflow [Lewis(2011)].

In what follows we write down the conceptual framework in a more formal way. Let us define the primary equation of interest, the determinants of innovation (y_{it}):

$$y_{it} = \beta_0 + \beta_1 imm_{it} + \beta_2 x_{it} + \beta_3 pop_{it} + u_{it}^{y} \tag{4.1}$$

where i and t are region and time subscripts, imm_{it} the share of immigrants on the population, x_{it} a vector of exogenous variables, pop_{it} population and u_{it}^{y} an error term. The share of immigrants is modelled as

$$imm_{it} = \lambda_0 + \lambda_1 x_{it} + \lambda_2 z_{it} + \lambda_3 c_{it} + u_{it}^{imm} \tag{4.2}$$

where z_{it} is a variable which enters the immigrants' share equation only ('excluded instrument'), c_{it} is another determinant of immigration, and u_{it}^{imm} an error term. If u_{it}^{y} and u_{it}^{imm} are correlated, then the share of immigrants is endogenous with respect to innovation. Let us now model population as a linear function

$$pop_{it} = \alpha_0 + \alpha_1 imm_{it} + \alpha_2 x_{it} + \alpha_3 c_{it} + u_{it}^{pop} \tag{4.3}$$

where u_{it}^{pop} is an error term. Pop_{it} is defined a *mediating factor* for imm_{it} if $\alpha_1 \neq 0$ and $\beta_3 \neq 0$. Pop_{it} is defined a *confounding factor* for imm_{it} if $\lambda_3 \neq 0$, $\alpha_3 \neq 0$, $\beta_1 \neq 0$ and $\beta_3 \neq 0$. This means that if pop_{it} is omitted from equation (4.1), its effect will be captured by imm_{it}. What are the modelling alternatives for the researcher? First, if pop_{it} is a mediating factor for imm_{it}, it is as endogenous as the latter variable is. Thus, in case mediating variables are included in the regression, they must be treated as endogenous variables, e.g., instrumented if the researcher uses an IVs strategy. Moreover, if all mediating factors are included, the researcher will estimate only the *direct effects* (e.g., 'diversity' in our conceptual framework) and not the *gross effect* of the independent variable ('treatment') of interest. Since it is difficult to find suitable instruments for all endogenous variables, the researcher may be tempted to omit the mediating factors and focus on the gross effect ('gross-effect' approach), which allows her to focus only on the endogeneity of imm_{it}. As in this case the 'third variable' c_{it}, which makes pop_{it} a confounding factor, enter the error term of equation (4.1) instrumental variables will produce consistent estimates only if the excluded instrument z_{it} and the confounding factor c_{it} are not correlated. In any case, also in this best case scenario, using the 'gross-effect' approach the effects of imm_{it} and pop_{it} cannot be separately identified.

As we do not have instruments for all potential mediating factors (e.g., population, average skill level in the population, working age population) we focus on a slight modification of the 'gross-effect approach'. Although we do not include in the primary equation contemporaneous or one-period lagged potential mediating factors, we do include the value of these factors in a pre-estimation period (2001). The rationale for doing this is to try to control for time-invariant or very time-persistent confouding factors, avoiding at the same time to include variables which are likely to be affected by immigration during the estimation period. This also has the advantage of making the excluded instruments we use for immigration more credible. Indeed, we will use to build instruments for our main independent variables of interest (immigrants' share and diversity) a shift and share approach which is based on the distribution of immigrants by nationality across provinces in 1995 and the idea of immigrant *enclaves* (see section 4). The main concern with this instrument is that also in 1995 immigrants (of all nationalities) may have located in more populated provinces, and since population is quite persistent overtime the instrument may be correlated with the error term in the innovation equation —if population is an important determinant of innovation— violating the instrument's exogeneity assumption. As we will see in the following section, in which we report a brief summary of the past literature, our approach partly differs from the one adopted by most researchers who have included potential mediating factors (e.g., population, human capital levels) in the estimation equation but treating them as exogenous variables.[4]

4.1.2 Past empirical evidence

The link between immigration, cultural diversity and economic performance has attracted considerable attention over the past decade. Most of the works in this field of research focused on the role of high skilled immigrants, defined in many ways. The impact of immigrants as a whole on host country's economic activity has been investigated only in [Ottaviano and Peri(2006)] and [Prarolo et al.(2009)Prarolo, Bellini, Ottaviano, and Pinelli]. However, these works are not focused on innovation but, more generally, on potential beneficial effects of a culturally diverse population on productivity. The analysis of [Ottaviano and Peri(2006)] aims to assess how diversity of American cities affects productivity, through its effect on natives wages and rental prices. Diversity is proxied by the 'fractionalization index'[5], initially computed for the whole population and then splitted in its two components: the share of immigrants and the index computed only for immigrants. The authors use a panel of U.S. metropolitan areas (MSA) for the years 1970 and 1990 and handle potential endogeneity of the share of immigrants with the 'shift and share' methodology: they construct their main instrument building on the fact that foreigners tend to settle in 'enclaves' where other people from their country already live. They use the share of residents in a MSA in 1970 for each country of birth and attribute to

[4]In the estimated innovation equation, [Hunt and Gauthier-Loiselle(2010)] consider for the population variable only its value at the beginning of the time period spanned by the analysis, but insert a contemporaneous variable for the average age of working age population. Measures of population size, composition of the working age population and human capital are included in the regression as contemporaneous variables in [Ozgen et al.(2012)Ozgen, Nijkamp, and Poot] and [Niebuhr(2009)]. However, none of these works took into account the possible endogeneity of these mediating factors.

[5]The 'fractionalization index' is also called 'diversity index' and is computed as the complement to one of a HH concentration index calculated on the shares of immigrants from different countries of birth. In the paper, we use indifferently one of the two terms to indicate the same index.

each group the growth rate of that group within the whole U.S. population in 1970-1990 time period. They compute the predicted composition of the city based on its 1970 composition attributing to each group the average growth rate of its share in the U.S. population. The predicted number of immigrants is then used to construct the instrument, that is the predicted diversity index. An additional instrument used in IV regression is the distance from the main gateways into U.S. The results show a positive effect of diversity on wages and rents, though the effect is mainly driven by the share of immigrants as a whole rather than diversity; IV regression allows to establish a causal relation between the presence of immigrants and productivity. [Prarolo et al.(2009)Prarolo, Bellini, Ottaviano, and Pinelli] find similar results for European regions (NUTS-3) from 12 countries of the EU15. Using a similar empirical framework, [Suedekum et al.(2009)Suedekum, Wolf, and Blien] estimate the effect of diversity on natives' wages and employment in a panel of German regions (NUTS-3) during the period 1995-2006, but, differently from the above works, they try also to separate the effect of low skilled immigrants from that of high skilled immigrants (defined as those who have completed tertiary education). They use region and year fixed effects and address the endogeneity problem using second order time lags in addition to other instruments (fertility of regional foreign population, regional vote share of Green party and historical regional employment shares of classic guest workers industries, included in separate regressions). Their results highlight a negative effect of the share of immigrants and a positive effect of diversity on wages and employment, when all foreigners from a given country are considered as an homogeneous group. The analysis by skill level shows the two groups of immigrants affect productivity in an opposite way: the authors observe significant positive effects only when migrants are high skilled, while the effect of the share of low skilled immigrants is negative and drives the effect of total immigration.

