INCENTIVES FOR INNOVATION: COMPETITION, INNOVATOR'S EFFICIENCY, AND LABOUR MARKET CONDITIONS

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Introduction

Western economies have now entered the digital era. The socio-economical transformations this technological revolution involves are massive. From the fear of job losses due to automation to the optimism of a new industrial revolution giving a new boost to world economy, the opinions on how large and beneficial this process will be are uncountable. For this reason, an economic investigation of the mechanisms and effects that drive and derive from innovation is an important point in the academic agenda. Identifying the way to prompt innovation and its possible impacts on society are fundamental steps in providing a comprehensive analysis of the wide and yet not fully understood phenomenon of technological progress. The identification of the forces that motivate firms' investments in innovative activities is still an open question in the literature: this doctoral research is an attempt in that direction. In a recent article, Pianta [2018] states that "technological change is a disequilibrium process". Therefore, a mainstream approach trying to bring technological progress back to an equilibrium outcome between product and labour markets would not properly fit the scope. In this sense, this thesis might seem a step in the wrong direction. However, although the definition in Pianta [2018] may be convincing from a pure theoretical perspective, yet I believe there are several insights that a mainstream analysis helps draw. First, by studying the equilibrium outcomes of a market, it is possible to understand why innovation becomes necessary, and to what extent the increasing competitive pressure makes technological progress such a valuable option for firms. Second, a mainstream analysis can help comprehend how the labour mar-

ket conditions and the institutions foster and, more generally, affect investments in R&D, and in which way technological progress impacts society. Do market structure and the characteristics of economic agents play a role in picking the winners of the innovation game? This research tries to answer these questions by providing a thorough analysis of the innovative process. In order to do so, I adopt an Industrial Organization perspective, that allows me to focus on the microeconomic aspects of innovation and technological progress. In order to differentiate between the incentives to invest in R&D and the incentives to adopt the new technology, I distinguish a vertically separated inventor from the producers that may decide to adopt the innovation. In this way, I can describe the forces in the production sector that affect the demand and the diffusion of innovative technologies. Also, this framework helps me understand what drives the innovator's incentives to sell its inventions to a particular sector. I believe this approach is useful to investigate some of the stylized facts usually associated to innovation and technological progress.

The nature of innovation

Modern economies are organized around global supply chains. Firms tend to outsource services and strategic inputs to other firms who can exploit regional advantages in terms of labour costs or the access to a fundamental technology (see Shy and Stenbacka [2003], among others). Moreover, in this way firms can specialize in particular sections of the production chain and rationalize costs. In such a context, innovations at the early nodes of the chain affect the industrial relations with firms operating in downstream sectors.

The first problem in carrying out a research on innovation is to define what innovation means, at least in the researcher's mind. A widely adopted definition of innovation consists in distinguishing between new product and new process. In the former case, we have new goods offered in the market, different from already existing ones. These new goods may be physical objects or services that were not

earlier available and are generally considered positive to consumers as they widen their choice. Conversely, a new process does not necessarily involve new consumption goods or services, as it consists in a more efficient way to produce an existing good. This more efficient production process may be due to a more efficient use of the resources, or to the introduction of a cheaper input. Usually, these two types of innovation are either treated separately (Basak and Mukherjee [2018], Chen and Sappington, [2010]) or analysed in comparative terms (Vives[2008], Beneito et al. [2015]). Although these approaches have clear advantages - as they allow the researcher to focus on particular relevant features - nevertheless, they become partially meaningless when one tries to include the supply chain in the analysis. When we try to analyse the incentives for innovation of firms operating in supply chains, the distinction between new products and new processes becomes blurred.

In 2005, Amazon launched the web service Amazon Mechanical Turk (MTurk). Clearly, it was seen by firms and workers as a new service. Soon, firms found out that, by means of the MTurk, they could perform some specific tasks in a cheaper way than by hiring workers (Hara et al. [2018]). Thus, the new product started looking like a new input to them. In other words, with the MTurk, Amazon has positioned itself on an early node of the supply chain, selling its new product to firms in subsequent nodes. Those firms adopt the new service as a way to perform more cheaply a task that would otherwise be more costly. The same service is, simultaneously, a new product and a new process. Examples of this kind abound in the ICT sector, but they are common also in more "traditional" industries, like manufacturing, logistics, or farming. Farming is indeed a particularly significant example, as the product-or-process feature of the innovation is immediately visible. For instance, let us think of fertilisers. When a new, slow-release fertiliser is released, farmers have to decide whether or not to use it in their production process: the producer of the new fertiliser sells a new product and the farmers adopt a new input. Also, the incentives of the inventors and those of the farmers are clearly connected, but it is not

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apparent if they coincide. Logistics represents an interesting example, too. When the container revolution occurred in the early Sixties, a new product (containers) was introduced, together with a new, cheap way to move commodities on a global scale. Today, innovations in the piece-picking tasks involve collaborative robots, while drones are expected to take over "last-mile" delivery of goods in the next years. Again, inventors' and adopters' incentives are intertwined and disentangling between the two is an important step for a more complete comprehension of what prompts innovative process. New technologies do not appear out of the blue, nor they are neutral. Instead, they are the result of scientific and technological research, which is driven towards a specific direction by those who are involved in it. Thus, before being able to fully define what innovation is from a socio-economic perspective, it is necessary to investigate what makes the firms invest in R&D and what the forces to which those incentives are subject are. In other words, we must investigate what the economic incentives for innovation are.

In this thesis, I look at cost-reducing innovations, without distinguishing between products and processes. Moreover, by analysing the incentives for innovation in a vertical market, I explicitly address the problem of how the incentives of the upstream inventor to invest in innovation and the incentives of the producers of a final good to adopt the innovation are influenced by market features. Moreover, this research is an attempt to distinguish between the incentives of firms at different market levels. Traditionally, the literature has dealt with innovation by outside inventors by considering it as a given. Here, I try to analyse the incentives of the inventor in terms of market structure and other features (e.g., the inventor's efficiency or the price of labour). Thus, I try to define endogenously the incentives to invest in R&D and adopt innovation.

In chapter 1, I analyse the problem of the diffusion of innovation introduced by an outside inventor who does not compete in the product market. More in detail, I analyse how competition in the product market affects the choice of the licensing

contract and, consequently, the diffusion of a superior technology. Also, I look at how competition alters the effects of innovation on Social Welfare. By means of a model of competition in a vertically related industry, I show that competition in the product market is an important element to determine the choice of the licensing scheme, and that it crucially affects the number of licensees in equilibrium. Instead, chapter 2 investigates more explicitly the twofold nature of innovation (new product and new process). I define innovation as a quality improvement of a capital input sold by a supplier to some manufacturers. In such a context, quality is defined in terms of how many workers must be combined with the capital input in order to produce one unit of a final good (the fewer workers needed, the higher the quality of input). Again, vertical structure helps investigate accurately the nature of incentives for the supplier and the buyers, both at a firm and sectoral level.

Competition and Innovation

One of the main research topics in economic theory is which market structure provides the firms with the optimal incentives to invest in innovation (see Vives [2008]). A slightly different, yet related question is which market structure guarantees the optimal diffusion of a superior technology. In chapter 1, I investigate channels through which competition affects the innovator's incentives to invest in innovation and to license it by means of a particular contract type. This research is related to a vast literature on market structure and optimal incentives to R&D. According to the Schumpeterian theory, as monopoly guarantees the highest rents, it is also the market structure that elicits more investments in R&D. In fact, under no other condition, a firm would be able to invest the same amount of resources. Instead, following the Arrowian theory of replacement effect, firms are more willing to invest in competitive markets, as this allows them to gain market share at the expenses of their competitors. A monopolist has no particular incentive to replace him/herself and would invest in R&D only to protect him/herself from potential entrants. Thus,

when firms are in the condition to fully appropriate the returns of their investments, Arrow says, perfectly competitive markets provide them with the optimal incentives to invest in innovative activities. Although these two theories go in opposite directions, they identify forces that operate simultaneously on the firms' incentives. The idea that both the monopoly rents theory and the replacement effect work simultaneously has been formulated also by Aghion et al. [2005]. According to the authors, when the market is highly concentrated, the Arrowian replacement effect is stronger and increasing competition leads to larger investments in R&D. However, after the competition intensity rises above a certain threshold, the market becomes too competitive and firms reduce their investments. Thus, the authors suggest there is a bell-shape effect of competition on incentives to R&D. In terms of diffusion, we would say that concentrated markets elicit the full diffusion of the new technological standard, while competitive ones elicit vertical foreclosure and an inefficiently low level of utilization of the new technology.

From the perspective of the potential adopters of an external innovation, instead, competition in product market tends to benefit investments in innovation. When the competition is stronger, firms are more willing to adopt a new technology (or to re-sell a new product), that allows them to escape the pressure exerted by rivals. Thus, when we look at the downstream sector, perfect competition provides the optimal incentives. Those incentives are connected to the inventor's incentives to invest in R&D, as competition guarantees the largest surplus extraction. This result has been largely studied in licensing literature (Katz and Shapiro [1985], Kamien and Tauman [1986, 2002], Kamien et al. [1992], Sen [2005], Sen and Tauman [2007, 2018], Marshall and Parra [2019], among others). However, the fact that competition increases investments does not necessarily mean that it also prompts the largest diffusion of the technology. The number of licensees, in fact, depends strictly on the contractual form of licensing. Intuitively, a per-unit royalty-based licensing would induce all the producers to adopt the new technology, as this allows the inventors

to maximise their revenues. However, Lapan and Moschino [2000] demonstrate that, in the case of a multi-factor production function, if the introduction of a new technology alters the price of at least one strategic input of production, licensing via royalties may result in an incomplete adoption of the superior technology. Similarly, a uniform fixed fee licensing would elicit an inefficiently low utilization of the new technology (from the welfare perspective), by limiting the number of adopters to those who find the adoption profitable only, and vertically foreclosing others firms. The role of competition on boosting diffusion through the choice of a particular contractual form is still a subject that requires a better understanding. Chapter 1 addresses this question explicitly.

Innovation and Market Power

Innovation is connected to market power, as it allows innovative firms to emerge from the competitive pressure and leapfrog their rivals (Cassiman and Vanormelingen [2013]). Therefore, the fact that the market share of innovating firms is becoming larger year after year should be neither surprising nor necessarily alarming. In fact, market power accumulation may be the evidence of strong competition. If some firms invest in innovation and become more efficient, they can expand their sales. One way to measure firms' market power and industry concentration is to look at markups. There have been several attempts to estimate the markups trend in recent years. Using U.S. national account data, Barkai [2016] estimates that markups increased from 1.02 to 1.19 in the time span between 1984 and 2014. Similarly, Gutierrez and Philippon [2017] find that markups increased from 2000 to 2015, while they were relatively flat between 1980 and 2000 (following the decline in the labour share of income). Likewise, De Loecker et al. [2018] estimate an increase in the weighted average of markups from 1.21 in 1980 to 1.61 in 2016; according to the authors, most of the increase took place during the twenty years between 1980 and 2000. A study by the International Monetary Fund (IMF [2019]) shows that, between 2000

and 2015, markups have moderately risen by 8% in Western countries, while they remained stable in emerging economies.[1] Looking at the distribution of this rise, the study says, one can see that a small number of firms in relatively few sectors are mostly responsible for it (see Calligaris et al. [2018]). Those high-markup firms tend to perform better than their rivals (they are more productive, and invest more in intangible assets, such as patents) and grow at the expenses of those with low productivity and low markups. According to the study, "this tentatively suggests that changes in the structure of product market have underpinned at least some of the overall rise in market power. One such change would be the winner-take-most outcome achieved by the most productive and innovative firms, rooted in part in specific intangible assets." The problem can hardly be solved with standard pro-competitive policies, as these may amplify the winner-take-most outcome and push high-markup firms to raise barriers to entry in order to protect the dominance achieved through innovation.

A well known result in innovation literature is that inappropriability of knowledge leads to frictions in investments on innovation. As a matter of fact, the Arrowian replacement effect would not exist if firms were not able to appropriate the returns on their investments. Indeed, if rivals could free ride on the inventor's investments through the appropriation of some spillovers, that would trigger the so-called hold-up problem. Namely, when a firm cannot appropriate all the returns on its investments, the relative cost of investing rises, leading the innovator to reduce investments. In order to solve this puzzle, patents have been seen as the most appropriate tool. Due to Intellectual Property Protection (IPP) laws, and in particular to patents, firms are granted a monopoly position in the market for their inventions that prevents leaks of spillovers and guarantees the disclosure of knowledge, prompting follow-on innovations.

However, patents may be dangerous for economy if firms start abusing the dom-

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[1]The study uses data on a pool of almost a million firms located in 27 developed and emerging countries, and calculate markups as the price-to-costs ratio.

inant position they are granted (see Acemoglu and Akcigit [2012]). Argente et al. [2019] show that large firms tend to use patents for protecting purposes rather than for introducing new products. By means of a novel dataset that allows the authors to match new products to patents, they find that, although patents are positively associated to new products, the patents of larger firms are mainly related to declines in the introduction of new products by competitors.

Also, inefficiencies related to the patent system are common in the ITC sector (see Comino et al. [2019] for a detailed survey). The reasons of such inefficiencies are several. One of the most common is patent fragmentation, which generates patent thickets (Hall et al. [2013]). If this is the case, potential innovators are forced to deal with many patentees in order to develop a new product. Another source of inefficiency is the potential problem of weak patents, namely, those patents that do not satisfy the criteria of novelty, non-obviousness, and usefulness. This last problem is analysed in Farrell and Shapiro [2008], who focus on the welfare effects of weak patents in the shadow of litigation. Although those patents can always be overturned in Court, the authors show that the mere possibility that such weak patents exist is detrimental to Social Welfare.

The problem of bigness is also analysed in Lamoreaux [2019]. In an interesting effort to compare the cases of Google, Amazon, and the other contemporary Tech-giants to the example of Standard Oil in the late XIX century, the author tries to explain the problem behind the existence of large companies, making use of the claims and reasoning of the self-proclaimed "New Brandeisians", a group of authors supporting the theses of Louis Brandeis about the dangers represented by the existence of too large companies. According to Lamoreaux, although large firms have not led to a fall in competition levels, serious concerns exist that the political power achieved, together with the large market shares, may help those companies impose barriers to entry and exclude competitors. From the legislator's perspective, the issue is how to regulate the market without triggering the anti-competitive reaction

of large firms harmed by such a regulation. A similar perspective is presented in Akcigit et al. [2018]. The authors analyse the political connection of large firms and their effects on investments in innovation. Studying the case of Italy, the authors show that large firms are more likely to form political connections, by hiring politicians in office right before close elections, and that those connections are especially exploited to create barriers to entry for potential competitors. They identify a so-called "leader paradox", where large firms with political connections are less likely to issue more patents, but display a larger survival rate. Such a behaviour increases the protection of large incumbents, reducing the incentives to invest in innovation.