When object of interest are the consequences of the changes in the 'ethnic' composition of population or labor force on innovation, mainly proxied by the number of patents applications, most of the existing studies focus only on high skill immigration, and basically refer to the U.S. context. In particular, U.S. based analyses do not take into account diversity as a potential driver of innovation (with the exception of [Stuen et al.(2012)Stuen, Mobarak, and Maskus]); they are more interested in the 'skill content' of immigrants. [Chellaraj et al.(2008)Chellaraj, Maskus, and Mattoo], using U.S. annual data for the period 1965-2001 (with regressors lagged 5-7 years), find a positive effect of skilled immigration and foreign graduate students on patents applications and grants. The share of skilled immigrants results to be beneficial for U.S. invention also in the work of [Hunt and Gauthier-Loiselle(2010)]; they use U.S. state panel data for the period 1940-2000 (Census decennial data) and consider 10 to 50 years differences to account for short-run and long-run effects. They apply the same methodology as [Ottaviano and Peri(2006)] (shift and share) to create an instrument for the share of immigrants; the IV estimate of the effect of the share of high skilled immigrants turns out to be larger than the OLS coefficient. [Kerr and Lincoln(2010)] analyze how the change in H-1B worker population influences ethnic patenting in U.S. cities during the period 1995-2008. They divide inventors in four groups according to their names and run separate regressions; according to their estimates, total invention increases with higher admissions of high skilled immigrants primarily through the direct contribution of Chinese and Indian inventors. The effect on native patenting is limited, but there is no evidence of displacement effects. [Moser et al.(2011)Moser, Voena, and Waldinger] finds a positive effect of German jewish *émigrés* on U.S. patenting during the period 1920-1970; changes in patenting are examined at the level of research fields, rather than locations. Pre-1933 research fields of dismissed scientists are used as instruments for the fields of U.S. émigrés; as in [Hunt and Gauthier-Loiselle(2010)], IV estimates are larger than OLS estimates. [Stuen et al.(2012)Stuen, Mobarak, and Maskus], analyzing American Science&Engineering departments from 1973 to 1998, try to identify the contribution of natives and foreign doctoral students to academic innovation, measured by publications and citations. The effect of foreign students on innovation turns out to be positive and significant, though not significantly different from that of natives. Using economic and policy shocks in the students' origin countries to instrument foreign enrollments the authors find that OLS underestimate the impact of foreign doctoral students, but again this effect is not statistically different with respect to natives. Also, they incorporate in the regression the 'fractionalization index' computed on regional shares to capture the degree of diversity in international doctoral students enrollments. OLS regression shows that diversity has a positive and significant effect on both publications and citations, but the index becomes no more significant with instrumental variables. Overall, it seems that the beneficial effect of foreigners on innovation comes from their provision of highly skilled work, not from cultural diversity *per se*.

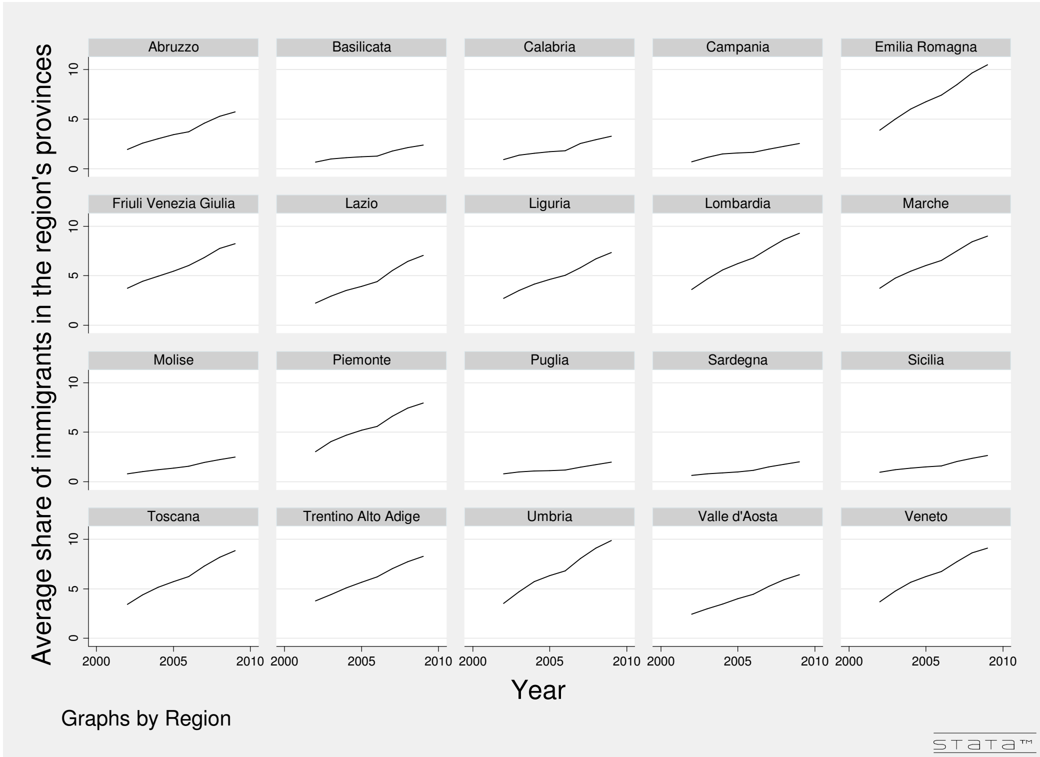
Recently, similar studies have been developed also in the EU context[6]. [Bosetti et al.(2012)Bosetti, Cattaneo, and Verdolini] estimate a positive effect of the share of immigrants employed in top skilled occupations on patenting and scientific publications[7]. The shift-share procedure is exploited to create the predicted share of immigrants, which is the instrument for the main regressor in IV estimation. An index measuring the tightness of national policy towards immigrations is used as additional instrument. Units of observations are 19 EU countries and the time period spans from 1997 to 2007. Other studies put particular interest on diversity as a potential determinant of innovation. [Ozgen et al.(2012)Ozgen, Nijkamp, and Poot] does not focus only on high skilled immigration and considers, in separate regression, the effect of the whole share of migrants and of population diversity (proxied by the fractionalization index) on innovativeness of EU regions, measured by patents applications. Further, he tries to separate the effect of low skilled migrants from that of high skilled migrants. Due to the lack of information about immigrants' skill levels, he groups migrants on the basis of the average skill level of the 'global region' from which the are from (Africa, Asia, America, Europe and Oceania). The panel is composed of EU NUTS-2 regions; the variables are average values over two five-year periods (1991-95 and 2001-2005). The number of McDonald's per million of inhabitants, a dummy for presence of capital cities and the total area represent the instruments to handle the endogeneity of the share of immigrants (diversity index is not treated as endogenous regressor). Pooled OLS and IV estimations find the share of total immigrant not significant, while the effect of population diversity turns out to be positive but non-linear. As for analysis by skill level, a higher share of skilled immigrants seems to be beneficial for innovation. The work of [Niebuhr(2009)] considers only German regions, but using smaller units of observation (NUTS-3), and aims to establish a causal relationship between the diversity of the labor force and patents applications for the years 1997 and 1999. Again, the focus is on high skilled foreign workers; only R&D employees and high skilled R&D employees are included in the computation of diversity index. Three different indexes are (separately) used to take into account diversity: the standard 'fractionalization index', the Theil index and the Krugman index. Lagged cultural diversity of low skilled workers in neighbouring regions and, as alternative, the lagged shares of foreigners in low skilled employment constitute the instruments for diversity indexes in IV regressions. OLS and IV estimations show a positive effect of diversity on patenting though this effect is no more significant once fixed effects are included in the regression.

From the review of the literature on the relation between migration and innovation, it does emerge that not only our work is the first one analysing the Italian case, but also that none of the previous papers involves at the same time very small geographical units of analysis (NUTS-3), the use of patents' data to proxy innovation, the analysis of the separate effects of low skilled and high skilled immigrants, and an attempt to address the endogeneity of immigration using a shift and share methodology to build instruments for both the share of migrants and the diversity index.

[6] As for the European context, most of the studies in this field of the literature are conducted at firm level and are based on surveys data, basically CIS data (Ozgen 2011, Parrotta et al. 2011, Brunow and Blien 2011, Simonen and McCann 2008, Lee Neil 2010). [Nathan(2011)] analyzes the effect of diversity of inventor communities on individual patenting (panel of UK-resident inventor's patenting activities between 1993 and 2004).

[7] The number of citations is used in some specifications to account for patents' 'quality'.

Figure 4.2: Italy: Foreigners on total residents (percentage values) by regions



Source: our data.