Another possible link between innovation (and technological progress) and the increase of markups is provided by Berry et al. [2019]. According to the authors, the shift towards a more digital intensive production process has led to an increase in fixed/sunk costs in relation to variable costs, determining an overall increase in markups. This is confirmed by Calligaris et al. [2018], who find evidences of larger markups in more digital intensive sectors and of an increasing gap in markups between more digital intensive sectors and less digital intensive ones. This argument, however, does not mean that larger markups imply more profitable or less competitive sectors, as those markups may be necessary to survive in a market where fixed costs represent a large barrier to entry (see also Jaumandreu and Lin [2018]). Also, Berry et al. [2019] suggest that an alternative connection between innovation and increasing markups may be represented by the rise of platform in sectors like the Social Media or entertainment, which has led to a less competitive market. In this case, markups may be a symptom of decreasing competition. Markets with strong network effects provide the first mover with a rent on the luck of being the first. The network effect, in this case, represents a benefit for the first mover but also a barrier for potential entrants, as it requires a larger effort to attract consumers who are already locked in by the incumbent. By slowing down the rate of substitution in the consumption choices of the consumers, the network effects guarantee the incumbent

with a market power that would be otherwise impossible to get. A further explanation of the presence of larger markups in digital intensive sectors comes from the fact that sellers operating in on-line markets have usually better information about consumer characteristics and can exercise perfect price discrimination when market is relatively concentrated.

Large markups and market power have implications on the factors' share of income, too. Autor et al. [2017] suggest that the rise of the so-called superstar firms may be associated to a decline in the labour share of income due to large profits. Thus, a microeconomic issue such as the size of the firms impacts on macroeconomic outcomes that are ultimately associated to income inequality. They explain that, due to the "winner-take-most" feature of the markets, with few firms which can capture a very large share of market sales, there is a reallocation of production between firms (rather than within firms), with the output shifting towards those few firms that are characterised by low labour shares. As in Berry et. al [2019], the authors suggest that the network effect may be responsible for the "winner-take-most" feature, as it locks consumer into the consumption of the products offered by dominant companies.

These issues are mainly addressed in chapter 1, where I show that market power accumulation is indeed a possible result when competition in the product market is strong and the inventor is efficient in investing in R&D. The effect of such an increase in the innovator's market power on the economy is beyond the scope of my thesis; however, concerns about the problem of bigness are justified by a process of increasing market share that is consistent with the theory presented in this research.

The role of labour market and institutions in fostering innovation

Technological progress has crucial implications on the labour market. As we are entering the fourth industrial revolution, several jobs are expected to be lost due

to automation of tasks and the introduction of Artificial Intelligence (A.I.) and robots. According to Frey and Osborne [2017], almost 47% of the US jobs are at risk of automation relatively soon. Also, McKinsey [2017] predicts that, globally, an average of 15% of the current jobs will be susceptible to automation, and between 3-14% of the global workforce will need to change their occupational category.[2]

Innovation has always been followed by fear of jobs losses, since the first episodes of machine-breaking by the Luddite protesters in Britain in the early XIX Century. However, neither all innovations are the same nor all the waves of technological progress have similar effects on society: how innovation impacts on jobs depends on the type of innovation. A new product opens new market, potentially boosting economic growth and increasing the demand for new labour. Thus, a product innovation is usually identified with a positive shock on the labour market. Instead, process innovations are implemented in order to lower the costs of production and be more competitive. As workers' wages are usually important components of the variable costs of the firms, process innovations are often labour saving. Jovanovich and McDonald [1994] propose a theory of industry shake-outs based on waves of innovations, which has been defined by Klepper and Simons [2005] as "Radical Invention Theory" (RIT). According to RIT, innovations occur in alternate waves of product and process innovations. First, a new product is introduced, and a new market is opened. Firms start entering the competition as the new product guarantees some supernormal profits to them. However, after competition drives profits to the competitive level, firms start investing in process innovations to lower their costs of production and escape the competitive pressure. Eventually, some firms develop a new technological standard that allows them to survive in the market, while others are forced out of it. In this sense, new products and new processes are necessarily subsequent and interrelated. In such a context, the consequences on the labour market are not well defined as they depend on the size of the market for

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[2]Similar results are suggested by the OECD 2019 Employment Outlook.

new products in relation to the cost-reducing impact of process innovations. The twofold effect of innovation on jobs is also stated in Pianta [2018]. According to the author, innovation can be of three main types: product innovation, process innovation, and organizational innovation. The effect that innovation has on the labour market depends on the type of innovation. When firms follow a strategy of "technological competitiveness", they compete on new products and open new markets with a possible positive effect on the labour demand. Conversely, a "cost competitiveness strategy" leads to labour saving innovations that produce an opposite effect. Today, an apparently new wave of technological progress is approaching and seems to feature some differences from the previous ones. The so-called industry 4.0, or the fourth industrial revolution, is defined as a set of new enabling technologies that are expected to automate large parts of manufacturing and non-manufacturing tasks. Acemoglu and Restrepo [2019] and Berg et al. [2018], among others, try to analyse the possible implications of automation on jobs with different perspectives. According to Acemoglu and Restrepo [2019], automation is going to represent a challenge for policy makers, who must protect people from jobs marginalization and technological unemployment. However, the net effect of such a process on the labour demand is still to be defined and heavily depends on the new markets that those enabling technologies are going to open. If new tasks and jobs are created, then it is possible that automation and Artificial Intelligence (A.I.) have a balanced, or even a positive effect on the labour demand. Instead, if the shift from a non-automated to an automated process is too fast, then jobs losses may occur. Instead, Berg et al [2018] advance a more pessimistic view. According to the authors, the introduction of robots and A.I. is occurring too fast to be compensated, and the eventual recovery is going to be too distant in time to be socially acceptable. As a matter of fact, the authors say, we should fear the robot revolution.

However, the labour market is not only a target of technological progress, however. The structure of the market, the demand and supply of labour, and unionisa-

tion are all features that influence the firms' decision to invest in cost-reducing/labour-saving technologies. Lordan and Neumark [2018], among others, suggest that a minimum wage increase would be detrimental to workers by increasing the price of low-skill labour (low-skilled workers are those whose wage is mainly affected by policies on minimum wage levels). Adopting a pure economic intuition, the authors suggest that, as automation increases the substitutability between labour (especially low-skill) and capital (especially robots and A.I.), raising the minimum wage would prompt the investments of the firms in robots and, ultimately, a fall in the labour demand. Instead, Riley and Rosazza Bondibene [2017] provide evidences that UK firms employing large share of national minimum wage workers reacted to the increase in national minimum wage by fostering labour productivity, rather than replacing workers with other factors of production.

A large portion of the literature on the connection between labour market structure and the incentives to invest in innovation has been devoted to analysing the role of unions and the centralization of the bargaining process between unions and firms. Wage bargaining is the process that allows unions to exploit part of the quasi-rents that the firms obtain from competing in an oligopolistic market – i.e., for the temporary absence of perfect competition. When it comes to innovation, however, the problem shifts from the division of the quasi-rent to the appropriation of the surplus generated by the invention. Thus, when the bargaining process occurs ex-post, the workers' appropriation of innovative outcomes triggers the common hold-up problem, which lowers the investments in R&D. As firms are not able to fully appropriate the fruits of their investments, the relative cost of investing increases and their decisions on investments change. On the other hand, when the bargaining occurs ex-ante, firms and workers share not only the outcomes of innovation, but also the costs, moderating the hold-up problem. However, ex-ante bargaining implies a strong assumption, namely, the transfer to the workers of some control over the production and the investments, which is unrealistic in most sectors

of real world economy.

In addition to when the bargaining process occurs, there is also the problem of where the wage bargaining occurs or, to be more accurate, who the agents involved are. Wage bargaining may be centralized or decentralized; this means that it may involve a firm and its workers only or take place between workers joint in a monopoly union and a confederation of firms, with all the shades of grey in the between. Usually, centralization is associated to negative externalities, such as wage rigidities and the inability of firms to exploit regional differences in the labour market. However, the discussion is far from being concluded. Grout [1984] states that unionisation is always detrimental to innovation, as it sets the conditions for firms to reduce their investments due to the hold-up problem. Instead, Tauman and Weiss [1987] argue that unionisation may help firms increase their investments, if unions and firms cooperate to discourage potential entry. A similar behaviour is identified in the context of the so-called "Pennington case" by Williamson [1968], according to whom cooperation between firms and unions may act as a barrier to entry for potential competitors. In Haucap and Wey [2004], centralization is shown to be positive for incentives for innovation, under certain conditions, as a rigid wage rate favours innovative and more productive firms, compared to less productive ones which rely more heavily on labour. This kind of efficiency razor tends to punish old firms and award innovative ones, fostering the incentives to invest in innovation (see also Calabuig and Gonzalez-Maestre [2002], Manasakis and Petrakis [2009], Mukherjee and Penning [2011], among others).

These topics are addressed in chapter 2, where the focus is on the effects of the labour price on the incentives to invest in labour-augmenting innovations. Moreover, I show that labour market conditions widely affect innovative activities and, under some circumstances, raising the cost of labour uniformly may be beneficial for the industry as a whole, as it puts in motion a process of innovation and output expansion that ends up accruing both Consumer and Private surplus.

Purpose of this thesis

This doctoral research is an attempt to improve the understanding of why firms invest in innovative processes, why they adopt them, and how their choices impact on Social Welfare. More in detail, chapter 1 deals with the effect of downstream competition on innovation diffusion (licensing), the market power accumulation of the inventors, and the impact of innovation on Social Welfare. I show that competition affects both the size of the innovation (positively) and its diffusion among the producers (negatively). Also, the results of this chapter suggest that policy makers have reasons to be concerned about the market power accumulation of the innovators, in particular when their innovations are sold to competitive sectors. Consistently with the results in IMF [2019], I suggest that weak pro-competitive policies may be ineffective to tackle this issue, as they trigger the inventors to raise barriers to entry in the producers' sector and reduce the diffusion of the new technology in order to preserve their market power. Furthermore, innovators benefit from competition more than consumers and producers. I show that there is a "subsidy" effect of competition on innovation that makes technologies developed by an inefficient innovator impact more heavily on Social Welfare. Therefore, weak pro-competitive policies in the product market may result in further market power accumulation and lower benefits for consumers. Similar results are obtained by looking at competition as the horizontal differentiation between two products. In the appendix to chapter 1, I add product differentiation as an alternative measure of competition. I show that the incomplete adoption of a superior technology is associated to high degree of product substitutability (intense competition), while large product differentiation (soft competition) promotes the full adoption of the new technology.

In chapter 2, I deal with the connection between the wage rate and the incentives to invest in innovation. By means of a model of competition in a vertically related industry, I design technological progress as the introduction of a qualitatively superior capital input in the production process; quality is measured in terms of the

number of workers employed together with the capital input to produce a unit of output. When the quality of capital rises, the labour demand is subject to two opposite forces: on the one hand, firms require less labour to produce a unit of the final good and demand falls. On the other hand, by reducing the cost of labour per unit of output, the firms' best reply shifts outwards and their output rises, increasing the labour demand. This trade off summarises the discussion about the effects of technological improvements depending on the type of innovation. Moreover, chapter 2 addresses the problem of what the incentives that make firms invest in labour-saving innovations are. Similarly to Lordan and Neumark [2018], I show that the price of labour triggers new labour-saving technologies. However, results suggest that, under certain conditions, new technologies may increase the production level and, ultimately, the labour demand.

Both chapter 1 and chapter 2 adopt a theoretical I.O. perspective, with a focus on innovation in vertical market, in order to investigate the role and the effects of technological progress on supply chains and industrial relations. I believe this research contributes to a better understanding of why firms decide to adopt a new technology and how innovators exploit the producers' incentives in order to maximise their payoffs. This doctoral thesis must be understood as a first step towards a better comprehension of industrial and firm-labour relations. I show how market structure affects the diffusion of a new technology and, more importantly, how it modifies the channels through which innovation contributes to Social Welfare. Finally, I show how labour market and innovation mutually influence each other as well as the forces that operate in order to transform an increase in the wage rate into a larger investment by the inventor.

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Chapter 1

Innovation, Competition, and Incomplete Adoption of a Superior Technology

Sandrini, L. (2019)

1.1 Introduction

Innovation is a fundamental source of economic growth. For this reason, how to prompt the firms' incentives to invest in R&D has always been among the most investigated topics in Industrial Organization and economic theory in general. In particular, a core issue is how to guarantee the innovators the rightful appropriation of the returns on investments in R&D, in order to encourage them to keep investing and disclose their inventions. Today, the solution to this trade off between innovation's disclosure and appropriability is given by patents and intellectual property right laws. Once a patent is granted, the innovator is provided with a temporary monopoly on his/her invention, so that (s)he is able to disclose it with no risk of exploitation by free riding rivals. From the seminal work of Kenneth Arrow, we know that, when firms are able to appropriate the value generated by their investments

in R&D, perfect competition provides the highest incentives to innovate. This is so because firms want to escape the competitive pressure and leapfrog their rivals by becoming more efficient. However, market structure does not only affect incentives to invest in innovative activities. Once a new technology has been granted, a secondary issue emerges, that is the diffusion of this innovation in the market. In this article, I deal with this issue and show that the level of competition is indeed a crucial element to determine the contract chosen by an upstream monopolist to license its invention, and, consequently, the rate of adoption of the new technology by competing manufacturing firms. Moreover, adopting a linear Cournot model, I show that licensing via upfront fees is more profitable for the inventor than licensing via royalties, when the innovation is sufficiently large or very small. On the contrary, for intermediate level of innovation size, royalties yield larger profits to the monopolist inventor. As competition level affects both the manufacturers' incentives to adopt the innovative technology and the innovator's incentives to invest in its development, the choice of the contract and the rate of adoption are crucially affected by how many firms are competing in the product market. Kamien and Tauman [1984, 1986], and Sen and Tauman [2007], among others, show that the optimal contract type from the innovator's perspective is either licensing via auction or an upfront fee. With these contracts, (s)he is able to obtain a level of profits as close as possible to the one achievable by a monopolist manufacturer embedded with the innovative technology on licensing. On the other hand, royalties are always associated with complete adoption of the new technology, while auctions and upfront fees imply a restriction in the number of licensees. This is so, because the innovator wants to shield her/his source of revenues from competition, thus allowing only some of the competing manufacturers to exploit the competitive advantage derived from adopting the innovative technology. The superiority of upfront fees and auctions compared to royalties has been questioned by Sen [2005], Ertuku and Richelle [2007], and Sen and Tauman [2018]. As the revenues due to licensing via auctions

and upfront fees are somehow bounded to a maximum level when competition exceeds a certain threshold, while revenues from profits are always increasing in the number of manufacturers, Sen [2005] shows that, depending on the actual level of competition, royalties may be superior to upfront fees, partially explaining the firms' overwhelming preference for royalty based contracts in real economy. Similarly, Sen and Tauman [2018] show that, for generic values of magnitude of the innovation, royalties yield better outcomes to the inventor when competition is sufficiently intense.[1] However, these articles analyse the licensing game taking the invention size as given and find the best way to license the invention. My contribution to this literature is to further analyse the role of the intensity of competition to elicit a certain size of cost-reducing innovation. Moreover, I show that the innovator prefers licensing the new technology via upfront fees rather than via royalties when the innovation is sufficiently large or small. As the intensity of product market competition positively affects the size of innovation in equilibrium, I show that upfront fee licensing scheme is preferred when the number of competitors in the downstream sector is either large or very small. Furthermore, the equilibrium number of licensees is negatively related to the intensity of competition and the efficiency of the innovator - i.e., his/her ability to convert investments in R&D into innovation size. I suggest that internalising the size of innovation is a relevant feature, as it allows to link together the incentives to adopt an innovation by downstream firms, which is necessarily affected by the market structure, and the incentive to develop the innovation by the upstream inventor, which is in its turn influenced by the behaviour of downstream manufacturers.

Finally, I discuss some welfare implications of licensing an innovation via upfront fees. I show that competition in the product market disproportionally fosters the benefits of the innovator compared to those of consumers and manufacturers. This happens for two main reasons: first, when competition becomes more intense, the

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[1]See also Sen and Stamatopoulos[2016].

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opportunity cost of adoption falls, raising the innovator's ability to extract the surplus. Second, large innovations push the price of the final good down to the marginal cost of production associated with the rival technology. Thus, the more competitive the market, the less effective the innovation in lowering the market price, and the higher the adopters' markups.[2] From a policy-maker's perspective, however, the markups of adopting firms do not constitute an issue, as they do not lower Consumer surplus and are mainly due to the change in the cost structure of the adopters, which shifts from a variable cost structure to a mixed one with a variable and a fixed component.[3] Instead, the increase in market power experienced by the innovator may raise some concerns in the regulators, as it may be at odds with an ex-post pro-competitive behaviour. A proper analysis of the effects of such a distribution of the surplus generated by the introduction of a new technology goes beyond the scope of this article. Here, I suggest that market power accumulation by an outer innovator is a possible outcome of the introduction of a cost-reducing technology in a vertical market.

This paper is organized as follows: the rest of this section contextualizes this article in the literature. In section 1.2, I describe the model and the main assumptions. Section 1.3 outlines the main results, first focusing on royalty-based licensing contracts (section 1.3.1), then on upfront fees (section 1.3.2). A comparison of the results is provided in section 1.4. Finally, section 1.5 concludes.

1.1.1 Literature Review

Katz and Shapiro [1985], Kamien and Tauman [1986, 1984], Kamien et al. [1992], Sen [2005], and Sen and Tauman [2007, 2019], among others, analyse the optimal

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[2]See De Loecker et al. [2018], Hall [2018], Gutierrez and Philippon [2017], and Barkai [2016] for evidences on markups trend, among others.

[3]This is a topical issue, which attracts the attention of policy-makers and researchers. In a recent study, IMF [2019] finds that, between 2000 and 2015, markups have increased in advanced economies. Apparently, the increase is more concentrated among a small fraction of innovative and productive firms. In this article, I adopt the definition of markups as the ratio of the difference between price and marginal cost of production to the price - i.e., the Lerner Index - while in IMF [2019] the authors use the price to marginal cost ratio.

licensing scheme confronting fixed fee licensing, royalty licensing, and licensing via auction. Generally, fixed fee and auction are found to be superior to licensing via royalty, although Sen [2005] and Sen and Tauman [2018] find conditions for royalties to yield larger patents' value. Also, they show that market outcomes are affected by the contractual form chosen by the innovator. In particular, fixed fee licensing drives the post-innovation price of the final good down and the Consumer surplus up, making the firms worse off and consumers better off. Instead, licensing via royalty-based contracts does not alter the price of the final good, and allows the firms to earn at least the same amount of profits as in the pre-innovation scenario (see also Katz et al.[1990], Gallini and Wright [1990], Arora and Fosfuri [2003], and Hermosilla and Wu [2018]).[4] Furthermore, they show that perfect competition provides at least the same incentives as monopoly. Ertuku and Richelle [2007] find that it is always possible to design a two-part tariff contract scheme which ensures complete adoption of the superior technology and a level of profits for the inventor which replicates the monopoly profits of a manufacturer which is embedded with the superior technology. This article builds on these results on licensing and contributes by stressing the role of competition in determining both the optimal licensing contract (and therefore the equilibrium number of licensees) and the size of the innovation developed by the inventor. My contribution is to identify and sort the direct and indirect effects of competition on the innovation size and the value of the patent. Moreover, I show that, as competition intensity has always a positive impact on the size of the cost-reducing effect, it also drives the choice of the optimal contract type towards uniform upfront fees. In fact, this contract type grants the innovator a far better exploitation of the surplus increasing effect of the new technology and increases the value of the patent.

Vives[2008] and Beneito et al.[2015] provide theoretical and empirical support

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[4]Lapan and Moschini [2000] show that licensing via royalty may lead to incomplete adoption of the superior technology if the innovation affects the demand, and therefore the price, of some of the other inputs used by the firms.

for opposite effects of competition on product and process innovations. According to the authors, high product substitutability and high costs of entry are associated with a higher amount of process innovations. Aghion et al. [2005] suggest that there is an inverted-U relation between competition and investments in innovation. This view synthesizes the two main theories on innovation and competition. On the one hand, there exists a monopoly advantage in fostering investments as the monopolist is able to collect high rents from his/her position; on the other hand, there is a replacement effect, or *escape from competition* effect, which is triggered by increasing competition. In a recent article, Marshall and Parra [2019] show that competition may affect innovation and Consumer Welfare in a non-obvious way, depending on the properties of the product market game (See also Parra [2019]). This article contributes to the literature by investigating the effect of competition in the product market on the profits of the innovator, the innovation's size, and the Social Welfare. I show that investments in R&D and the profits of the innovator are larger when competition is strong. Instead, competition reduces the effect of innovation on the Consumer surplus.

Berry et al. [2019] and Lamoreaux [2019] highlight the risks of market power accumulation and the concerns around the issue of increasing markups. In this article, I show that, although the rise of markups of adopting firms may be due to the fact that firms have to sustain a large fixed cost in order to be able to remain in business, the innovator's ability to "regulate" the market has some anti-competitive effects and hinders full adoption of the superior technology.

Voudon [2019], Alipranti et al. [2015] and Milliou and Petrakis [2011], among others, investigate the connection between vertically related markets and innovation diffusion (see Fundenberg and Tirole [1985]). However, they mainly focus on innovation by analysing the problem in a dynamic setting. As time proceeds, competition pushes the price of the innovation down and the rate of adoption increases; however, early adopters have some advantages and thereby a trade off emerges. Here, I do

not focus on the timing of adoption. Instead, my goal is to show that the number of licensees that an outer patentee elicits is a decreasing function of product market competition and the innovator's efficiency. As above mentioned, this article deals with the issue of the exit of firms after the introduction of a new invention. Linking together market characteristics and firms' profitability, I show that the market structure and the strategic behaviour of the innovator and the producers help explain why some firms exit the market after the introduction of a new technology.

The results in this model are consistent with the "radical invention theory" in Jovanovic and McDonald [1994], according to the taxonomy in Klepper and Simons [2005] - although in a hardly comparable setting. According to the radical invention theory, a major invention generates a new market that immediately attracts several firms, which enter until the marginal profits fall to zero. Then, process innovations start lowering the costs of production for some firms and driving the inefficient ones out of business. This article sheds light on the moment when process innovations are introduced and start lowering the costs of production of the final good. A wide literature investigates the causes of post-innovation industry shake-outs (see Klepper [1996] and Geroski [1995] for a detailed analysis). However, this literature surveys the issue by following two main approaches: an event-based approach and an evolutionary one. Instead, I show that, since competition raises the licensing fee set by the inventor, it also prompts investments and increases the size of invention in equilibrium. When competition is sufficiently strong, the resulting innovation is large enough to generate an industry shake-out.

1.2 The model

Consider an industry with n identical firms (or manufacturers) that compete $à$ la Cournot for a homogeneous good and face a linear demand $P(Q) = a - bQ$, with

$Q = \sum_{i=1}^{n} q_i$ being the total industry output.[5] There are two technologies that can be used to produce the final good. The first one is a standard technology and represents the state of the art of the technological progress. It is freely available in the market and enables manufacturers to produce one unit of output at the cost c. Instead, the second technology is new and, if adopted, reduces the cost of producing a unit of output to $c - x$, with $x > 0$ being the size of the innovation. The innovative technology is owned by a monopolist innovator (or supplier) who does not compete in the product market and is protected by a patent that prevents the replication by other agents. In order to develop the invention, the supplier invests $I(x) = \gamma x^2$, where γ is a cost parameter.[6] In order to license the new technology, the inventor sets either a royalty-based licensing scheme (with r being the royalty rate) or an upfront fee F. For sake of simplicity, I will refer to downstream firms and to upstream innovator with the female pronoun "she" and the male pronoun "he", respectively.

Let us portion the manufacturers into two groups: I define A as the set of firms that are selected by the innovator to adopt the innovative technology, and B as the set of firms that produce by means of the standard technology. Then, the objective function of the ith manufacturer can be written as:

$$\pi_i = \begin{cases} (a - bQ - (c + r - x))q_i + F(x) & \text{if} \quad i \in A \\ (a - bQ - c)q_i & \text{if} \quad i \in B \end{cases} \tag{1.1}$$

The inventor objective function is:

$$\pi_u = \sum_{j=1}^{m} q_j r + m F(x) - I(x) \tag{1.2}$$

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[5]The assumption of homogeneous products is adopted for sake of simplicity. In Appendix A.1, I show that, at least for the case of non-drastic innovations under licensing fee, the same relation between competition and the number of licensees in equilibrium can be obtained if we assume that firms produce different products.

[6]The parameter γ adjusts the convexity of the R&D cost function and it can be interpreted as the inverse of the innovator's efficiency. The lower γ, the less expensive it is to invest in the innovative technology.

where the subscript u stands for *upstream* innovator, and $m \in [0, n]$ represents the number of manufacturers in A. Conversely, $n - m$ is the number of manufacturers in B. Depending on the size of innovation x and the number of adopters m, the innovation can be either non-drastic or k-drastic. In the first case, it does not alter the competition in the market (non-adopters are always able to produce positive quantities of the final good, as the market price of the final good never falls below the non-adopters' marginal cost of production). Instead, when the innovation is k-drastic - i.e., $x > (a - c)/k$ - the adoption of the new technology by at least k manufacturers forces the non-adopters to exit the market as they are no longer able to produce any positive quantity with the standard technology.[7] Thus, in this case, the innovative technology has an impact on the market structure and alters the post-innovation market concentration.

The timing of the game is as follows: at $t = 0$, the monopolist innovator sets the size of the technology x; then, at $t = 1$, he chooses which contract scheme to enforce (royalties vs upfront fee) and decides how many adopters m to elicit. Finally, at $t = 2$, the manufacturers compete in quantities. The game is solved by backward induction.

Notice that, as the number of adopters is a discrete variable, equilibrium in pure strategies may not exist due to discontinuity problems. Thus, in the following sections, I consider the number of adopters m as a continuous variable. This assumption comes together with some carefulness in interpreting the results. Indeed, a more elegant way to deal with this issue would be to solve the equilibrium in mixed strategies. This would avoid any assumption on m. In Appendix A.3, I solve the upfront fee game following this last approach (it does not influence the royalty-based contract outcomes) and show that the results are qualitatively robust. In what follows, I prefer keeping the procedure as simple as possible, as mixed strategies are not an obvious concept when we consider the investments of the firms.

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[7]See Sen and Tauman [2007] for a formal definition of k-drastic innovations.

1.3   Results

From eq. (1.1) we derive the Cournot output and profits of the manufacturers given the licensing contract type:

$$q^A = \frac{a - c + (n - m + 1)(x - r)}{b(n + 1)} \tag{1.3}$$

$$q^B = \frac{a - c - m(x - r)}{b(n + 1)} \tag{1.4}$$

$$\pi^A = \frac{(a - c + (n - m + 1)(x - r))^2}{b(n + 1)^2} - F(x) \tag{1.5}$$

$$\pi^B = \frac{(a - c - m(x - r))^2}{b(n + 1)^2} \tag{1.6}$$

The manufacturers choose the technology knowing the contract type offered by the inventor. Moreover, the contract is either royalty-based or an upfront fee (I am not considering combinations of the two). Thus, whenever the royalty-based contract is offered, we have that $r > 0$ and $F(x) = 0$. Alternatively, if the innovator sets an uniform upfront fee $F(x) > 0$, then $r = 0$.

1.3.1   Royalty-based licensing scheme

Let us first consider the scenario with royalty-based licensing contract. It is easy to show that the unique equilibrium royalty rate is $r = x$, regardless of the size of innovation (see Kamien and Tauman [2002], among others). In this case, the benefit from adopting the new technology is wiped out by the per-unit expenditure that the manufacturer has to sustain in order to produce the output. Consequently, from eqs. (1.3) and (1.4) it follows that, as $q_i^A = q_i^B = \frac{a-c}{b(n+1)}$, the firms are all indifferent between adopting or not the innovative technology. Let us assume as a tie-breaking rule that the manufacturers prefer the innovation, when it comes at no extra costs.

Then, with $r = x$, the innovator licenses his technology to $m = n$ firms.[8] Starting from the downstream subgame, we can write the manufacturers' output and profit functions:

$$q = \frac{a - c}{b(n + 1)} \tag{1.7}$$

$$\pi = \frac{(a - c)^2}{b(n + 1)^2} \tag{1.8}$$

which are the standard outcomes for a Cournot Oligopoly and do not depend on the size of innovation x. Using eqs. (1.7) into (1.2), and knowing $r = x$, it is possible to write the upstream monopolist maximisation problem as:

$$\max_x \quad \frac{n(a - c)}{b(n + 1)} x - \gamma x^2 \tag{1.9}$$

which leads to:

$$x^+ = \frac{n(a - c)}{2b\gamma(n + 1)} \tag{1.10}$$

Using eq. (1.10) into (1.9), we can compute the innovator's total revenues (TR) and profits in equilibrium:

$$TR = \frac{n^2(a - c)^2}{2b^2\gamma(n + 1)^2}$$

$$\pi_u^+ = \frac{n^2(a - c)^2}{4b^2\gamma(n + 1)^2} \tag{1.11}$$

Consistently with the standard results in the literature, royalty-based total revenues - as well as the incentives to invest in the innovative technology - are increasing in the number of manufacturers active in the product market, as fierce competition comes together with larger industry output and, consequently, more royalties. We can decompose the effect of competition on TR as follows:

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[8]Lapan and Moschini [2000] demonstrate that, in the particular case of more than one factor of production, if a new technology that increases the productivity of an input alters the price of at least another factor (by lowering its demand), then incomplete adoption of the superior technology may emerge also with a royalty-based licensing scheme. However, here I focus on the standard case of a single input, or, alternatively, of a technology that uniformly increases the productivity (cuts the costs) of all the factors of production.

$$TR = n\,q(n)\,r(n)$$

$$\frac{\partial TR}{\partial n} = \frac{\partial TR}{\partial n} + \frac{\partial TR}{\partial q}\frac{dq}{dn} + \frac{\partial TR}{\partial r}\frac{dr}{dn} \qquad (1.12)$$

There are three forces operating on the total revenues as competition becomes more intense ($n \uparrow$). First, increasing the number of competitors leads to an increase in the industry output downstream and the number of royalties collected. Second, even if total industry output increases, firms produce fewer units individually due to the stronger competition. Third, as competition raises the incentives to invest in innovation and the equilibrium size of the cost-reducing effect, the level of royalties is higher when competition is fiercer. The two positive forces more than compensate the negative one.

Remark 1.1. *Competition (n) affects positively the size of innovation in equilibrium, the royalty-based revenues, and the innovator's profits.*

1.3.2 Upfront fee licensing scheme

Let us now turn to the case where the innovative technology is licensed via an uniform, non-discriminating upfront fee $F(x) > 0$. The impossibility of price discriminating the manufacturers makes the inventor set a fee which elicits an inefficiently low level of utilisation of the new technology. However, in this case, the size of the innovation is a relevant information to determine the equilibrium number of licensees. As mentioned above, depending on the size of innovation and the competition intensity, a new technology can be defined as a non-drastic innovation or a k-drastic innovation. In the following sections, I focus on both the cases and I analyse the condition for a k-drastic innovation to be introduced.

Non-drastic innovation

First, let us consider the case of non-drastic innovation. In this case, the size of the innovation is small enough to allow non-adopting manufacturers to produce positive quantities of the final good by means of the standard technology - formally, $x \leq (a - c)/n$.