4.2 The country context[8]

Italy has been exposed to a very fast and large wave of immigration during the 2000s, as many other European countries. The share of foreigners on Italian population grew from 2.7% in 2003 to 5% in 2007, though significant growth rates have been registered in Northern and Central Italian regions, while in the South the share of immigrants did not show relevant changes (Figure 4). At the beginning of 2007, foreigners accounted for 6.8% of population in Northern-Central regions, while they represented 1.6% of residents in South Italy. In fact, immigrant population results to be unevenly distributed across Italian territory; not surprisingly, foreign people moving to Italy tend to settle in the richer regions and in big cities, that offer better opportunity of employment; 86.9% of immigrants are concentrated in Northern and Central Italy, 23.2% live in Lombardy, 11.8% in Lazio, 19.2% just in the provinces of Milan and Rome. Nowadays foreigners are roughly 7% of total Italian population; in some areas in the Center and the North of the country they exceed the level of 10% [9].

Figure 4 shows a map of Italy where provinces are colored according to the share of foreign-born population in the total population, with ‘darker’ provinces hosting a higher share of immigrants. The map of Italy also reveals some spatial clustering of immigrants: provinces richer in immigrants are more likely to be close to each other.

Foreigners turn out to be an important resource for the Italian economic system. In 2008 immigrants accounted for 12.1% of GDP formation; also, they are relatively young (32.6% of foreign employees is aged between 25 and

[8] The main source of the information provided in this section is ’Rapporto annuale sull’economia dell’immigrazione - Edizione 2011’, il Mulino.

[9] The percentage of foreigners on resident population is 12.9% in Brescia, 12.7% in Prato, 12.5% in Piacenza.

34, whereas for Italian employees the percentage is 20.9%) and represent 6.5% of entrepreneurs. However, the big majority of them tend to take manual-intensive and routine-type occupations (e.g. in construction, agriculture and personal-household sectors). One third of low skilled labor force is composed by immigrants (the share in high skilled workforce is 1.9%); 37.7% of foreign workers are employed in low skilled jobs (this percentage is 7.1% for Italian workers), 89.9% are blue collars. This is mainly due to low schooling levels that characterize most of foreign population in Italy, which fails to attract high skilled workers and students[10] Apart from the fact that immigrants in Italy are prevalently low skilled, the Italian context is peculiar also in another respect: also high educated immigrants often takes low skilled job. It has been shown that, given similar characteristics (in terms of sex, age, education and experience), foreigners are three times more likely to fill low skilled positions. For low skilled jobs, firms seem to prefer immigrants: even if foreigners are 9% of the total workforce, they are more than 80% of agricultural workers, and represent 40% of workers in low skilled personal services and 18% of workers in the construction sector. This phenomenon has been called *'Job Ethnicization'*.

The described situation is reflected on wages: immigrants' wages are 23% lower than Italians' and, differently from Italian employees, there seems to be no correlation between wage and the education level of foreign employees. To put it in other words immigrants are affected by substantial over-education.

So, it emerges that the characteristics of immigration in Italy are such that immigrants mainly appear as a source of low-skilled or cheap labour force, which is employed in traditional (i.e. low value added) economic sectors. As we will see later, this fact is very likely to be reflected on the role that immigration plays for Italy's innovation.

4.3 Data

Our dataset contains information on demographic and economic indicators for 103 Italian provinces (NUTS-3 level) and covers the time period 2002-2008[11]. The main sources of data used in this study are ISTAT (Italian National Statistical Institute) and EUROSTAT. All data (except those regarding R&D intensity) are taken at NUTS-3 level of aggregation. During the period covered by our dataset the number of Italian provinces has changed: the data are recorded according to 103 provinces before 2006 and to 107 provinces thereafter in the source databases[12]. So, data from 2006 onward have been manipulated in order to have 103 units of observation for the whole time period considered in our analysis. More precisely, the values referring to the four new provinces have been imputed to the provinces from which they 'exited' (so, for example, data post-2006 of Carbonia and Medio Campidano have been assigned to Cagliari).

As a proxy for innovative performance of Italian provinces we use the number of patents applications to European Patents Office (EPO)[13]. These data are available in EUROSTAT database-regional science&technology statistics for the time period 2002-2009 at the NUTS-3 level of aggregation. However, available data for the year 2009 display a

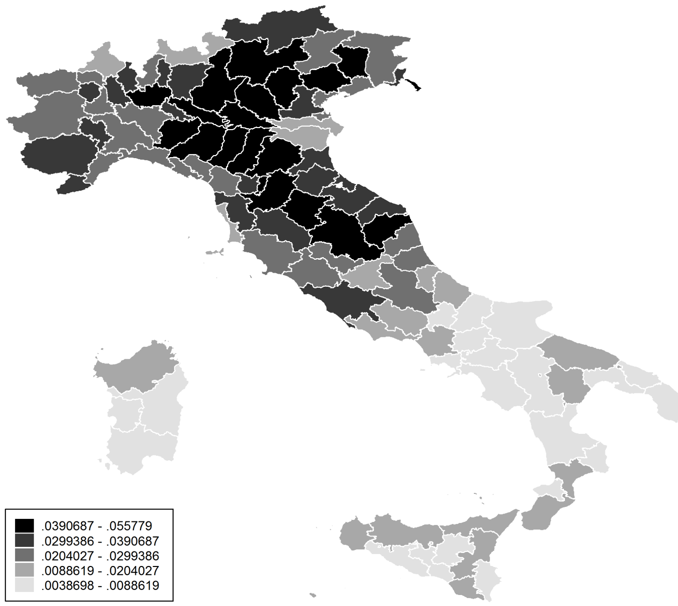
[10]Consider that the top five countries by the number of immigrants in 2009 were Romania, Albania, Morocco, China and Ukraine, accounting for about 50 percent of the total foreign-born population. According to Docquier-Markouf database (http://perso.uclouvain.be/frederic.docquier/oxlight.htm), the shares of high skilled emigrants (those with completed tertiary education) on total emigrant to Italy in 1991 and 2001 (basically constant across the two periods) were 10% for Romania and Albania, 6% for Morocco and China, 35% for Ukraine.

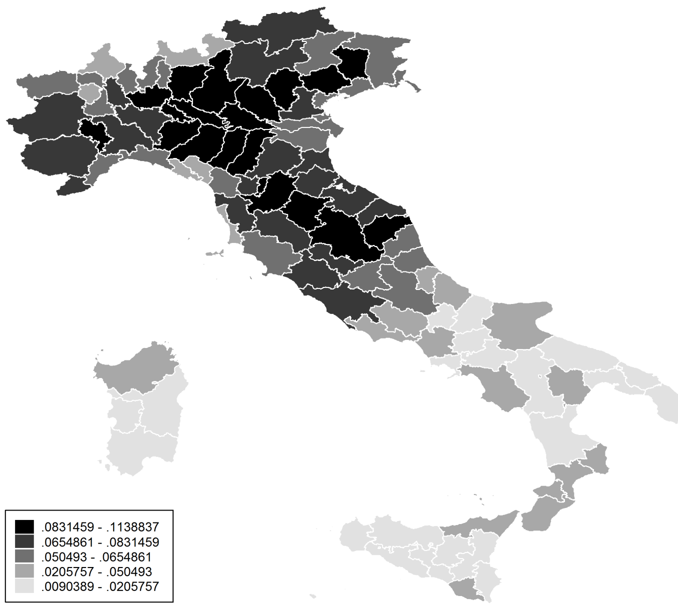
[11]Due to some missing data, we have an unbalanced panel of 607 observations.

[12]The number of Italian provinces changed in recent times. In the mid 1990s the number of Italian provinces was 103. In 2001 the autonomous region of Sardinia established 4 new provinces, that became operative in 2005. In 2004 the Italian Parliament established 3 new provinces that became operative in 2009. The total actual number of provinces is 110. Since our dataset does not include observations for the years after 2009, the latter change does not affect our dataset.

[13]We use this information to build our dependent variable, that is the logarithm of patents' application per 1000 inhabitants.