From the maximization of eq.(1.1), we can derive the manufacturers' output level, given the size of innovation.

$$q^A = \frac{a - c + (n - m + 1)x}{b(n + 1)} \tag{1.13}$$

$$q^B = \frac{a - c - m x}{b(n + 1)} \tag{1.14}$$

Where superscripts A, B indicate whether the manufacturer adopts the innovative (A) or the standard (B) technology. Consequently, the manufacturers' profits become:

$$\pi^A = \frac{\left(a - c + (n - m + 1)x\right)^2}{b(n + 1)^2} - F \tag{1.15}$$

$$\pi^B = \frac{\left(a - c - m x\right)^2}{b(n + 1)^2} \tag{1.16}$$

Notice that, if $m = 0$, then $\pi^A = \varnothing$ and $\pi^B = \frac{(a-c)^2}{b(n+1)^2}$. Instead, if $m = n$, then $\pi^B = \varnothing$ and $\pi^A = \frac{\left(a-(c-x)\right)^2}{b(n+1)^2} - F$. It is possible to consider π^B as the opportunity cost of adoption, as it represents the profits that the mth manufacturers would earn by producing the final good by means of the standard technology, all else equal.

These general payoffs can be used to derive the individual payoff of a firm which has to decide which technology to choose. From eqs. (1.13) and (1.14), we know that the output level depends on the number of firms that adopt the innovative technology. Therefore, each firm takes into consideration the adoption of the technology by her rivals in order to decide which choice is the profit maximizing one. The innovator sets a uniform licensing fee F that, given the size of the innovation

and the intensity of competition, elicits the desired number of adopters m. The problem of the mth firm, taking the size of the licensing fee F as given, is to choose which strategy yields the best payoff:[9]

$$\pi_m = \begin{cases} \frac{(a-c+(n-m+1)x)^2}{b(n+1)^2} - F & \text{if} \quad m \in A \\ \frac{(a-c-(m-1)x)^2}{b(n+1)^2} & \text{if} \quad m \in B \end{cases} \tag{1.17}$$

From eq.(1.17), we know that the mth firm chooses A whenever:

$$F \le \frac{n\,x\left(2(a-c-x(m-1))+x\,n\right)}{b(n+1)^2} \tag{1.18}$$

Eq.(1.18) represents the Participation Constraint of the inventor's maximization problem, which is marginally increasing in the size of the innovation x. Also, eq. (1.18) is increasing in the intensity of competition n, provided that the innovation is sufficiently large: $x > \frac{(n-1)(a-c)}{m(n-1)+1}$. Therefore, we can say that $i)$ the inventor can charge a larger licensing fee for larger invention, and $ii)$, interestingly, if the cost-saving effect x is sufficiently large, the same invention can be licensed at a higher price in a more competitive market.[10]

Now, the problem of the innovator can be written as:

$$\max_{m;x} \pi_u = m\,F - \gamma\,x^2 \tag{1.19}$$

$$\text{s.t.} \quad F \le \frac{n\,x\left(2(a-c-x(m-1))+x\,n\right)}{b(n+1)^2}$$

By embedding the Participation Constraint into the innovator's profits, it is possible to rewrite eq.(1.19) as:

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[9]As a tie-breaking rule, I assume the new technology is always preferred by the manufacturers if it comes at no extra costs.

[10]Eq. (1.18) represents a sufficient condition for the equilibrium to be stable. One can see that the Participation Constraint satisfies also $F > \frac{(a-c+(n-m)x)^2}{b(n+1)^2} - \frac{(a-c-m\,x)^2}{b(n+1)^2}$ - i.e., the condition under which the non-adopting firms do not prefer deviating by purchasing the innovation.

$$\max_{m;x} \pi_u = m \, \frac{n \, x \left(2(a - c - x(m - 1)) + x \, n \right)}{b(n + 1)^2} - \gamma \, x^2 \qquad (1.20)$$

From which we derive:

$$m^\circ = \frac{2b\gamma(n + 1)^2}{n(n + 2)} \qquad (1.21)$$

$$x^\circ = \frac{2n(n + 2)(a - c)}{8b\gamma(n + 1)^2 - n(n + 2)^2} \qquad (1.22)$$

For the innovation to be non-drastic $(x^\circ < \frac{(a-c)}{(n-1)})$, the condition $\gamma > \frac{3n^2(n+2)}{8b(n+1)^2} \equiv \Gamma^*$ must hold. Moreover, this condition is sufficient to guarantee positive innovation size and output.

Eq.(1.21) represents the first results of this analysis. For sake of simplicity, let us define $\frac{n(n+2)}{(n+1)^2} \equiv N(n)$ as a monotonic transformation of the intensity of competition $(N'_n > 0)$. It is possible to rewrite eq.(1.21) as:

$$m^\circ = \frac{2b\gamma}{N(n)} \qquad (1.23)$$

Proposition 1.1. *The number of manufacturers that adopt the innovative technology is decreasing in the intensity of competition and in the efficiency of the inventor, where:*

$$m = \begin{cases} m^\circ & \text{if} \quad \gamma < \frac{n \, N(n)}{2b} \equiv \tilde{\Gamma} \\ n & \text{otherwise} \end{cases}$$

Corollary 1.1. *The threshold in Proposition 1.1 ($\tilde{\Gamma}$) is increasing in n, meaning that when competition is more intense, relatively less efficient inventors are able to introduce larger innovations.*

Figures 1.1 graphically represents Proposition 1.1 and Corollary 1.1. Instead, Figure 1.2 shows the condition in Proposition 1.1 in terms of the intensity of competition.[11] Using eqs. (1.21) and (1.22), it is possible to analyse and decompose the

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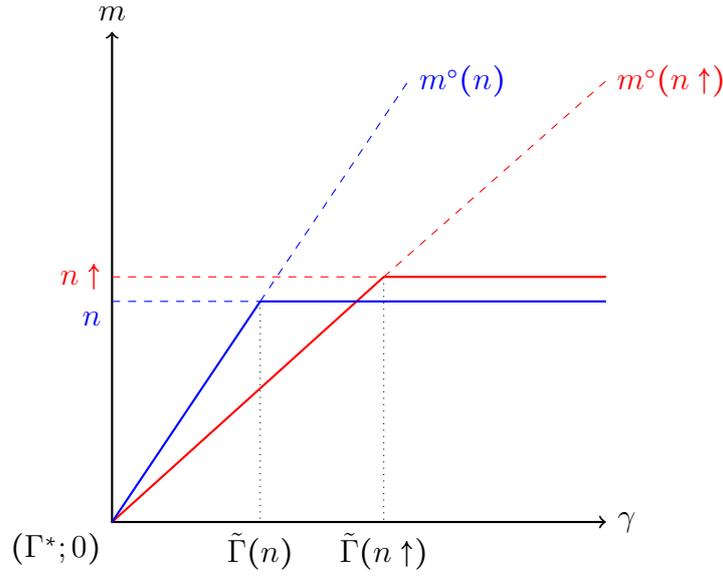[11]It is possible to rewrite the condition in Proposition 1.1 as: $m = m^\circ$ if $n > \tilde{n}(b\gamma)$

Figure 1.1: Optimal number of licensees m and the cost of technology γ.

effect of competition intensity on total revenues from licensing TR:

$$TR = \frac{32b\gamma^2 n(n+1)^2(a-c)^2}{\left(8b\gamma(n+1)^2 - n(n+2)^2\right)^2} = m^\circ F^\circ$$

$$\frac{\partial TR}{\partial n} = \frac{\partial TR}{\partial m}\frac{dm}{dn} + \frac{\partial TR}{\partial F}\frac{dF}{dn}$$

As the first component is always negative, the general effect will be positive only if the effect of competition on the licensing fee (which is the difference between the gross payoff of the adopters minus their opportunity cost) is positive and sufficiently large. This happens when the innovator is efficient enough, that is $\Gamma^* < \gamma < \frac{n(2+n)(2+3n(n+1))}{8b(n-1)(n+1)^2} \equiv \Gamma^\circ$.

Remark 1.2. *Competition (n) affects positively the size of innovation, and negatively the number of licensees. The revenues from licensing increase if the innovator is efficient enough ($\gamma < \Gamma^\circ$), and decreases otherwise.*

Let us now compute the equilibrium outcomes of the game. Replacing eqs.(1.22) and (1.21) in the profit function of the inventor and the payoffs of the manufacturers,
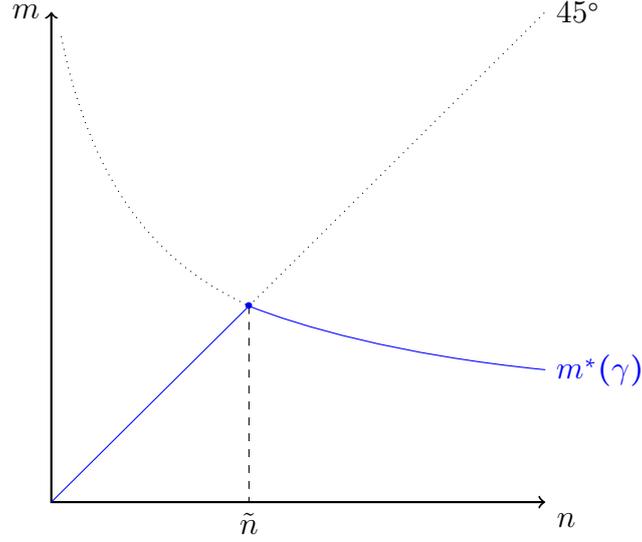
Figure 1.2: Equilibrium of licensees m and the number of active firms n

it is possible to derive:

$$\pi_u^\circ = \frac{4n(a-c)^2\gamma}{8b\gamma(n+1)^2 - n(n+2)^2} \tag{1.24}$$

$$\pi^A = \frac{(a-c)^2 \left(4b\gamma(n+1)^2 - n^2(n+2))^2\right)^2}{b(n+1)^2 \left(8b\gamma(n+1)^2 - n(n+2)^2)^2\right)^2} \equiv \hat{\phi}\pi_0 \quad \text{with} \quad \hat{\phi} < 1 \tag{1.25}$$

$$\pi^B = \frac{(a-c)^2 \left(4b\gamma(n+1)^2 - n(n+2)^2)^2\right)^2}{b(n+1)^2 \left(8b\gamma(n+1)^2 - n(n+2)^2)^2\right)^2} \equiv \hat{\theta}\pi_0 \quad \text{with} \quad \hat{\theta} < 1 \tag{1.26}$$

Where $\pi_0 = (a-c)^2/b(n+1)^2$ is the n-oligopoly Cournot per-firm profits if the technology A is not available - i.e. when $\gamma \to \infty$. From a comparison of the payoffs of the manufacturers, it is possible to see that both the adopters and the non-adopters are worse off after the introduction of the new technology. This result is not surprising, as it is a standard conclusion for fixed fee licensing contracts and I implicitly assume that the innovator is fully entitled to set the licensing fee he prefers.

Remark 1.3. *When the innovation is non-drastic, the fiercer the competition, the larger the investments in the cost-saving innovation, the lower the value of a patent.*

Finally, the total output is:

$$Q = m^\circ q^A + (n - m^\circ) q^B = q_0 \lambda \tag{1.27}$$

where

$$\lambda = \frac{4b\gamma(n+1)^2(2n+1) - n^2(n+2)^2}{8b\gamma(n+1)^2 - n(n+2)^2} > n$$

From eq.(1.27), we can write:

Remark 1.4. *Innovation has always a positive effect on the Consumer surplus, as it increases the output and lowers the market price of the final good, by improving the efficiency of the production process.*

Intuitively, from a welfare perspective, we observe underinvestment in R&D, as the innovator does not take into consideration the Consumer surplus in its maximisation problem, while a policy maker does. However, even considering a policy-maker who is totally producer-oriented - i.e., a policy-maker who assigns a zero-weight to Consumer surplus - one can see that the presence of an old technology that raises the opportunity cost of adoption poses the problem of double marginalization. Therefore, even in the extreme case of a producer-oriented policy-maker, we would observe underinvestment in equilibrium. To avoid this problem and establish efficient investments, the policy-maker should mandate a switch off of the old technology and let the innovator supply the new one in complete monopoly. However, a switch off of the old technology means that the supplier of the new technology would be able to extract the entire Producer surplus and that, crucially, only the adopters would be able to produce the final good. Therefore, as monopoly guarantees the highest Producer surplus, the innovator would set a sufficiently high licensing fee (equal to monopoly profits) to elicit the adoption by one firm only. Although this may be optimal from a pure Producer surplus perspective, it may worse off Consumer surplus by raising the market price in equilibrium. To give an example, consider the case of a market with n manufacturers, where market price is $P = \frac{nc+a}{n+1}$. A switch off of

the old technology would drive the market towards an "efficient" monopoly - i.e., a monopoly where production occurs by means of the new technology. This would alter the price of the final good to $P^M = \frac{c+a-x}{2}$. Consumer surplus increases if and only if:

$$P^M = \frac{c+a-x}{2} < \frac{nc+a}{n+1} = P \quad \Leftrightarrow \quad x > \frac{n-1}{n+1}(a-c)$$

After computing all the algebra, we have:

$$P^M < P \qquad \text{if} \quad \gamma < \frac{n}{2b(n-1)}$$

Which means that only a very efficient innovator can achieve a similar result. It is possible to summarise these results as:

Proposition 1.2. *The monopolist inventor underinvests in R&D. Removal of the standard technology (B) would induce an equilibrium investment in innovation that maximises the Producer surplus. However, if the inventor is not sufficiently efficient, such a policy makes consumers worse off.*

Industry shake-outs: k-drastic innovations

So far, I have only considered the case of a small innovation that does not alter the number of active firms in the market. Even under incomplete adoption, all the manufacturers produce positive quantities, and thus no potential sources of concern emerge from a Social Welfare perspective. Moreover, a larger rate of adoption is always beneficial to the Consumer surplus, as it necessarily comes together with a larger industry output and, consequently, a lower price of the final good.

In this section, I drop this assumption and extend the analysis to large innovations. Following Sen and Tauman[2007], let us define a k-drastic innovation as a cost-reducing technology which is large enough to imply the exit of non-adopting manufacturers when the innovation is sold to at least $k < n$ manufacturers. From Arrow [1962], we know that a drastic innovation consists in a large cost reduc-

tion that allows the innovator to set a monopoly price below the rival's marginal costs. This kind of innovation can be considered as a 1-drastic innovation, where the adoption by only one firm is sufficient to prevent any non-adopting firm from producing positive quantities of the final good. Formally, an innovation is k-drastic when the condition $k = \frac{a-c}{x}$ holds. When $m < k$ manufacturers pay the licensing fee, output expansion is relatively small and non-adopters are still able to produce positive quantities of the final good and stay in the market. Instead, if $m \geq k$, the adopters' output expands to such an extent that the price of the final good falls at the marginal costs of production faced by non-adopters, who are not allowed to produce any positive quantities.

It can be proved that the optimal number of licensees never exceeds $m^* = k = \frac{a-c}{x}$ (see Kamien and Tauman [1986]). The reason for this result is straightforward. If the number of licensees is $m^* = k$, by eqs.(1.13) and (1.14), we know that the final good is entirely produced by adopters by means of the new technology. Therefore, Producer surplus is simply the k-oligopoly industry profits - i.e., the sum of the profits made by the $m = k$ adopters. In order to extract part of the Producer surplus, the innovator sets a licensing fee that is equal to the difference between the gains derived from the adoption of the innovation (π_k^A) and the opportunity cost of adoption (π_{k-1}^B). In other words, as in the previous section, the mth firm is made indifferent between adopting the new technology and producing with the standard one.