Figure 4.3: Shares of immigrants in italian provinces, 2003 (Top), and 2008 (Bottom)





Note: Provinces with dark colors correspond to those in higher quintiles of the distribution. From the figure it can be noted that provinces with high (low) shares of immigrants tend to be clustered.

sharp decline with respect to the previous year, suggesting that this data are likely to be still incomplete. This potential problem, given the short time period covered by our dataset, may affect the results in a significant way; for this reason, in our regressions, the observations referring to this year are not taken into account. The EPO data used in this paper refer to all patents applications by priority year. Priority year refers to the first date the patent application was filed anywhere in the world. The OECD recommends using priority year as the closest to the actual timing of innovation. The distribution of patents applications is assigned according to the inventor's province of residence. If one application has more than one inventor, the application is divided equally among all of them and subsequently among their province of residence (fractional count), thus avoiding multiple counting. Using the residence of inventors rather than that of proponents (usually the headquarter) allows not to under-estimate peripherical regions innovation activity [Moreno et al.(2005)Moreno, Paci, and Usai] and makes more likely that innovations, related to the characteristics of the sorrounding territory, are imputed to the regions where they actually have been produced. Although they represent up to now the single best available measure of innovative output, commonly used in empirical research, patent numbers are an imperfect indicator of overall innovative activity. [Griliches(1990)] highlights the limitations of using patents as a proxy of innovation: (i) not all innovations are patented[14], thus patent data is only a partial indicator of innovative activity, (ii) not all patented innovations have the same level of quality[15], and (iii) propensity to patent changes across areas, sectors and time. As an extreme case, patents may even be an obstacle to innovation if they slow down the diffusion of knowledge or pose prohibitive barriers to market entry. International comparisons are also affected by differences in procedures and standards across patenting offices. Despite all the above mentioned limitations, patents continue to be considered the most reliable measure of innovation output. [Moreno et al.(2005)Moreno, Paci, and Usai] argue that applications to EPO account for patents of homogeneously high quality, because applying is difficult, time consuming and expensive, so the related innovations are likely to be potentially highly remunerative. The problem arising from the fact that different sectors have intrinsecally different propensities to patent can be handled by controlling for the industrial structure in regression analysis, as we do. Moreover, there seems to exist a positive relationship between patent counts and other indicators related to innovative performance (OECD Patent Statistics Manual).

Figure 4 gives an idea of the distribution of patents applications across Italian provinces. It is evident that patents applications are not evenly distributed and a clustered pattern emerges: provinces with higher patents applications per 1000 inhabitants are located close to each other. A similar pattern can be found in the distribution of immigrants across provinces (see section 4)[16].

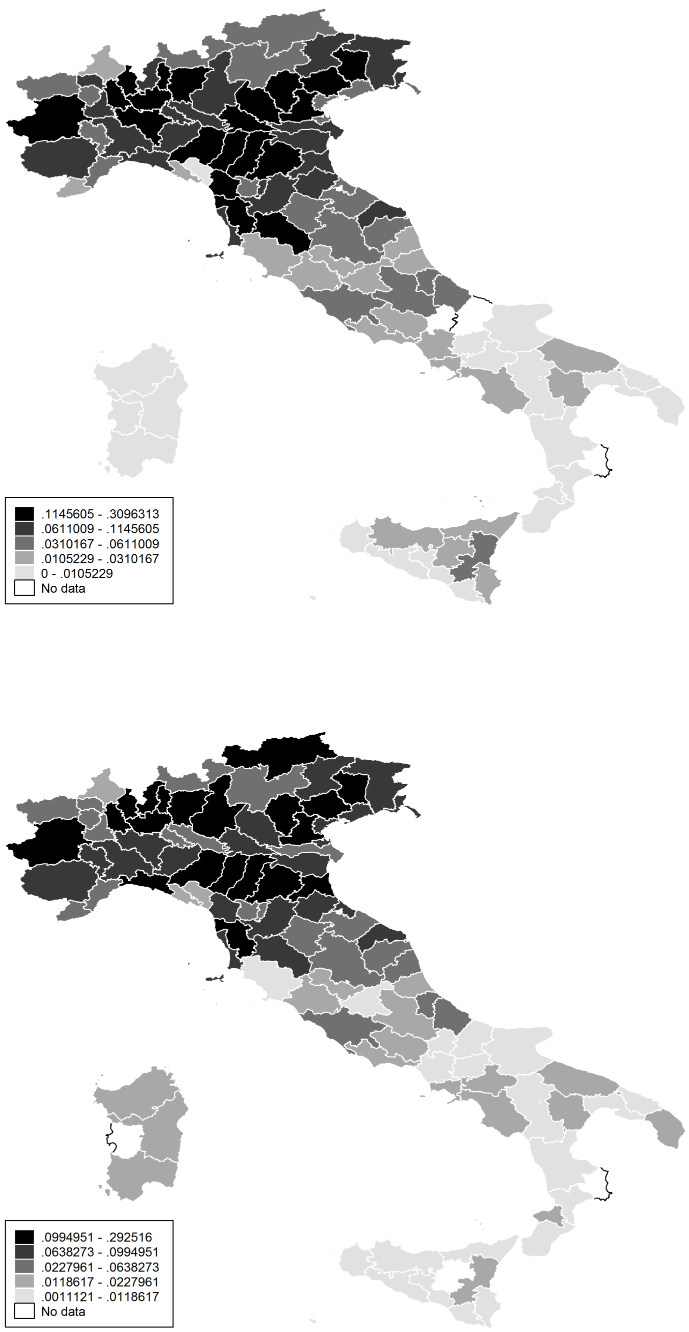
The two variables used in our analysis to assess the impact of immigration on innovation are the share of immigrants on resident population and the 'diversity index', an indicator that accounts for the 'variety' of province population (the construction of the index is described in subsection 4). Immigrants are defined as residents born abroad with a foreign nationality. Data on foreign born residents by province (NUTS-3) are taken from the demographic portal of ISTAT, that contains information on the stock of legal immigrants from 195 country of origin (home-country) resident in each province at 31 of December (data are available for all the years under consideration). Here a clarification is worth to be done. As mentioned before, in analyzing the effects of immigration on innovation, an important aspect is the degree of diversity immigrants bring to the community in which they decide to settle. 'Cultural diversity' is

[14] For example firms often choose to keep secret innovations that are strategic or commercially sensitive, or some innovations are simply non-patentable.

[15] However there are no generally recognised, easily applicable methods for measuring the value of patents. Some authors [Bosetti et al.(2012)Bosetti, Cattaneo, and Verdolini, Stuen et al.(2012)Stuen, Mobarak, and Maskus] used the number of citations to account for patents' 'quality'; in our case, given the short time period covered by our dataset — 6 years — and the (not negligible) time lag between applications and grants, it would not be clear how to use this kind of information.

[16] We will take into account this fact in our analysis by correcting the standard errors through the cluster option.

Figure 4.4: Logarithm of patents per capita in Italian provinces, 2003 (Top) and 2008 (Bottom)



Note: Different colors account for the quintile to which each province belongs; darker colors represent higher quintiles.

what could affect positively (complementarities) or negatively (increased transaction cost) the efficiency of an economic system. Unfortunately, there is no general agreement on the criteria to distinguish 'cultural groups' within the population; language, race, natural origin or other characteristics are alternatively taken into account in related studies[17]. However, [Ottaviano and Peri(2006)] show that, for the U.S., measures of urban diversity based on country-of-birth, language-spoken-at-home, citizenship and race are highly correlated across cities. Given the information in our dataset, we use the country of origin as the indicator of cultural identity used to compute the 'diversity index'. Information on immigrants disaggregated at level of country of birth is also the reference point to construct the instruments for IV estimation, based on the shares of immigrants from 195 countries in each province in 1995; data regarding the distribution of immigrants by country of origin across provinces in 1995 are provided by the Italian Ministry of Interior (foreign residence permits).

To build the time-varying control variables used in the regressions, we relied upon the dataset 'ISTAT-*Sistemi Indicatori Territoriali*' (Systems of Territorial Indicators). We took data on the value added generated by each province divided by sectors (agriculture, services, manufacturing and construction) to construct the shares of valued added accounted by each sectors; this should allow to control for the provinces' industrial structure and so for different propensities to patent across sectors. These variables are included in the regression as contemporaneous variables since the industrial structure might be affected by immigration, but this is likely to happen only in the long run (industry structure is very time persistent); so endogeneity issues are less likely to arise for this variable. Data on value added are available only until 2007; however, since we lagged by one year all the time-varying covariates, this does not represent a problem for our estimates. From ISTAT database are also the data we used to build the time-invariant (2001 values) control variables (resident population, working-age population and number of graduates[18]).