Suppose now that the innovator decides to license an additional manufacturer to produce with the patented technology. Now, the number of active manufacturers becomes $m' = k + 1$ and the Producer surplus is the (k+1)-oligopoly industry profits. The opportunity cost of adoption is zero in this case, as it is not possible for any firm to produce positive quantities with the standard technology. Thus, the licensing fee set by the supplier is equal to π_{k+1}^A. This is true for any $m > k$, but, as Producer surplus is decreasing in the number of active firms, any additional firm endowed with

the innovative technology implies lower profits for the innovator. Since $k\left(\pi_k^A - \pi_{k-1}^B\right) > (k+1)\pi_{k+1}^A$, the equilibrium number of licensees is never above $m^\star = k$. Instead, if $m^\star < k$, non-adopters are able to produce positive quantities of the final good. This implies a re-allocation of the Producer surplus to non-adopters and a lower ability of the innovator to extract the surplus of the invention he sells. Thus, the equilibrium number of licensees is never below $m^\star = k$.

In this section, I focus on innovations that satisfy $k \geq \frac{a-c}{x}$, where $k < n$. In fact, as I am not assuming free entry, when $k \geq n$, the innovation can be considered as a non-drastic one and we go back to the non-drastic innovation scenario, which is analysed in section 1.3.2.

Remark 1.5. *In case of k-drastic innovation, where $k = \frac{a-c}{x} < n$, the optimal number of licensees is $m^\star = k$.*

Apparently, Remark 1.5 implies that the number of licensees is independent from the number of firms in the market and depends on the pre-innovation cost c and the size of the innovation x. I show that, as competition affects the size of the innovation, it also has an impact on the equilibrium number of licensees (m). Let us consider the value $m(x) = \frac{a-c}{x} = k$. When the innovator sells the innovation to $m(x)$ manufacturers, non-adopters exit the market and the equilibrium output of adopters is:

$$q^A(x) = \frac{(a-c+x)}{b(\frac{a-c}{x}+1)} = \frac{x}{b} \tag{1.28}$$

$$\pi^A(x) = \frac{x^2}{b} - F(x)$$

The total industry output is $Q = m(x) q^A(x) = \frac{a-c}{b}$ and the market price is $P(Q) = a - b(Q) = c$. Similarly to the previous section, the licensing fee paid by the adopters cannot exceed the difference between the profits they earn with the new technology, minus their opportunity cost of adoption (Participation Constraint):

$$F(x) \leq \frac{x^2}{b} - \frac{a - c - \left(\frac{a-c}{x} - 1\right)x}{b(n+1)^2} = \frac{n(n+2)x^2}{b(n+1)^2}$$

Which also implies that, in equilibrium, adopters earn:

$$\pi^A(x) = \frac{x^2}{b(n+1)^2}$$

Instead, the profits of the innovator consist of the sum of all the fixed fees collected minus the investment in the cost-reducing innovation $I(x) = \gamma x^2$:

$$\pi_u(x) = m^* F - I(x) = \frac{n(n+2)}{b(n+1)^2} x(a-c) - \gamma x^2$$

By embedding the Participation Constraint in the maximization problem of the inventor, simple maximization w.r.t. x yields the optimal size of the innovation:

$$x^* = \frac{n(n+2)(a-c)}{2b\gamma(n+1)^2} \tag{1.29}$$

from which we derive:

$$F^* = \frac{n^3(n+2)^3(a-c)^2}{4b^3\gamma^2(n+1)^6} \tag{1.30}$$

$$\pi_u^* = \frac{n^2(n+2)^2(a-c)^2}{4b^2\gamma(n+1)^4} \tag{1.31}$$

I use x^* to compute the optimal number of licensees:

$$m^* = \frac{2b\gamma(n+1)^2}{n(n+2)} \tag{1.32}$$

which is a decreasing function of n and coincides with the number of licensees $m°$ derived in the case of non-drastic innovations. Remember from section 1.3.2 that $N(n) = \frac{n(n+2)}{(n+1)^2}$; we can rewrite $m^* = \frac{2b\gamma}{N(n)}$. From eq.(1.32), we are able to state the following proposition:

Proposition 1.3. *The equilibrium number of licensees with k-drastic innovation is $m^* = 2b\gamma/N(n)$. Moreover, the number of licensees decreases when competition increases.*

Proposition 1.3 contributes to the literature on licensing and the value of patents by considering the size of the innovation as a variable which is not exogenously given, but which is chosen by the innovator and depends on the environment in which he is operating. Moreover, Proposition 1.3 shows that, as the innovator's investments depend on competition, the equilibrium number of licensees is also connected to the initial number of manufacturers active in the product market. As competition intensifies, the incentives to invest in innovation grow, because the competitive pressure strengthens the drastic effects of the innovation and zeros out the opportunity cost of adoption of the manufacturers, raising their willingness to pay in order to survive in the market $(F_n' > 0)$.[12] When the incentives to invest rise, the innovator puts more effort in the development of the innovation and the size of the innovation in equilibrium increases. Therefore, we expect that, in concentrated markets, where the incentives to invest are relatively weak - as the standard technology already provides the manufacturers with a substantial payoff - the innovation size is more likely to be small.

The implications of the introduction of a k-drastic innovation are several. Proposition 1.3 states that m^* is lower in markets with many manufacturers. That is, the more competitive the market, the more drastic the innovation, and consequently the fewer the number of licensees. So, competition affects also the magnitude of the shake-outs due to the introduction of an innovation. As the equilibrium size of x increases because of the competition, the innovation becomes more drastic and the number of licensees m^* decreases. We can decompose the effect of n on m^*, x^* and total revenues as follows:

$$ m^* = \frac{2b\gamma(n+1)^2}{n(n+2)}; \qquad x^* = \frac{Q}{m^*}; \qquad TR = m^* F^* $$

---

[12] When the competitive pressure is stronger, the innovation size increases and the condition $x > \frac{a-c}{n-1}$ is more easily satisfied. Moreover, if $x \uparrow$, the number of licensees shrinks. The adopters' payoff (before paying the upfront fee) increases with n and their opportunity cost π^B falls. Thus, as F is such to satisfy $\pi^A = \pi^B$, we have that $F_n' > 0$.

where $Q = \frac{(a-c)}{b}$ is the total industry output.

$$\frac{\partial m^*}{\partial n} = -\frac{4b\gamma(n+1)}{n^2(n+2)^2} < 0 \tag{1.33}$$

$$\frac{\partial x^*}{\partial n} = \frac{\partial x^*}{\partial m^*}\frac{dm^*}{dn} \tag{1.34}$$

$$\frac{\partial TR}{\partial n} = \frac{\partial TR}{\partial m^*}\frac{dm^*}{dn} + \frac{\partial TR}{\partial F^*}\frac{dF^*}{dn} \tag{1.35}$$

Eq. (1.34) is always positive, as depends uniquely on the number of licensees chosen in equilibrium by the innovator. Instead, total revenues depend on both m^* and the upfront fee F^*. The first component of the RHS of eq. (1.35) is negative as $\frac{\partial m^*}{\partial n} < 0$. Instead, the licensing fee increases when competition becomes fiercer. The increase in the magnitude of the upfront fee more than compensates the reduction in the number of licenses collected.

Remark 1.6. *The industry shake-out that results from the introduction of a large innovation is expected to be more severe in a more competitive market. This is so, as competition increases the size of the cost-saving effect x in equilibrium, making the innovation more drastic. Consequently, the innovator's total revenues from licensing increases as competition intensifies.*

It is worth spending few words on the cost parameter γ. Similarly to the previous section with small innovations, γ represents the cost associated to the R&D activities and can be interpreted as a proxy for the inverse of innovator's efficiency. The higher γ, the more the innovator must pay to obtain a given size of innovation - i.e., the cost parameter γ affects the size of the innovation produced, as it alters the innovator's cost of developing an innovation. Therefore, an efficient innovator is more likely to produce a more drastic innovation than an inefficient one. Formally,

$$x'_\gamma = -\frac{n(n+2)}{2b(n+1)^2\gamma^2}(a-c) < 0$$

Also, we already know that a k-drastic innovation implies, at least, $(n-1)x \geq$

$(a - c)$. Adapting the condition derived in section 1.3.2, we know that for the innovation to be k-drastic, it must be that:

$$\gamma < \frac{3n^2(n+2)}{8b(n+1)^2} \equiv \Gamma^* \tag{1.36}$$

Eq. (1.36) represents the efficiency requirement that the innovator must satisfy in order to be able to produce a k-drastic innovation. Intuitively, less drastic innovations are achievable by less efficient innovators. However, competition alters the efficiency requirement helping inefficient innovators $(\Gamma'_n > 0)$ develop innovations that are larger than if they were sold them in a concentrated market, given their "type" γ. The logic behind this result is simple and consistent with the previous part of the article, as it derives from the fact that competition acts as a trigger for the incentives and the size of the innovation $(x'_n > 0)$. We can summarise this analysis and state that:

Corollary 1.2. *The more efficient the innovator* $(\gamma \downarrow)$*, the more drastic the innovation. However, competition fosters less efficient innovators to produce k-drastic innovations* $(\Gamma^* \uparrow)$*.*

Finally, let us compare the results above with those derived in the previous section; for the innovation to be k-drastic, we must have:

$$m^* = \frac{2b\gamma(n+1)^2}{n(n+2)} < n \iff \gamma < \frac{n^2(n+2)}{2b(n+1)^2} \equiv \tilde{\Gamma}$$

For any $n \geq 2$, one can see that $\tilde{\Gamma} \geq \Gamma^*$ - which is the lowest bound of γ for the innovation to be non-drastic. Thus, Γ^* can also be interpreted as the efficiency threshold that sorts the inventors who are sufficiently efficient to introduce a k-drastic innovation $(\gamma < \Gamma^*)$ from those who are not $(\gamma \geq \Gamma^*)$, while $\tilde{\Gamma}$ sorts inventors that elicit incomplete adoption of the superior technology $(\gamma < \tilde{\Gamma})$ from those who elicit complete adoption $(\gamma > \tilde{\Gamma})$. Interestingly, and consistently with both Corollary
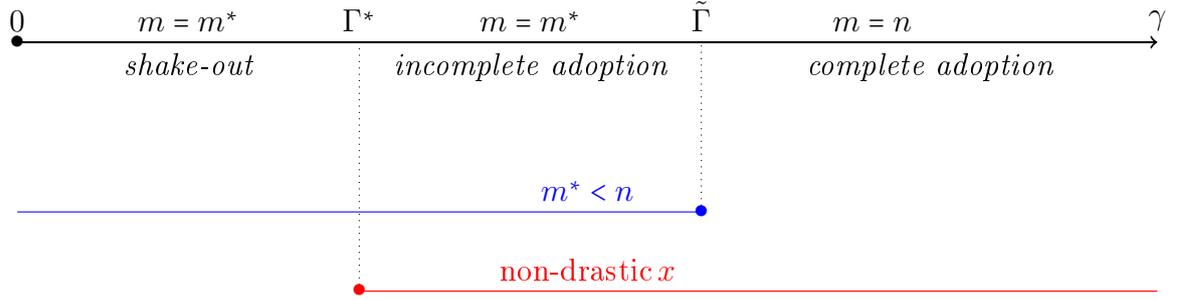
Figure 1.3: The effects of innovation on market structure, depending on the efficiency of the innovator γ.

1.1 and Corollary 1.2, both thresholds are negatively related to the intensity of competition $(\Gamma_n^*, \tilde{\Gamma}_n > 0)$. It follows that:

Proposition 1.4. *Consider an inventor ℓ. We observe the following cases:*

i) if $\gamma_\ell < \Gamma^*$, we have a k-drastic innovation and the non-adopters' exit from the market;

ii) if $\Gamma^* < \gamma_\ell < \tilde{\Gamma}$, we have a non-drastic innovation and incomplete adoption;

iii) if $\gamma_\ell > \tilde{\Gamma}$, we have a non-drastic innovation and complete adoption.

Figure 1.3 represents Proposition 1.4 graphically.

We can summarise the effects of a cost-saving innovation on market price and firms' cost structure by looking at figure 1.4. In both panels, the horizontal axis measures the inverse of the cost parameter γ - i.e. it measures the efficiency of the inventor. Inventors associated to a higher $1/\gamma$, all else equal, are going to introduce a more effective innovation. The two panels represent two different market structures, with n and $n' > n$, as downstream producers. As competition becomes more intense, it becomes easier to produce a k-drastic innovation - i.e., $1/\Gamma^*$ shifts to the left. Moreover, the effect of innovation on the market price P^* is lower - i.e., $\frac{nc+a}{n+1} > \frac{n'c+a}{n'+1}$. Instead, the downstream producers' marginal costs $(MC = c - x)$ fall sharply, as competition prompts the size of the innovation $(x'_n > 0)$. This means that, when the market is highly competitive, the rise of markups is expected to be larger.[13]

---

[13]Here, I adopt the Lerner index to define the markups of the adopting manufacturers: $\mu^A = \frac{P-MC}{P} = \frac{c-(c-x)}{c} = \frac{x}{c}$. It is easy to see that, as $x'_n > 0$, then $\mu'_n > 0$.
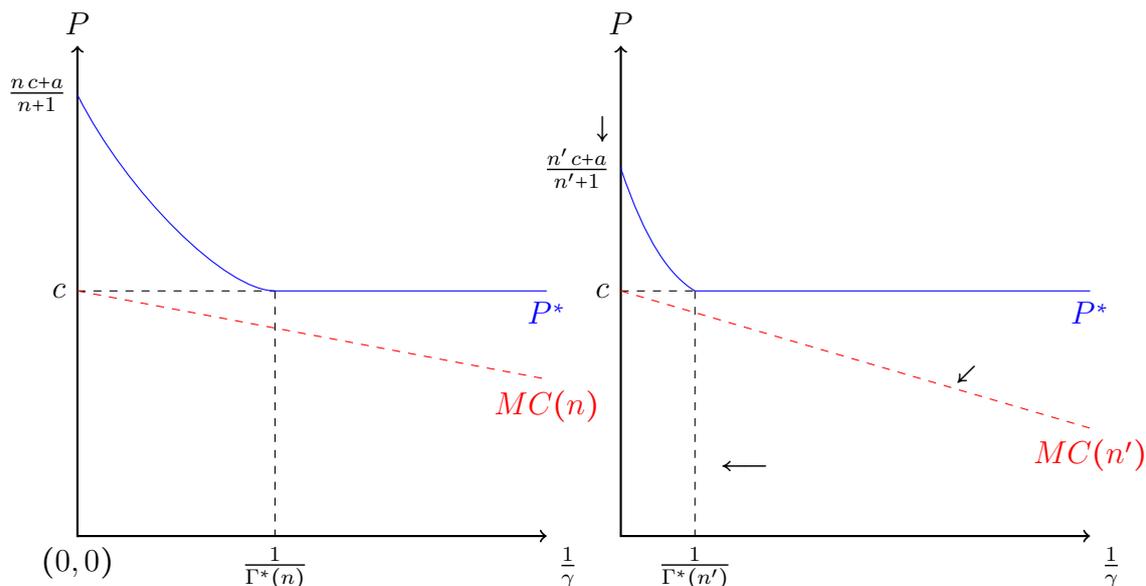
Figure 1.4: The effect of innovation on the market price P and the marginal costs of downstream producers MC with different market structures $n' > n$. The size of the innovation is measured in terms of innovator's efficiency $1/\gamma$ (given the market structure). The more competitive the market (right hand panel), the less effective the innovation in lowering the price of the final good. When the market is highly competitive, inefficient inventors (high γ) are relatively more successful in introducing larger innovations.