Finally, data on R&D expenditure as percentage of GDP are not available at NUTS-3 level of aggregation; we took the data at NUTS-2 level (corresponding to Italian regions) and assigned to each province the R&D expenditure of the region to which it belongs.

4.4 Empirical strategy and main results

4.4.1 Ordinary least squares

Following the discussion in section 4, we propose the following linear specification of the data generating process of patents' applications,

$$\ln PATN_{ijt} = \alpha_0 + \delta_t + \delta_j + \alpha_1 MIGsh_{it-1} + \alpha_3 \mathbf{X}_{it-1} + \alpha_4 \mathbf{X}_{jt-1} + \alpha_5 \mathbf{D}_{i2001} + \varepsilon_{ijt} \tag{4.4}$$

where i, j and t are province (NUTS-3), region (NUTS-2) and time subscripts, respectively. $\ln PATN_{it}$ are patents' applications per 1000 inhabitants in logarithms; δ_t and δ_j are year and region (NUTS-2) fixed effects; $MIGsh_{it-1}$ is the share of immigrants on the population; $\mathbf{X}_{it-1}$ is a vector of time-varying province characteristics, including the

[17] Also the level of aggregation is often different. For example [Prarolo et al.(2009)Prarolo, Bellini, Ottaviano, and Pinelli] use information about country of birth to aggregate the immigrants in larger groups: EU countries, Africa, America, Asia, Oceania, unknown. [Ozgen et al.(2012)Ozgen, Nijkamp, and Poot] operates a similar aggregation.

[18] The number of graduates is from Census 2001.

provinces' industrial structure (the shares of valued added accounted for by agriculture, construction and services)[19]; $\mathbf{X}_{jt-1}$ includes the R&D intensity on regional GDP (the same variable is not available at NUTS-3 level). $\mathbf{D}_{i2001}$ is a vector of covariates which may represent both mediating and confouding factors, and whose values have been included at a year pre-dating the estimation period (2001): population size, the share of active age population and the college share in the population, as a proxy of human capital. All these latter variables are expected to have a positive effect on innovation. Our data spans the years 2003-2008 (6 years), and has a panel structure. Since for some years information on patents' applications is not available for all provinces, we have a unbalanced panel of 607 observations.[20] All time-variant regressors have been lagged one period to make them predetermined with respect to the dependent variable. ε_{it} is an error term. As in the regression we are including some covariates which are more aggregated with respect to the panel unit of analysis (i.e., $\mathbf{X}_{jt-1}$), the standard errors are clustered at the region by time level [Moulton(1990)].

In analogy with the study of [Ottaviano and Peri(2006)] on the effect of immigrants' diversity on wages and rents, we do not limit our analysis to skilled immigrants only, like most previous literature did, but consider all immigrants irrespective of their educational level. Indeed, although skilled immigration is expected to have a positive impact on innovation (see section 4), this does no exclude that unskilled immigration can have a negative effect by reducing social capital, creating communication problems among workers or pushing firms to lower their efforts to introduce product and process innovations. Firms located in provinces rich in low skilled immigrants might indeed concentrate on the production of traditional (low-value added) goods, using production processes which make a more intense use of unskilled workers. Including all the immigrants, irrespective of their skill level, allows to assess their overall impact on provinces innovativeness.

One thing is worth noting. Because of the short time interval spanned by our data, we preferred not to include in the *benchmark* specification (4.4) province fixed effects. $MIGsh_{it}$ is quite persistent overtime, and the within estimator would use only very limited time variation in this variable.[21] We use a mid-way approach. Indeed, we do not include NUTS-3 fixed effects but we do include NUTS-2 fixed effects. This enables us not only to use time variation but also *cross-sectional variation between provinces within the same region*. Region fixed effects, in turn, enable to catch all potential unobserved differences existing across Italian regions, which are likely to be important especially because of the strong North-South geographical divide. [22] For the same reason, owing to the short time span considered, our estimates only refer to the *short- and medium-run effects of immigrants on innovation*.

As a proxy of the diversity of a province's population we do not only use the immigrants' share, but also the so-called Ethnolinguistic Fractionalization (ELF) index [Mauro(1995)], specifically:

$$POPdiv_{it} = 1 - \sum_{g=1}^{G_{it}} \left(\frac{P_{git}}{P_{it}} \right)^2 \tag{4.5}$$

where g is the subscript for country of origin, G_{it} the total number of countries (including Italy since also natives are considered as ethnic group) present in province i in year t, P_{git} the population of ethnic group g residing in province i at time t and P_{it} the total population of province i at time t. The value of this index is determined both by the 'richness'

[19]The main rationale for including this variable is that a province's patenting capacity is likely to be highly correlated with its industrial structure — as the degree of innovation strongly differs across industries [Klevorick et al.(1995)Klevorick, Levin, Nelson, and Winter] — which is in turn correlated with immigrants' employment opportunities and geographical location.

[20]Out of a 618 (103 provinces multiplied by 6 years) theoretical number of observations.

[21]This problem is stressed, for instance, in [Niebuhr(2009)], who dismisses the results of the fixed effects model because of the very low time variation in her data, and the potential large attenuation bias caused by measurement error.

[22]A similar approach is used, for instance, by [Wagner et al.(2002)Wagner, Head, and Ries] and [Bratti et al.(2012)Bratti, De Benedictis, and Santoni], in their analyses of the effect of immigration on trade. Fixed-effects specifications are instead used by the authors who consider Census data and a long time span (see, for instance, Hunt and Gauthier-Loiselle 2010).

(number of groups) of the local population and by its 'evenness' (similar distribution of individuals across groups), and can be interpreted as the probability that two randomly drawn individuals in the population will not belong to the same ethnic group. Higher values of the index means a more diverse population. As a matter of fact, most of the variation in $POPdiv_{it}$ is driven by the share of immigrants in a province, and a simple OLS regression of the former on the latter returns an R-squared of 0.99[23].

Table 4 reports the OLS estimates. Column (1) shows the specification without control variables. A very significant correlation between the share of immigrants and patents' applications emerges. Rising the share of immigrants by one percent point (p.p.) is associated with a 0.36 percent increase in patents' applications (per 1,000 inhabitants); however, provinces' unobserved factors could be responsible for this correlation. In column (2) we control for year and region fixed effects. The coefficient on the share of immigrants is one third the one in column (1) and the R-squared increases by 0.30, suggesting that a great deal of the variation in patents' applications is accounted for by regional differences and time trends. In column (3) we add two important potential determinants of innovation, R&D intensity on GDP and the province's industrial structure. Inclusion of these further controls has little effect of the coefficient of immigrant share. Column (4) reports our *benchmark* specification, which includes variables which may act as both confounding and mediating factors for the effect of immigration: log population, the share of active age population and the college share in the province. We try to isolate their mediating role by including their values in 2001, i.e. before the estimation period, so as they are not affected by changes in immigrants' shares. All three variables turn out to be key determinants of patents' applications, and more importantly the coefficient on the share of immigrants is greatly reduced in magnitude, changes in sign, falling to -.017, and becomes statistically insignificant. These results suggest that in the previous columns immigrants' share may be picking up the fact that immigrants tend to settle in highly populated provinces, in provinces with higher shares of active age population and college graduates, provinces which are *ex-ante* more innovative. In column (5) we use the population diversity index instead of the share of immigrants, and the results are very similar.

4.4.2 Endogeneity and identification: Two-stage least squares estimation

OLS give consistent estimates only if, conditional on the observables included in the innovation equation, the error term is uncorrelated with the immigrant's share. There may be several reasons why this assumption fails. It may happen, for instance, that shocks to local demand, e.g. an increased foreign demand for a low-skilled good produced in the province, will attract more immigrants locally and also have negative consequences for innovation. Identification of the effect of immigrants requires therefore a presumably exogenous shock in the supply of immigrants at the province level. The shock does not necessarily need to be completely random, but uncorrelated with the innovation capacity of a province.

Here, to build an 'instrument' for the share of immigrants on the population we follow the procedure proposed in [Altonji and Card(1991)], which has been already intensively employed in the empirical literature on immigration (see, for some recent applications, Hunt and Gauthier-Loiselle 2010, Lewis 2011, Peri 2012), and is based on *immigrants' enclaves*. The idea is that immigrants tend to settle where individuals of the same nationality are already located. This may happen for a variety of reasons. For instance, immigrant networks may provide newly arrived individuals

[23] The diversity index computed including natives can be considered as composed by two parts: the share of immigrants on the population and the diversity index computed only on foreigners. In the regressions for wages and rental prices, [Ottaviano and Peri(2006)] consider first the overall index and then separately its components, concluding that the positive effect found for the overall index is mainly driven by the share of immigrants.

with important information on the local labour market and the availability of vacancies, increasing the returns to migration, or providing hospitality thereby reducing the costs of migration. Although $MIGsh_{it}$ relates to the total share of immigrants on the population, separate information by country of origin is provided by the Italian National Statistical Institute (ISTAT). Our instrument has been built as follows. We took the yearly stock of immigrants by nationality in Italy as a whole (M_{gt}) and imputed it to provinces (M_{git}) according to the distribution of nationalities across provinces in 1995 (θ_{i1995}), computed using foreign residence permits data provided by the Italian Ministry of Interior[24]:

$$\widehat{M}_{git} = \theta_{i1995} M_{gt} \tag{4.6}$$

We then aggregated at the province level all immigrants' predicted stocks by nationality ($\widehat{M}_{git}$) across all nationalities present in each province in 1995 (G_{i1995}) to compute the total stock of immigrants of province i at time t, and divided the latter by the predicted total province's population obtaining the instrument, the predicted immigrants' share $\widehat{MIGsh}_{it} = (\sum_{g=1}^{G_{i1995}} \widehat{M}_{git})/\widehat{POP}_{it}$. As we did for immigrants, also the predicted total population $\widehat{POP}_{it}$ was computed apportitioning to provinces the population of each year according to the 1995 provincial distribution.

The same procedure was followed to compute an instrument for population diversity. Indeed the predicted stocks of immigrants by nationality can be used to compute a 'predicted' ELF index[25] [Ottaviano and Peri(2006)]:

$$\widehat{POPdiv}_{it} = 1 - \sum_{g=1}^{G_{i1995}} \left(\frac{\widehat{P}_{git}}{\widehat{P}_{it}} \right)^2 . \tag{4.7}$$

Both instruments are based on two components. The first is the total stock of individuals by nationality in Italy, which should be uncorrelated with single provinces' supply and demand shocks impacting on local innovation. The second component is the distribution of immigrants and of the total population in 1995. We claim that the distribution of immigrants (or the population) in 1995 should be uncorrelated with *unobserved factors* affecting patenting more than 7 years later, conditional on the observables we included in the regressions. The main identifying assumption is that, conditional on the observables, within-region differences[26] in the distribution of immigrants by different nationality in 1995 are approximately random with respect to provinces' future innovation prospects. We posit that the main factors which could be responsible for very persisting differences in innovativeness across provinces are their industrial structure, and the existence of agglomeration economies, both of which have been controlled for in our *benchamark* specification.

Table 4 reports the 2SLS results. In all cases we adopted the *benchmark* specification and clustered the standard errors at the region by time level. In column (1) we use the predicted share of immigrants. The F-test in the first stage is quite high at 181.76, confirming the strength of the excluded instrument (the predicted share of immigrants). The instrument's t-value is 13.48, and the coefficient is 0.38 suggesting that although immigrant *enclaves* contributes to explaining immigrants' location, there are other factors which also affect immigrants' choices of residential location. From the second stage we estimate that a one p.p. increase in a province's immigrant share reduces patents' applications per 1000 inhabitants by 0.06 percent. In column (2), we use the ELF index. The first stage is equally strong with an F-test of 170.56. From the second stage we estimate that a one-standard-deviation (0.047) increase in population diversity reduces patents' applications by 0.16 percent.

The results in this section suggests that, at least for Italy, immigration has overall a negative effect on innovation,

[24] As disaggregated data on residents by foreign nationality is only available for Italian provinces since 2002 through the Italian National Statistical Institute (ISTAT). We focus on 1995's data as in that year there were 103 provinces, while the number of provinces was 95 before.

[25] Predicted natives are computed as the difference between predicted population and predicted total number of immigrants.

[26] Since we control for region fixed effects.

proxied by patents' applications per 1000 inhabitants. This finding is likely to be the result of the characteristics of Italian immigration which, as we outlined in section 4, is prevalently unskilled. As a matter of fact, almost all studies who have found a positive effect of immigration on innovation have focussed on skilled immigration, e.g., immigrants with a university education (Hunt and Gauthier-Loiselle 2010, Stuen et al. 2012) or working in high profile occupations (Kerr and Lincoln 2010, Niebuhr 2009). For this reason, in the following section we try to investigate the separate effects on innovation of high skilled and low skilled immigrants. Our prediction is that the overall negative effect is mostly driven by (i) a negative effect of low educated immigrants on innovation and (ii) the prevalence in Italy of unskilled immigration.

4.4.3 Differences by immigrants' skill levels

The 2SLS results in the previous section suggests that the overall share of immigrants and the 'diversity' they create in the society have a negative impact on Italian provinces' innovativeness. This could seem to be at odds with the existing literature, but we have to keep in mind that we were considering immigrant as whole, while previous works, mostly concordant in finding a positive effect of immigrants on innovation, were restricting the analysis only to a subset of the immigrant population, namely its high skilled component. Actually, our estimate of an overall negative effect may hide more complex dynamics related to the large heterogeneity in immigrants' levels of skill, which can generate different effects working in opposite directions. For this reason, in the current section we try to disantangle the (possibly different) effects on innovation of low skilled and high skilled immigrants. To this aim, we need to split the population of immigrants resident in each province into its high skilled and low skilled component. Unfortunately, our dataset does not contain information that can be used to infer the skill level of immigrants by nationality (such as the level of education or occupation), so we had to rely on external data and some simplifying assumptions. We used the dataset provided by Docquier and Marfoukof[27] which contains detailed information on international migration by educational attainment. This dataset provides the number of emigrants to Italy in 1991 and 2001 from 195 countries, divided in low, medium and high skilled. The authors count as migrants all working-aged (25 and over) foreign-born individuals living in an OECD country; high skilled migrants are those with at least tertiary educational attainment wherever they completed their schooling[28]. We took the data regarding 2001, that have less missing values, to compute for each country of origin the share of medium-high skilled emigrants on total emigrants to Italy[29]. Then, we used two different procedures to assign the skill level to individual immigrants, in order to create the shares of low skilled and high skilled immigrants for each province[30]. The first procedure consists in dividing the immigrants between high skilled and low skilled according to their country of origin, that is, after having classified a given country as source of high or low skilled immigrant, we impute the same skill level to all the immigrants from that country[31]. We define a country as a source of high skilled individuals if its share of medium-high skilled emigrants to Italy is larger

[27] http://perso.uclouvain.be/frederic.docquier/oxlight.htm

[28] Medium and low skilled migrants are those with secondary and primary education respectively. The source of these data can be different according to the country of origin of migrants. Detailed information can be found in the document 'International Migration by Educational Attainment (1990-2000) - Release 1.1' by Frédéric Docquiera and Abdeslam Marfoukb, p.14. http://perso.uclouvain.be/frederic.docquier/oxlight.htm

[29] We refer to the share of medium and high skilled to obtain information about the immigrants that will be defined 'high skilled'; this is justified by the fact that natives' average level of education is the medium one, so, with respect to the Italian case, immigrants whose education level is not lower than medium can be classified among the high skilled workforce.

[30] In the regressions by skill level the diversity index is not taken into account as we have seen in the previous section that most variation in the diversity index is driven by the share of immigrants.