However, this is mainly driven by the change in the cost structure of the firms that have now to repay a fixed cost component - i.e., the licensing fee - and it is not associated to a fall in the Consumer surplus.

Corollary 1.3. *The more intense the competition in the product market, the higher the threshold Γ^* and the easier it is to introduce a k-drastic innovation. However, competition softens the effects of the new technology on the price of the final good, while it increases the firms' markups.*

1.3.3 Discussions and Welfare implications

From the Social Welfare perspective, k-drastic innovations imply a clear and general increase in Social Welfare, defined as the sum of Consumer and Producer surplus. In fact, by lowering the market price to the pre-innovation marginal costs of production and increasing the efficiency of the production process, k-drastic innovations have a

positive impact on both the components of Social Welfare.

If we look at the optimal size of the innovation, we observe underinvestment in R&D in equilibrium, as the upstream innovator does not internalise the Consumer surplus in his maximization problem, and the presence of an alternative technology prevents the innovator from fully extracting Producer surplus. If we consider the problem of a policy-maker that wants to maximize Social Welfare, we have:

$$SW = \frac{bQ^2}{2} + (a - c + x - bQ)Q - \gamma x^2$$

Simple maximization w.r.t. the total output and the size of the innovation leads to, respectively:

$$Q^w = \left(\frac{2b\gamma}{2b\gamma - 1} \right) \frac{a - c}{b} > Q^*$$

$$x^w = \frac{a - c}{2b\gamma - 1} > x^*$$

The policy-maker expects a larger output and more investments in R&D. However, it is impossible to reach an efficient allocation in a market where a k-drastic patented innovation is introduced. In fact, the monopolist innovator is always able to keep the market price at the pre-innovation competitive level by lowering the number of active firms and controlling the total output produced. We can refer to this ability of the inventor as the "hidden bargaining power". The analysis of the potential effects (either positive or negative) of such a distribution of the surplus generated by the introduction of the new technology is beyond the scope of this article. Here, I simply show that a process of market power accumulation by the inventor is a possible outcome and the policy-makers' concerns may be valid.

The innovator benefits from operating in a competitive market $(\partial \pi_u^* / \partial n > 0)$, as he can appropriate all the surplus generated by innovation. The more competitive the market, the higher the licensing fee paid for adoption and the lower the adopters' profits in equilibrium $(\partial \pi_d^A / \partial n < 0)$. Thus, inventions in perfectly competitive mar-

kets generate a surplus which entirely increases Producer surplus (the price of the final good does not vary) and is fully appropriated by the innovator. Instead, when the market is highly concentrated, part of the surplus generated by the innovation goes to Consumer surplus (lowering the price of the final good from $n(c+a)/(n+1)$ to c). Moreover, the innovator's surplus extraction is frustrated also by the fact that the manufacturers have large market power and opportunity costs of adoption, and are therefore more reluctant to pay a high licensing fee. It is possible to summarise these results as:

Proposition 1.5. *The effect of a k-drastic innovation on the Consumer surplus is always positive. However, the more firms are driven out of the market, the larger the markups of the adopting manufacturers, and the larger the profits of the inventor.*

Finally, looking at the incentives to invest in innovation, it is apparent that competition in the downstream sector is beneficial to the innovator's effort to produce a large innovation. This is in line with the Arrowian theory, according to which the manufacturers are willing to pay a larger fee to leapfrog their rivals when competition is stronger. However, things are less clear when we look at the innovator's sector. Here, the analysis focuses on the case of a monopolist inventor who benefits from patent protection that prevents competition in the innovative technologies. Dropping this assumption makes the analysis fuzzy. On the one hand, competition reduces the ability of the innovator to appropriate the value generated by his invention, generating the well-known hold-up problem, which may further lower the already insufficient investments in R&D. On the other hand, several firms competing in the R&D stages may prompt replication of efforts, inducing overinvestments. Competition in R&D, however, decreases the licensing fee, increases the manufacturers' surplus, and reduces the market price to a lower level than a patented k-drastic innovation. Thus, the effect of competition among inventors, although ambiguous, highlights the fact that both competition and concentration might be required to stimulate investments in R&D and there might not be a superior market structure.

1.4 The choice of the licensing scheme: a comparison of the incentives

In this section, I compare the results in sections 1.3.1 and 1.3.2, in order to understand which licensing contract the innovator enforces in order to sell his innovation to the manufacturers and maximise his profits. From section 1.3.1, we know that, when the inventor licenses his technology with a royalty-based contract, his profits would be as described in eq. (1.11), regardless of the size of the innovation x. Instead, if the licensing scheme enforced by the inventor is an upfront fee, then the size of innovation is an important variable in order to determine the revenues from licensing. In particular, in section 1.3.2 we have seen the case of both non-drastic and k-drastic innovations, where the inventor's profits are defined by eqs. (1.24) and (1.31), respectively. If the type of the innovator is such that $\gamma \geq \Gamma^*$, then the innovation would be non-drastic. Otherwise, when $\gamma < \Gamma^*$, the innovator is able to develop a k-drastic innovation.

Therefore, in order to determine the optimal licensing scheme from the inventor's perspective, we have to compare all the outcomes, case by case.

$$
\pi_u^F > \pi_u^r \quad \Leftrightarrow \quad
\begin{cases}
\frac{n^2(a-c)^2}{4\gamma b^2(n+1)^2} < \frac{n^2(n+2)^2(a-c)^2}{4b^2\gamma(n+1)^4} & if \quad \gamma < \Gamma^* \\[2mm]
\frac{n^2(a-c)^2}{4\gamma b^2(n+1)^2} < \frac{4n(a-c)^2\gamma}{8b\gamma(n+1)^2 - n(n+2)^2} & otherwise
\end{cases}
\tag{1.37}
$$

where the superscripts F and r indicates the contract type and stands for upfront fee and royalties, respectively. Since $n^2(n+2)^2/(n+1)^4 > n^2/(n+1)^2$, the first condition in eq.(1.37) is always satisfied. Instead, the second condition is satisfied for $\gamma > \bar{\bar{\Gamma}} > \Gamma^*$, as:

$$
\frac{4n(a-c)^2\gamma}{8b\gamma(n+1)^2 - n(n+2)^2} - \frac{n^2(a-c)^2}{4\gamma b^2(n+1)^2} > 0
$$

$$
\frac{(4\gamma b^2(n+1)^2)(4n(a-c)^2\gamma) - (8b\gamma(n+1)^2 - n(n+2)^2)(n^2(a-c)^2)}{(8b\gamma(n+1)^2 - n(n+2)^2)(4\gamma b^2(n+1)^2)} > 0
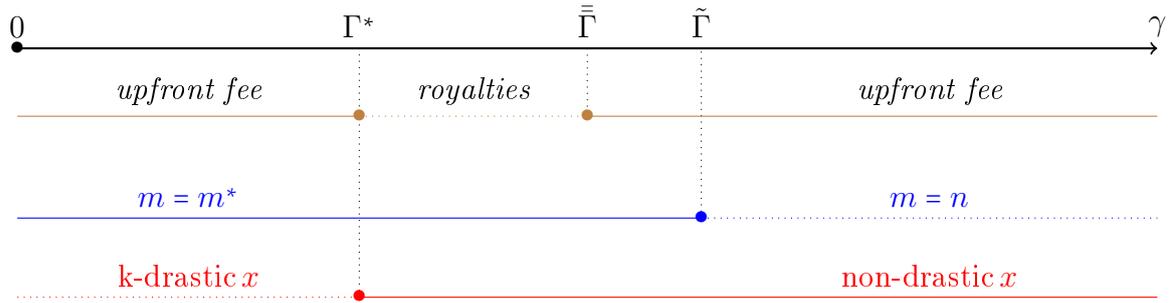$$

Figure 1.5: the innovator chooses the licensing contract depending on his own efficiency (and competition level). When the innovation is k-drastic, upfront fee is always preferred to royalties. The same when the innovator is very inefficient. Instead, for intermediate value of γ, royalties are superior to upfront fee.

$$\frac{(a-c)^2 n \left((8b\gamma(n+1)^2)(2b\gamma-n)+n^2(n+2)^2\right)}{(8b\gamma(n+1)^2-n(n+2)^2)(4\gamma b^2(n+1)^2)} > 0$$

The denominator is always positive for $\gamma > \Gamma^*$. The numerator is positive if $\gamma > \frac{n\left((n+1)+\sqrt{n^2+3n+3}\right)}{4b(n+1)} \equiv \bar{\bar{\Gamma}}$. Furthermore, one can see that $\Gamma^* < \bar{\bar{\Gamma}} < \tilde{\Gamma}$. It follows that:

Proposition 1.6. *Consider an inventor ℓ. We observe the following cases:*

i) if $\gamma_\ell < \Gamma^*$, the innovator develops a k-drastic innovation and licenses it by offering an upfront fee licensing contract;

ii) if $\Gamma^* < \gamma_\ell < \bar{\bar{\Gamma}}$, the innovator develops a non-drastic innovation and licenses it to all manufacturers by offering a royalty-based licensing contract;

iii) if $\bar{\bar{\Gamma}} < \gamma_\ell < \tilde{\Gamma}$, the innovator develops a non-drastic innovation and licenses it to just $m^* < n$ manufacturers by offering an upfront fee licensing contract;

iv) if $\gamma_\ell > \tilde{\Gamma}$, the innovator develops a non-drastic innovation and licenses it all manufacturers by offering an upfront fee licensing contract.

Figure 1.5 represents Proposition 1.6 graphically. Proposition 1.6 contributes to the recent findings in the literature on licensing and the value of patents (Sen and Tauman [2018] and Sen[2005]), where royalty based licensing contracts are found to be superior to upfront fees, for general size of the innovation, if the number of competitors in the product market is sufficiently high. The results in this article

suggest that competition intensity in the product market affects the equilibrium size of innovation ($x_n' > 0$). Thus, the same innovator would invest more in x if the product market is more competitive. Moreover, if the competition is particularly intense, the inventor is able to develop an innovation that is large enough to generate an industry shake-out. When this is the case, an upfront fee licensing contract is always preferred to royalties, as it increases the value of the patent and allows the innovator to earn larger profits.

1.5   Discussion and Conclusion

This article investigates the effect of competition on the choice of licensing contract and consequently, the number of licensees in equilibrium. Furthermore, the results suggest that upfront fee licensing contracts are preferred by an external innovator when competition is either very soft or very strong. Instead, for an intermediate value of competition intensity, the innovator maximises his profits by offering a per-unit royalty-based contract. The analysis is divided into two main parts. First, I analyse the scenario where the innovation is licensed with a royalty-based contract. Second, I turn to the case in which the contract type chosen by the innovator is an upfront fee. Here, I differentiate the analysis between non-drastic and k-drastic innovations and I compare the two cases. Also, I define some useful thresholds that help characterise the results and understand when a k-drastic innovation is a feasible market outcome.

The main purpose of this analysis is to understand the effect of competition on the three main licensing outcomes: the size of innovation, the number of licensees, and the revenues from licensing. I show that, regardless of the type of contract chosen by the innovator, the size of innovation is always larger when competition is stronger. Instead, the number of licensees depends on the licensing contract enforced by the innovator: on the one hand, in case of royalties, the optimal choice

is to license the innovative technology to all the manufacturers; therefore, as the number of firms in the product market increases, so does the number of licensees. On the other hand, in case of upfront fees, competition entails a negative effect on the number of adopters. In fact, the stronger the competition, the larger the innovation and the investment in equilibrium, and the higher the fee asked by the innovator. Since the new technology becomes more expensive, the manufacturers are willing to pay the high fee only if the number of adopters is small (as the benefit from adoption decreases in the number of adopters). Finally, the effect of competition on the revenues from licensing also depends on the contract type. In case of royalties, expanding the number of manufacturers leads to an increase in the number and the level of the royalties collected. In case of upfront fees, competition always raises the revenues from licensing if the innovation is k-drastic (which implies either strong competition or high innovator's efficiency). If the innovation is non-drastic, then competition has a positive effect only if the innovator is sufficiently efficient.

Interestingly, the effect of a cost-reducing innovation on the Consumer surplus is weaker when competition is stronger. Moreover, if the market is perfectly competitive, introducing an innovation does not alter the market price and the total output, regardless of the size of the cost-reducing effect. This result suggests that monopolist innovators who are able to produce large innovations are entitled to be market makers. Thus, the post-innovation market becomes impervious to competition and external regulation. The problem of market power accumulation by the so-called superstar firms is a topical issue and this paper suggests that such a process is compatible with the introduction of a new technology in a vertical market. However, an analysis of the impact of this market power accumulation on the economy is beyond the scope of this article and is left aside as a subject for future investigations.

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Appendix 1

Appendix A.1

Product differentiation

Throughout Sections 1.2-1.3, I assume that firms sell homogeneous products. As already mentioned, such a simplification does not hide any fundamental result and it is therefore made in order to keep the analysis as simple as possible. However, here I am going to change this assumption with a more general one. Let us consider the same setting as illustrated in Section 1.2, but instead of identical firms that produce the same good, let us assume that the downstream sector is populated by n firms that produce differentiated products, with β being the parameter that indicates how the products differ. If $\beta = 1$, the final goods produced are identical and we go back to the case analysed in the core part of the article; instead, if $0 < \beta < 1$, the firms produce final goods which are not perfect substitute. For technical reasons, I do not consider independent goods - i.e., $\beta = 0$, which would imply monopoly. Instead, I assume $\beta > 2/n \equiv \underline{\beta}$. In this way, it is possible to test the robustness of the main results derived above with a different measure of competition - i.e., the degree of product differentiation. The inverse demand function faced by each manufacturer becomes:

$$P_i(Q) = a - b\left(q_i + \beta \sum_{j \neq i} q_j \right)$$

with $i, j = 1, ..., n$. For sake of simplicity, in what follows, I set the slope of the inverse demand function $b = 1$.

Let us rewrite eq. (1.1) accordingly:

$$\pi_i = \begin{cases} (a - q_i - \beta Q_{j \neq i} - (c - x))q_i - F(x) & \text{if} \quad i \in A \\ (a - q_i - \beta Q_{j \neq i} - c)q_i & \text{if} \quad i \in B \end{cases} \tag{1.38}$$

while eq. 1.2 does not vary.

The structure of the game is the same as shown in Section 1.2; first, from eq. (1.38) I derive the solution of the downstream subgame, given the size of innovation x and the licensing fee $F(x)$; then, I go backward to the innovator's problem and I find the equilibrium size of x and number of adopters m.

Let us rewrite eqs. (1.13), (1.14), (1.15), and (1.16) according to the new setting:

$$q^A = \frac{(a - c)(2 - \beta) + (2 + \beta(n - m - 1))}{(2 - \beta)(2 + \beta(n - 1))} \tag{1.39}$$

$$q^B = \frac{(a - c)(2 - \beta) - m \beta x}{(2 - \beta)(2 + \beta(n - 1))} \tag{1.40}$$

$$\pi^A = \frac{\left((a - c)(2 - \beta) + (2 + \beta(n - m - 1))\right)^2}{\left((2 - \beta)(2 + \beta(n - 1))\right)^2} - F(x) \tag{1.41}$$

$$\pi^B = \frac{\left((a - c)(2 - \beta) - m \beta x\right)^2}{\left((2 - \beta)(2 + \beta(n - 1))\right)^2} \tag{1.42}$$

Consider the case where the innovator wants to elicit the adoption of the new innovation by exactly m manufacturers. Then, the payoffs of the mth downstream firm are:

$$\pi_m = \begin{cases} \frac{\left((a-c)(2-\beta)+(2+\beta(n-m-1))\right)^2}{\left((2-\beta)(2+\beta(n-1))\right)^2} - F(x) & \text{if} \quad m \in A \\ \frac{\left((a-c)(2-\beta)-(m-1)\beta x\right)^2}{\left((2-\beta)(2+\beta(n-1))\right)^2} & \text{if} \quad m \in B \end{cases} \tag{1.43}$$

The sufficient condition for m to be a stable equilibrium is:

$$F \leq \frac{x(2 + \beta(n-2))\left((a-c)(2-\beta) + (2 + \beta(n-2m))x\right)}{\left((2-\beta)(2+\beta(n-1))\right)^2} \quad (1.44)$$

Eq. (1.44) is the Participation Constraint of the innovator's maximization problem, which can be written as:

$$\max_{x;m} \pi^u = m F - \gamma x^2 \quad (1.45)$$

$$\text{s.t.} \quad F \leq \frac{x(2 + \beta(n-2))\left((a-c)(2-\beta) + (2 + \beta(n-2m))x\right)}{\left((2-\beta)(2+\beta(n-1))\right)^2}$$

By embedding the Participation Constraint in the profit function of the innovator, it is possible to rewrite eq.(1.20) as:

$$\max_{x;m} \quad \frac{m x(2 + \beta(n-2))\left((a-c)(2-\beta) + (2 + \beta(n-2m))x\right)}{\left((2-\beta)(2+\beta(n-1))\right)^2} - \gamma x^2 \quad (1.46)$$

from which we have:

$$m^* = \frac{2(2-\beta)^2\gamma(\beta(n-1)+2)^2}{(\beta(n-2)+2)(\beta n+2)} \quad (1.47)$$

$$x^* = \frac{2(a-c)(2-\beta)(\beta(n-2)+2)(\beta n+2)}{\beta\left(8(2-\beta)^2\gamma(\beta(n-1)+2)^2 - n(\beta(n(\beta(n-2)+6)-8)+12)-8\right)-8} \quad (1.48)$$

One can see that, by setting $\beta = 1$, i.e., by considering identical products, we go back to the same results illustrated in Section 1.3.2.

The rest of the mathematical analysis follows accordingly. Unfortunately, the same procedure for k-drastic innovations does not yield tractable results for x and m and we can only derive the equilibrium values of the outcomes in the downstream subgame - i.e., the output level and the Participation Constraint, given the size of innovation. However, if we set $\beta = 1$ the partial results coincide with those obtained in eqs. (1.28)-(1.32).

Now, let us analyse the effect of "competition" - measured as product similarity - on the size of innovation and the number of licensees in equilibrium, if we keep n

constant :

$$x'_\beta|_{n=\bar{n}} > 0; \qquad m'_\beta|_{n=\bar{n}} < 0 \qquad \forall\, \beta \in (\underline{\beta}, 1]$$

Similarly, if we hold the product differentiation parameter β constant and look at the effects of the number of active firms:

$$x'_n|_{\beta=\bar{\beta}} > 0; \qquad m'_n|_{\beta=\bar{\beta}} < 0 \qquad \forall\, \bar{\beta} \in (\underline{\beta}, 1]$$

These results suggest that competition, either measured in terms of the number of active firms or the degree of product differentiation, has a negative impact on the diffusion of a superior technology.

Remark 1.7. *The number of manufacturers that adopt the innovative technology decreases as the degree of product differentiation between the final goods becomes lower and/or the efficiency of the inventor increases. Moreover, we can write:*

$$m = \begin{cases} m^* & if \quad \gamma < \frac{n(\beta(n-2)+2)(\beta n+2)}{2(2-\beta)^2(\beta(n-1)+2)^2} \equiv \tilde{\Gamma} \\ n & otherwise \end{cases}$$

Finally, in order for the innovation to be non-drastic, we must have that $mx \geq \frac{(a-c)(2-\beta)}{\beta}$. Using eqs. (1.47) and (1.48), we have that:

$$mx \geq \frac{(a-c)(2-\beta)}{\beta} \qquad if \quad \gamma < \frac{(\beta(n-2)+2)(\beta n+2)^2}{4(2-\beta)^2\beta(\beta(n-1)+2)^2} \equiv \Gamma^*$$

With $\Gamma^* > \tilde{\Gamma}\ \forall\, \beta \in (\underline{\beta}, 1]$, and $\partial(\Gamma^* - \tilde{\Gamma})/(\partial\beta) > 0$, which means that, as products become closer substitutes, it is easier to have k-drastic innovations and (even more) incomplete adoption of non-drastic ones. Figure 1.6 synthesises the results.
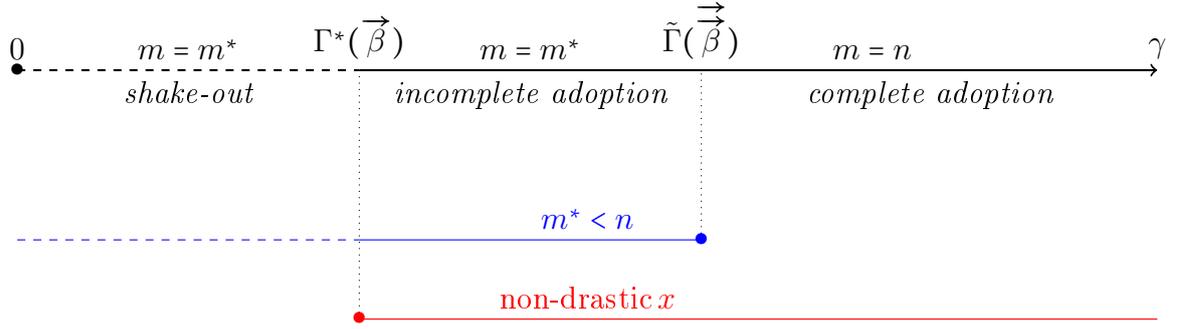
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Figure 1.6: The effects of innovation on market structure, depending on the efficiency of the innovator γ.

Appendix A.2

An alternative model of product differentiation

Instead of n firms competing on quantities for a homogeneous good, let us now assume that there are only two firms $\{i, j\}$ producing two differentiated products. There is a mass μ of consumers indexed by y uniformly distributed on the unit interval (Figure 1.7). A consumer with a "low" y prefers the brand produced by manufacturer i, while a consumer with a high y prefers the brand produced by manufacturer j. The utility function of the consumer can be written as:

$$
U_y \stackrel{\text{def}}{=} \begin{cases} a - p_i - t\,y \\[2mm] a - p_j - t(1-y) \end{cases}
$$

where a is the value the consumers assign to the final good, p_i and p_j are the prices of brand i and j, respectively, and t is the differentiation parameter: a low t means that the two products are similar, while a high t means that the two goods are very different in the eyes of the consumers. We assume that the two products are sufficiently differentiated, i.e., $t > \frac{\mu}{18\gamma} \equiv \bar{\bar{t}}$.

The two manufacturers can produce the final good either with a standard technology at a cost c per unit, or with an innovative technology sold by an outside
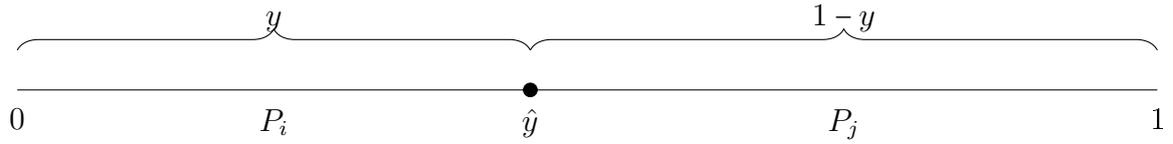
Figure 1.7: Hotelling's line: μ consumers indexed by y on the unit interval with uniform density

monopolist innovator at a price F. In this case, the firms lower their costs of production from c to $c - x$ per unit, where x represents the size of the cost-reducing effect. In order to develop the innovation, the innovator invests $I(x) = \gamma x^2$. The total cost function of the manufacturers can be written as:

$$TC(q_i) = \begin{cases} c\, q_i & \text{(Standard)} \\ (c - x)q_i + F(x) & \text{(Innovative)} \end{cases}$$

where $F(x)$ is the adoption fee, with $F(0) = 0$.

I assume that all the firms can produce the output with the standard technology at no extra cost than the marginal ones. Following the standard procedure, we can find the position of the indifferent consumer on the unit interval. We index him/her with $\hat{y}$:

$$\hat{y} = \frac{p_j - p_i + t}{2t}$$

Now, we define the profit functions of the two manufacturers:

$$\pi_i = \mu\, \hat{y}(p_i - c + x_i) - F(x_i)$$

$$\pi_j = \mu\, (1 - \hat{y})(p_j - c + x_j) - F(x_j)$$

There are four possible scenarios: i) the two manufacturers decide to produce with the standard technology $(x_i = x_j = 0)$; ii) the two manufacturers adopt the innovative technology $(x_i = x_j = x > 0)$; iii) and iv) one firm (either i or j) produces the good with the standard technology, while the rival adopts the innovative one $(x_i \neq x_j)$.

$$P_j$$

		A	B
P_i	A	$\pi_i(A,A), \pi_j(A,A)$	$\pi_i(A,B), \pi_j(B,A)$
	B	$\pi_i(B,A), \pi_j(A,B)$	$\pi_i(B,B), \pi_j(B,B)$

Figure 1.8: Downstream manufacturers subgame. Strategy {A}: adoption of the innovative technology. Strategy {B}: standard technology. Payoffs follow π_i, π_j.

Solving the four scenarios, we obtain the following payoffs:

$$\pi(A,A) = \frac{\mu t}{2} - F; \qquad\qquad \pi(B,B) = \frac{\mu t}{2} \qquad\qquad (1.49)$$

$$\pi(A,B) = \frac{\mu(3t+x)^2}{18t} - F; \qquad\qquad \pi(B,A) = \frac{\mu(3t-x)^2}{18t} \qquad\qquad (1.50)$$

with:

$$\pi(A,B) \geq \pi(B,B) > \pi(A,A) \geq \pi(B,A)$$

Matrix in Figure 1.5 shows eqs (1.21) and (1.21) in a normal-form game matrix. The innovator sets a price that maximizes its profits. The licensing fee F would be either the maximum fee that a manufacturer would pay in order to be the only adopter, or the maximum fee that elicits the adoption by the two manufacturers. In other words, depending on the innovator's interest between selling one contract or two, the price of the license would be equal to the difference between the gain from adoption minus the opportunity cost of adoption - i.e., the profits that a manufacturer would obtain by deviating and producing with the standard technology.

$$F(1) = \frac{\mu(3t+x)^2}{18t} - \frac{\mu t}{2} = \frac{\mu x(6t+x)}{18t}$$

$$F(2) = \frac{\mu t}{2} - \frac{\mu(3t-x)^2}{18t} = \frac{\mu x(6t-x)}{18t}$$

From this, we derive the optimal level of cost-reducing innovation and the profits of

the innovator in the two cases:

$$
x^+ = \begin{cases} \frac{3\mu t}{18\gamma t - \mu} & \text{if one adopter only} \\[2ex] \frac{3\mu t}{9\gamma t + \mu} & \text{if two adopters} \end{cases}
\qquad
\pi^u = \begin{cases} \frac{\mu^2 t}{2(18\gamma t - \mu)} & \text{if one adopter only} \\[2ex] \frac{\mu^2 t}{9\gamma t + \mu} & \text{if two adopters} \end{cases}
$$

A simple comparison of the profits of the innovator gives us the following proposition:

Proposition 1.7. *When the two goods are sufficiently differentiated in the eyes of the consumers ($t > \mu/9\gamma$), the innovator prefers granting the access of its technology to both firms in the downstream segment of the industry. Otherwise ($t < \mu/9\gamma$), the innovator supplies the innovative input only to one manufacturer.*

Proof. By comparing the profits of the innovator in case of one and two adopters, it is easy to observe that:

$$
\frac{\mu^2 t}{2(18\gamma t - \mu)} > \frac{\mu^2 t}{9\gamma t + \mu} \quad \text{if} \quad t < \frac{\mu}{9\gamma}
$$

$\square$

The result is comparable with the one derived in the main part of the article. In fact, a high degree of product substitutability lowers the number of licensees sold in equilibrium. This result may be explained following the usual Arrowian replacement effect. As the product differentiation decreases, the market power of the firms falls accordingly, and so does the rent generated by the innovation. This is particularly evident in this setting with product differentiation. When the products are similar, the price competition pushes the profits of the manufacturers to zero and the innovator can only extract low rents - if any. Therefore, by allowing one firm to access the new technological standard, the innovator is able to portion the market and take advantage from the asymmetry generated by the new technological endowment. In fact, as the adopter increases her share of the market, she also

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increases her market power and allows the innovator to extract a higher surplus.

Appendix A.3

Equilibrium in mixed strategies

Define p as the probability that a firm adopts the new technology and $1 - p$ as the probability of non-adoption. Then, the expected payoffs of the mth manufacturer are:

$$\Pi(A) = -F + \sum_{j=0}^{n-1} \binom{n-1}{j} p^j (1-p)^{n-1-j} \frac{\left(a - c + x(n-j)\right)^2}{b(n+1)^2} \qquad (1.51)$$

$$\Pi(B) = \sum_{j=0}^{n-1} \binom{n-1}{j} p^j (1-p)^{n-1-j} \frac{\left(a - c - j\,x\right)^2}{b(n+1)^2} \qquad (1.52)$$

Where $j = m - 1$. From the definition of variance:

$$\sum_{j=0}^{n-1} \binom{n-1}{j} p^j (1-p)^{n-1-j} j^2 = (n-1)p(1-p)$$

eqs. (1.51) and (1.52) can be rewritten as:

$$\Pi(A) = -F + \frac{(a-c)^2 + 2x(a-c)(n - p(n-1)) + x^2\left(n^2(1-p)^2 + 3np(1-p) - p(1-2p)\right)}{b(n+1)^2}$$

$$\Pi(B) = \frac{(a-c)^2 - 2(n-1)px(a-c) + (n-1)px^2((n-2)p + 1)}{b(n+1)^2}$$

One can see that the mth firm chooses A if and only if $\Pi(A) \geq \Pi(B)$. That is when:

$$p(F) \leq \frac{nx(2(a-c) + n\,x) - bF(n+1)^2}{2(n-1)nx^2} \qquad (1.53)$$

Not surprisingly, the probability $p(F)$, that makes the mth manufacturer indifferent between either adopting the new technology ($\Pi(A)$) or producing with the standard one ($\Pi(B)$,) falls when the price of that technology F increases. More-

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over, one can see that $p(F) = 0$ when $F \geq \bar{F} \equiv \frac{nx(2(a-c)+nx)}{b(n+1)^2}$, while $p(F) = 1$ when $F \leq \check{F} \equiv \frac{nx(2(a-c)-(n-2)x)}{b(n+1)^2}$. In other words, when the price of the technology is high, the manufacturer is willing to pay the licensing fee if and only if few rivals, if any, adopt the new technology too - i.e., when the probability of adoption $p(F)$ is low. In fact, only when the adopters are very few, the gain from the new technology offsets the cost of adoption. As the price F starts falling, the innovation becomes more attractive to several firms - i.e., the probability $p(F)$ increases.