[31] A similar procedure is followed by [Ozgen et al.(2012)Ozgen, Nijkamp, and Poot] which group migrants on the basis of the average skill level of the 'global region' from which they are from (Africa, Asia, America, Europe and Oceania). We consider here a finer classification using individual countries of origin.

than the median value (0.56). With the second procedure, we tried to divide the immigrants by skill level in a more precise way. In this case, the total number of immigrants from a given country is splitted by skill level according to the shares of high-medium skilled and low skilled emigrants on total emigrants from that country to Italy. We run separate regressions to estimate the coefficients of the variables created according to the described procedures, obtaining similar results, which will be discussed below[32]. To build the instrumental variables $\widehat{MIGsh}_{it}$ for the two groups, high skilled and low skilled, we started by the 'predicted number of immigrants' in a province from a given country, obtained using the 'shift and share' method described in section 4. We then applied to the 'predicted number of immigrants' the two procedures described above, in this case using data of 1991 in the Docquier-Marfoukof database, and get the 'predicted high skilled immigrants' by nationality. Summing up this latter for each province across nationalities and dividing by the province's predicted population we obtained the instrument for the share of high skilled immigrants ('predicted share of high skilled immigrants'). In the same way we computed the 'predicted share of low skilled immigrants'.

We estimated the *benchmark* model using the lagged share of low skilled and the lagged share of high skilled immigrants instead of the lagged share of immigrants as a whole. For the sake of completeness we report the results of both OLS and 2SLS estimates; Table 4 displays the regression output for the case in which the variables related to immigrants are computed with the first procedure, while Table 4 refers to the second procedure. OLS estimates of the coefficients of the lagged share of high skilled and low skilled immigrants are not significant, whatever the skill level of immigrants and the procedure adopted to split them is. The sign of the coefficient of the share of low skilled immigrants is always negative, while the sign of the coefficient on the share of high skilled immigrants becomes non-negative (actually very close to zero) when they are computed according to the share of medium-high skilled emigrants from their country of origin to Italy. Given the endogeneity of the variables related to immigrants (see section 4), we also estimate an IV regression. Results from the first stage confirm also in this case the strength of the instruments: the F-tests take value 57.78 for the share of high skilled immigrants and 176.88 for the share of low skilled immigrants, when the the first procedure to split the immigrants is used; as for the other procedure, the corresponding values of the F-tests are 70.63 and 165.81. The excluded instruments are highly significant, with the exception of the predicted share of low skilled immigrants in the first stage regression for the share of high skilled immigrants, when the first procedure is used to divide by skill level (Table 4). In the second stage, the coefficient of the share of low skilled immigrants is negative and significant. In the case in which we use dummy variables to define 'high skilled countries of origin' (Table 4) it is significant at 1% and indicates that an increase of the share of low skilled immigrants of one percent point induces a decrease in patents' application per 1,000 inhabitants of 0.09 percent. In the case in which immigrants from the same country of origin are divided in high skilled and low skilled (Table 4), the coefficient on the share of low skilled immigrants is significant at 5% and double in magnitude: a rise in the share of low skilled immigrants of one p.p. generates a reduction in patents' applications per 1,000 inhabitants of 0.19 percent. The coefficient of the share of high skilled immigrants is positive but not significant in both cases; it could suggest an increase in patents' applications per 1,000 inhabitants in a range between 0.03 and 0.11 percent (according to the method used to divide immigrants between skill levels) following an increase of 1 p.p. in the share of high skilled immigrants, but this effect is not precisely estimated in our sample. These results are consistent with the analysis of [Lewis(2011)] and [Peri(2012)]; they find evidence that a rise in the supply of low skilled workforce caused by large inflows of foreigners hampered investments in physical capital in the U.S. and favored the adoption of labor-intensive production technologies, thus reducing firms' incentives to innovate. The strongly significant negative effect of low skilled immigrants and the fact that the positive impact of high skilled immigrants turns out to be insignificant in our regressions can be explained by

[32] We tried also a finer division of immigrants in three groups (low, medium and high skilled); results do not change significantly, confirming the negative and significant effect of low skilled immigrants on patents' applications.

the particular features of the immigration phenomenon in Italy, characterized by thelarge prevalence of low educated immigrants and underutilization of immgrants' human capital. This point will be furtherly discussed more in the concluding remarks.

Concluding remarks

In this paper, we investigate the effect of the share of immigrants in the population and of the population diversity (enhanced by immigration) on Italian provinces' patent applications, as a proxy for innovation performance. We aim to address the potential endogeneity of these variables by employing a well established procedure in the literature based on immigrants' enclaves, which uses a 'shift and share' approach. Differently from most works in this literature, we do not limit the analysis to the effects of skilled immigration, but we look at the general impact of immigration, and at the separate effects of low-educated and high-educated immigrants on innovation. This choice has been determined by the consideration that, in addition to possible positive effects on the production of new ideas arising from skills' complementarities, the most recent literatures has suggested that there may also be adverse effects on innovation generated by the inflow of foreign population [Lewis(2011)]. Increasing transaction and communication costs, reduction of social capital and the scarce incentive to the adoption of new capital-intensive technologies, owing to the abundance of cheap low-skilled labor force, may all act as obstacles to innovation and growth, in particular when immigrants are characterized by low levels of education and skills. We have shown that this is likely to be the case for Italy, which mostly attract low-skilled immigrants who are employed in traditional sectors. So, excluding the low skilled component of immigration from the analysis would give a very misleading picture of the *overall* effect of immigration on innovation. In fact, our analysis suggests that as far as total immigration is concerned, the positive association between the presence of immigrants and patenting, dominant in the past literature focused on skilled migration, does not emerge in Italian provinces. We find an overall negative effect of the share of immigrants and of population diversity: rising immigrants' share by 1 p.p. produces a 0.064 percent reduction in patents' applications per 1,000 inhabitants. Investigating the separate effects on innovation of high skilled and low skilled immigrants, our results support the hypothesis that the overall negative effect is mostly driven by a negative effect of low educated immigrants on innovation (consistent with the findings of [Lewis(2011)], [Peri(2012)] and [Suedekum et al.(2009)Suedekum, Wolf, and Blien]), and the prevalence in Italy of unskilled immigration. Indeed, the impact of low skilled immigrants turns out to be negative, highly in magnitude and highly significant, while the effect of high skilled immigrants, though positive, cannot be precisely estimated. A one p.p. increase in the share of low-skilled immigrants is estimated to cause a 0.094 to 0.186 reduction in patenting, according to the procedure used to assign immigrants to skill groups. The fact that the positive impact of high skilled immigrants turns out to be positive (0.113) but not significant can be explained by the particular features of immigration phenomenon in Italy. We have seen that on top of Italy's mainly attracting skilled immigrants, even high-skilled immigrants are often employed in traditional sectors and fill low-skilled positions, suffering from substantial overeducation. So, due to their scarce presence and the 'waste' of their human capital the (potentially) positive effect of high skilled immigrants on innovation does not emerge in our country and results to be overshadowed by the negative effect of low skilled foreign population.

Our results point to the importance of immigration policies, given the assessed impact of foreign population on a main driver of economic performance, and the importance of a correct functioning of the labour market in order to grant a good match between immigrants workers' skill levels and the work positions they fill, in order to fully exploit their innovative potential, as other countries seems to do, in Italy. Also, given the short-time spanned by our data, all the effects we estimated should be interpreted as medium-run/short-run effects and this does not exclude that, considering longer periods, additional effects on the economy may emerge, for instance mediated by capital accumulation and technological changes [Lewis(2011)]. This is particularly important because the negative effect of low skilled immigrants on innovation can intensify in the long run, if the economic system adapts its technological choices to the availability of a large share of unskilled workforce. A greater exploitation of the competencies of skilled immigrants and the valorisation of their human capital could help to compensate the discussed short and long run negative effects, by attracting educated immigrants, giving complementary skills the possibility to emerge and shifting firms' decisions towards investment in the production and adoption of innovative technologies.

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Table 4.1: OLS estimates of the effect of immigrants on patents' applications

	(1)	(2)	(3)	*benchmark* (4)	(5)
share of immigrants	0.364***	0.107***	0.093***	-0.017	
	(0.024)	(0.020)	(0.021)	(0.019)	
population diversity (ELF)					-0.933
					(1.020)
RD expenditures (% GDP)[(a)]			1.071***	1.034***	1.033***
			(0.397)	(0.391)	(0.390)
share VA agriculture			-0.119***	-0.032**	-0.032**
			(0.014)	(0.015)	(0.015)
share VA services			-0.021***	-0.064***	-0.064***
			(0.004)	(0.006)	(0.006)
share VA construction			-0.126***	-0.021	-0.021
			(0.028)	(0.025)	(0.025)
log pop 2001				0.277***	0.277***
				(0.051)	(0.051)
active age pop share 2001				0.056**	0.056**
				(0.024)	(0.024)
% of graduates on pop 18-64				0.191***	0.191***
				(0.019)	(0.019)
Year fixed effects	No	Yes	Yes	Yes	Yes
Region (NUTS-2) fixed effects	No	Yes	Yes	Yes	Yes
N. observations	607	607	607	607	607
R-squared	.46	.76	.80	.85	.85

*** significant at 1%; ** significant at 5%; * significant at 10%.

Note. The dependent variable is log patents' applications per 1000 inhabitants at the province (NUTS-3) level for Italy, 2003-2008. When not differently specified all independent variables are lagged one year. Standard errors are clustered at the *region* × *year* level because of the inclusion of an 'aggregated' variable [Moulton(1990)] and robust to heteroskedasticity. Diversity of immigrants is measured using the ELF index [Mauro(1995)].
[(a)] only available at the NUTS-2 level.

Table 4.2: 2SLS estimates of the effect of immigrants on patents' applications

	(1)	(2)
Second stage		
share of immigrants	-0.064**	
	(0.031)	
population diversity (ELF)		-3.457**
		(1.693)
RD expenditures (% GDP)[(a)]	0.944**	0.942**
	(0.378)	(0.378)
share VA agriculture	-0.025*	-0.025*
	(0.014)	(0.014)
share VA services	-0.069***	-0.069***
	(0.007)	(0.007)
share VA constructions	-0.022	-0.022
	(0.025)	(0.025)
log pop 2001	0.316***	0.317***
	(0.050)	(0.050)
active age pop share 2001	0.055**	0.055**
	(0.024)	(0.024)
% of graduates on pop 18-64	0.199***	0.199***
	(0.019)	(0.019)
First stage		
predicted share of immigrants	0.375***	
	(0.028)	
predicted population diversity		0.374***
		(0.029)
F-test excluded instrument	181.76	170.56
N. observations	607	607
R-squared	.37	.37

*** significant at 1%; ** significant at 5%; * significant at 10%.

Note. The dependent variable is log patents' applications per 1000 inhabitants at the province (NUTS-3) level for Italy, 2003-2008. When not differently specified all independent variables are lagged one year. All models include year and region (NUTS-3) fixed effects. Standard errors are clustered at the $region \times year$ level because of the inclusion of an 'aggregated' variable [Moulton(1990)] and robust to heteroskedasticity. Diversity of immigrants is measured using the ELF index [Mauro(1995)].
[(a)] only available at the NUTS-2 level.

Table 4.3: OLS and IV estimates by skill level (1)

	OLS	2SLS 1st stage: high skilled	1st stage: low skilled	2nd stage
share of immigrants: high skilled[(b)]	-0.079			0.025
	(0.055)			(0.102)
share of immigrants: low skilled	-0.001			-0.094***
	(0.023)			(0.036)
RD expenditures (% GDP)[(a)]	0.998**	-0.355	-0.908*	0.988**
	(0.384)	(0.314)	(0.546)	(0.391)
share VA agriculture	-0.027*	0.061***	0.037*	-0.031**
	(0.016)	(0.010)	(0.022)	(0.015)
share VA services	-0.061***	0.013***	-0.081***	-.073***
	(0.007)	(0.005)	(0.011)	(0.008)
share VA construction	-0.015	0.044**	-0.093*	-0.031
	(0.026)	(0.018)	(0.048)	(0.026)
log population (2001)	0.281***	0.099**	0.193**	0.313***
	(0.052)	(0.039)	(0.095)	(0.051)
15-65 population share (2001)	0.058**	0.038***	0.142***	0.052**
	(0.025)	(0.014)	(0.047)	(0.023)
% of graduates on pop 18-64 (2001)	0.194***	0.022	-0.045**	0.195***
	(0.020)	(0.013)	(0.020)	(0.020)
predicted share of immigrants: high skilled[(c)]		0.337***	-0.213***	
		(0.032)	(0.049)	
predicted share of immigrants: low skilled		-0.027	0.528***	
		(0.020)	(0.028)	
Year fixed effects	yes	yes	yes	yes
Region (NUTS-2) fixed effects	yes	yes	yes	yes
F-test (1st stage)		57.78	176.88	
N. obs.	607	607	607	607
R^2	0.846	0.409	0.467	0.364

*** significant at 1%; ** significant at 5%; * significant at 10%.

Note. The dependent variable is log patents' applications per 1000 inhabitants at the province (NUTS-3) level for Italy, 2003-2008. When not differently specified all independent variables are lagged one year. All models include year and region (NUTS-3) fixed effects. Standard errors are clustered at the *region* × *year* level because of the inclusion of an 'aggregated' variable [Moulton(1990)] and robust to heteroskedasticity.

[(a)] only available at the NUTS-2 level.

[(b)] the skill level is assigned to immigrants according to their country of origin: all immigrants from a country with the share of high-medium skilled emigrants on total emigrants to Italy in 2001 (Docquier-Marfoukof database)larger than 0.56 (median value) are considered high skilled.

[(c)] for the construction of the instruments the year of reference is 1991 (Docquier-Marfoukof database).

Table 4.4: OLS and IV estimates by skill level (2)

		2SLS		
	OLS	1st stage: high skilled	1st stage: low skilled	2nd stage
share of immigrants: high skilled[(b)]	0.001			0.113
	(0.083)			(0.154)
share of immigrants: low skilled	-0.029			-0.186**
	(0.053)			(0.091)
RD expenditures (% GDP)[(a)]	1.041***	-0.617*	-0.688	1.010**
	(0.389)	(0.356)	(0.433)	(0.394)
share VA agriculture	-0.033**	0.062***	0.027	-0.033**
	(0.016)	(0.013)	(0.017)	(0.015)
share VA services	-0.064***	-0.017***	-0.049***	-.073***
	(0.007)	(0.006)	(0.008)	(0.007)
share VA construction	0.002	-0.008	-0.053	-0.027
	(0.026)	(0.024)	(0.034)	(0.026)
log population (2001)	0.275***	0.159***	0.105	0.304***
	(0.052)	(0.041)	(0.066)	(0.053)
15-65 population share (2001)	0.056**	0.069***	0.104***	0.053**
	(0.024)	(0.016)	(0.032)	(0.024)
% of graduates on pop 18-64 (2001)	0.190***	-0.016	-0.020	0.190***
	(0.020)	(0.014)	(0.014)	(0.020)
predicted share of immigrants: high skilled[(c)]		0.163***	-0.401***	
		(0.055)	(0.063)	
predicted share of immigrants: low skilled		0.145***	0.742***	
		(0.044)	(0.051)	
Year fixed effects	yes	yes	yes	yes
Region (NUTS-2) fixed effects	yes	yes	yes	yes
F-test (1st stage)		70.63	165.81	
N. obs.	607	607	607	607
R^2	0.846	0.429	0.462	0.368

*** significant at 1%; ** significant at 5%; * significant at 10%.

Note. The dependent variable is log patents' applications per 1000 inhabitants at the province (NUTS-3) level for Italy, 2003-2008. When not differently specified all independent variables are lagged one year. All models include year and region (NUTS-3) fixed effects. Standard errors are clustered at the $region \times year$ level because of the inclusion of an 'aggregated' variable [Moulton(1990)] and robust to heteroskedasticity.

[(a)] only available at the NUTS-2 level.

[(b)] for each province, the total number of immigrants from a given country is splitted by skill level according to the shares of high-medium skilled and low skilled emigrants on total emigrants from that country to Italy in 2001 (Docquier-Marfoukof database).

[(c)] for the construction of the instruments the year of reference is 1991 (Docquier-Marfoukof database).