Given the probability $p(F)$, it is now possible to write the expected profits of the supplier:

$$\pi^u = -I(x) + \sum_{m=1}^{n} \binom{n}{m} p(F)^m (1 - p(F))^{n-m} \, m \, F \tag{1.54}$$

Again, by Binomial Theorem, eq.(1.54) can be rewritten as:

$$\pi^u = -I(x) + \left[n \, p(F) \right] F$$

The maximization of the innovator's profits w.r.t. the price of technology F yields to:

$$F = \frac{nx(2(a-c)+nx)}{2b(n+1)^2} \tag{1.55}$$

One can see that $F < \bar{F}$. Therefore, at least one firm is always willing to purchase the new technology and $p > 0$. On the other hand, $F > \check{F}$ if $x > \frac{2(a-c)}{3n-4}$ - i.e., when the innovation is sufficiently high, relatively to the competition level n. Finally, using eq.(1.55) in the profit function of the innovator and maximizing it w.r.t x, we obtain

$$x^* = \frac{2n^3(a-c)}{8b\gamma(n-1)(n+1)^2 - n^4} \tag{1.56}$$

which leads to the probability of adoption:

$$p^* = \frac{2b\gamma(n+1)^2}{n^3} \tag{1.57}$$

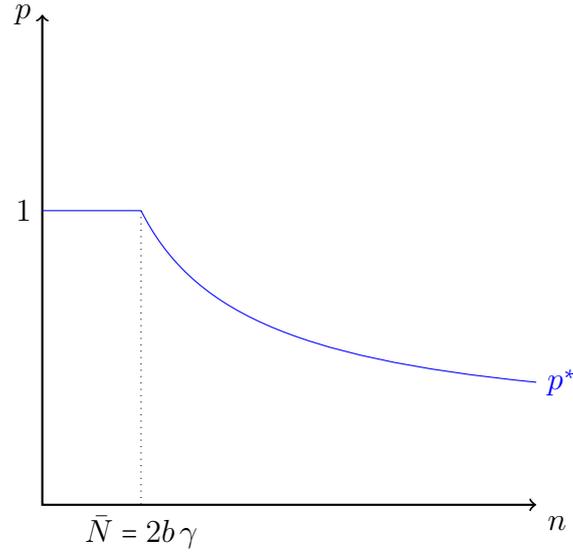Figure 1.9: The probability of adoption p, depending on the number of active firms n. If $\bar{\bar{N}}(n) < 2b\gamma$, the number of licensees is $m^* = n$. Instead, if $\bar{\bar{N}}(n) > 2b\gamma$, the number of licensees is $m^* = n\,p^*$.

where $\gamma > \frac{3n^4}{8b(n-1)(n+1)^2}$, to guarantee that the innovation is non-drastic - i.e., $nx \leq (a-c)$. Define $\bar{\bar{N}}(n) \equiv n^3/(n+1)^2$, therefore, eq.(1.57) can be rewritten as $p^* = 2b\gamma/\bar{\bar{N}}(n)$. Because $\bar{\bar{N}}(n)$ is a monotonic function of n, with $\bar{\bar{N}}'_n > 0$, it is possible to state that an increase in competition implies a lower probability of adoption - i.e., $p'_n < 0$. From the results above, we confirm the results in Proposition 1.1 and Corollary 1.1:

Remark 1.8. *The probability that a manufacturer adopts the innovative technology is decreasing in the number of manufacturers (n), where:*

$$
p = \begin{cases} p^* & \text{if} \quad \bar{\bar{N}}(n) > 2b\gamma \equiv \bar{N} \\ 1 & \text{otherwise} \end{cases}
$$

Remark 1.9. *The average number of licensees elicited by the innovator is decreasing*

in the number of manufacturers (n), where:

$$m = \begin{cases} n\,p^* & \text{if} \quad \bar{\bar{N}}(n) > 2b\,\gamma \equiv \bar{N} \\ n & \text{otherwise} \end{cases}$$

Moreover, $\partial(n\,p^*)/\partial n < 0$.

Using eq.(1.57) in the payoffs of the downstream manufacturers and the upstream inventor, it is possible to derive the equilibrium outcomes of the game, which are coherent with those derived in Section 1.3.2. Figure 1.9 shows Remark 1.8 graphically.

Chapter 2

Incentives for Labour-Augmenting Innovations: The Role of Wage Rate

SANDRINI, L. (2019), MARCO FANNO WORKING PAPER 232

2.1   Introduction

The relationship between technological progress and labour market conditions is increasingly attracting the attention of scholars and policy-makers. Usually, firms adopt factor-augmenting technologies in order to replace the most expensive factors of production, making better use of cheaper and relatively more abundant ones (Dosi [1984], and Acemoglu [2002]). In particular, innovative technologies often improve the productivity of labour, allowing adopting firms to replace labour with capital inputs. In this article, I argue that the degree of this replacement is influenced by the cost of labour. Furthermore, I show that, for a given market size, there is a non-obvious relationship between the wage rate and the incentives to invest in innovation based on two opposite forces: a positive cost-reducing effect and a negative output contraction effect. When the cost-reducing effect dominates, increasing the wage rate may have a positive effect on the size of the innovation, as well as on Producer and Consumer surplus. The link between the cost of labour and the incentives

to innovate is relevant in light of today's problems. Worldwide, more and more people are claiming for an increase in minimum wage at a national level.[1] This article represents a novel attempt to analyse the role of labour market conditions to determine not only the incentives to adopt labour-augmenting technologies, but also the incentives of an outside innovator to produce these technologies. I follow an Industrial Organization approach based on a model of a vertically related industry. I show that the incentives of an upstream innovator to develop a cost-reducing innovation depends on the characteristics of the product market.

Nowadays, firms often acquire innovative technologies developed by outside innovators, rather than producing them internally. As a consequence, the conditions of the labour market faced by those firms are likely to be relevant also in affecting the incentives of the upstream supplier of the new technology.

Examples of technologies that improve the productivity of labour abound. One may think at the ICT sector: developed by large upstream innovators, new software and services such as cloud computing services, algorithms, or 3D printers allow adopting firms to significantly improve the productivity of labour. Another example are robots and cobots (i.e., collaborative robots). In particular, cobots are industrial robots which are designed to collaborate with humans in the production process. Differently from traditional industrial robots, cobots are flexible units that help workers perform their routinised activities. Due to their flexibility, cobots are increasingly adopted by firms in sectors where industrial robots have never been adopted before. One of the most interesting sector is logistics, where many firms have introduced cobots in order to increase labour productivity in piece picking tasks. All these technologies have a great impact on the industry's performance, as they allow to improve both the quality and the quantity of the production. However, many scholars have pointed out the risk of a too fast rate of technological improvement on society, as it may foster unemployment and increase inequalities

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[1]Recently, the U.S. House of Representatives voted an increase in the federal minimum wage to 15 dollars/hour after years of workers' campaigns.

(see Acemoglu and Restrepo [2019], Berg et al. [2018], among others). In this article, I show that these concerns may be justified in case of large innovations, as the expansion in output following the cost-reducing effect of the innovation may be too low to absorb all the workers displaced by the introduction of the innovation. Instead, both total wage bill and profits benefit from a small improvement of the existing technology.

From a policy perspective, this article suggests that the introduction of a minimum wage may result in an adequate tool to improve the level of investments in innovative activities. Alternatively, a policy that generally raises the cost of labour - i.e., by making the labour market more rigid - should be taken into consideration. Raitano and Fana [2019] shows that young cohorts of workers who entered the job markets after the labour market reform of 2001 in Italy had worse economic conditions than colleagues that had entered the market before the reform. Hara et al. [2018] show that only 4% of the workers on the Amazon MTurk platform earn a hourly wage higher than the U.S. minimum wage. These works, among others, suggest that, in recent years, the approach followed by policy-makers has been to reduce the cost of labour by deregulating the labour market and making new atypical contract types emerge. This article suggests that this trend should be reverted and firms should be stimulated to invest in order to foster labour productivity.

This chapter is organized as follows: the rest of this section contextualises this article in the literature. Section 2.2 describes the model and the timing of the game; section 2.3 outlines the main results of the analysis, focusing first on the nature of the innovation and the conditions enabling its production and its adoption, then on the equilibrium outcomes of the game; a welfare analysis and extensions to the main model are developed in sections 2.4 and 2.5, respectively; finally, section 2.6 concludes.

2.1.1 Literature Review

The role of wage on the incentives to innovate has been the subject of a vast literature, with a special focus on rent sharing mechanism and the unionization structure (Grout [1984], Calabuig and Gonzalez-Maestre [2002], Haucap and Wey [2004], Manasakis and Petrakis [2009], and Mukherjee and Pennings [2011]); here, I am interested in understanding how an increase in workers' reservation wage affects the firms' incentives to innovate. Interestingly, I show that, under particular market conditions, industrial performance improves alongside with the wage level. Riley and Rosazza Bondibene [2017], with UK data, provide evidences that firms employing national minimum wage (NMW) workers respond to increases of the minimum wage level by fostering labour productivity. Contrary to mainstream arguments, they do not replace workers with capital, but they rather offer trainings in order to foster their productivity or they organize labour in a more efficient way. Moreover, the relationship between minimum wage and innovation has been widely studied in the literature, with a particular focus on the effects of a rise of the former on the incentives to invest in innovative activities (Lordan and Neumark [2018], Kleinknecht et al. [2014] and Petrakis and Vlassis [2004], among the others).

In order to address my research question, I adopt an approach that is directly inspired by the literature on automation (Acemoglu and Autor [2011], Acemoglu and Restrepo [2019]), where the quality of capital input determines the amount of labour that is necessary for the production of the final good.[2] Several studies try to show how innovation works and how it affects the production process, but the vast majority of them adopt a macroeconomics approach (Acemoglu and Restrepo [2017] and Aghion et al. [2017], among others). Instead, in this article I follow an Industrial Organization approach in order to further highlight the nexus between innovation, firms' strategic interaction and the conditions of the labour market. Interestingly,

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[2]From an Industrial Organization perspective, an increase in labour productivity is hardly distinguishable from automation in tasks. In fact, in both cases firms end up having a more capital intensive production function.

I find that small innovations tend to be beneficial to both the total wage bill and the profits, while large innovations may have negative impact on the total wage bill. This result seems to be at odds with findings in automation literature, according to which small changes in automation of tasks have the most negative effect on labour demand. However, in this paper I do not consider creation of new jobs as a consequence of innovation, and this may partially explain the divergence between the two very different approaches.

I model innovation in a vertically related market where an upstream firm produces an innovative/superior technology and sells it to several downstream firms (see Farrell and Shapiro [2008], Sen and Tauman [2007], Kamien and Tauman [1986], among others). Furthermore, I analyse how labour costs affect the incentives to invest in innovation of a monopolist innovator. When the market is sufficiently large, a positive variation in the wage rate raises the demand for a labour-augmenting innovation, which in turn decreases the costs of production and allows the downstream firms to expand their output. If the total production increases, the innovator extracts higher rents from each adopter. Instead, when the market is relatively small, the increase in wage may trigger an output contraction effect that ultimately lowers the incentives to innovate of the monopolistic innovator.

This paper also extends the analysis in Acemoglu and Pischke [1999] on firms' incentives to invest in labour-augmenting activities in an imperfect labour market. In particular, I apply the authors' results to an oligopolistic framework in order to discuss how the incentives for process innovation are affected by competition.[3]

2.2   The model

Consider an industry made of an upstream and a downstream sector. The downstream segment is populated by $n \geq 2$ identical firms (or *manufacturers*) that com-

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[3]Moreover, I show that innovation's profitability is not the only element that plays a role in affecting the incentives to invest in R&D and adopt innovation. Indeed, the conditions of the labour market are crucial for the innovator to decide to prompt or shrink the investments in innovation.

pete *a là* Cournot for a homogeneous good and face a linear inverse demand function $P(Q) = \delta - Q$, with $Q = \sum_{i=1}^{n}$ being the total industry output. In order to produce one unit of the final good, the downstream firms employ labour (L) and capital (K) inputs in fixed proportions, with the proportions depending on the quality of capital. Just to give a relevant example: the capital input can be seen as a new software, an algorithm, or, alternatively, an industrial collaborative robot. Technological progress improves the efficiency of the algorithm/cobots, namely, it increases their quality, enabling workers to complete their tasks at a faster pace, to waste less time moving from a workstation to the other, or simply to carry heavier weights. This improvement allows the manufacturers to employ fewer labour per unit of good produced.

Capital is produced in the upstream segment and sold to manufacturers as an input of production. There are two types of capital available to downstream firms: a *standard* capital input, and an *innovative* one. The former is produced competitively; it is of relatively low quality and produced in accordance with the current state of the art of the technology. Instead, the latter is sold in monopoly by an upstream inventor (or *supplier*) who owns a patent for the new technology. I normalize to zero the quality of the standard capital input, while the high quality input has a quality $\alpha > 0$ chosen by the inventor.

The production of the standard capital input requires one unit of labour for each unit of input produced $K = L$. Competition drives the price r of the standard input down to its marginal cost of production, which is the minimum wage paid to the workers, $r = w$. As the price of the innovative capital is concerned, I assume that the supplier offers a two-part tariff scheme made of a per-unit price and a non-discriminatory fixed fee. Following the standard theory of optimal non-linear pricing, the supplier sets the per-unit price r at his/her marginal cost of production and sets a fixed fee F to extract the downstream value that he/she generates. In order to keep the analysis as simple as possible, I assume that both types of capital

input are physically produced in the same fashion ($K = L$, with no differences in the type of workers employed). However, the supplier invests $I(\alpha) = \gamma\,\alpha^2$ in order to increase the quality of the input, where the parameter γ represents the cost of investing in quality.[4] Therefore, the objective function of the supplier can be written as follows:

$$\Pi_u = (r - w)K + m\,F(\alpha) - I(\alpha)$$

$$\Pi_u = m\,F(\alpha) - \gamma\,\alpha^2 \tag{2.1}$$

with $m \leq n$ being the number of manufacturers that adopt the innovative technology and pay the licensing fee $F(\alpha)$.

Formally, the production function of the manufacturers can be written as:

$$q_i = \min\left\{\frac{L}{1 - \alpha_i}; K\right\}$$

The parameter $\alpha_i = \{0; \alpha\}$ represents the quality of the capital input chosen by the firm i; a high quality capital input increases the productivity of workers and reduces the amount of labour input which is necessary to produce a single unit of the final good. The manufacturers observe the price of the two types of capital input and decide which one to adopt and how many workers to hire. Furthermore, I assume that capital inputs of different qualities are perfect substitutes. Depending on the choice of the technology, the profit function of the downstream firms is:

$$\Pi_d = \begin{cases} q_i\big(\delta - w - w - q_i - Q_{j\neq i}\big) & \text{if} \quad \alpha_i = 0 \\[2mm] q_i\big(\delta - w - w(1 - \alpha) - q_i - Q_{j\neq i}\big) - F(\alpha) & \text{if} \quad \alpha_i = \alpha > 0 \end{cases} \tag{2.2}$$

The timing of the game is as follows. At time 1, the supplier chooses the optimal

[4]I assume the investment is made before the production begins. One can think to $I(\alpha)$ as the combination of the cost of machinery and the salary of high-skilled workers who are hired to develop a new software which has no replication costs and it is simply added to the existing hardware.

level of α and sets the price of the high quality capital input. At time 2, the manufacturers which input to purchase and hire the correspondent number of workers at price w and compete (Cournot competition). As I am interested in the Subgame Perfect Nash Equilibrium, the game is solved by backward induction.

2.3 Results

2.3.1 Equilibrium size of innovation

Manufacturers choose their output to maximize profits. In order to produce, they either purchase the innovative capital input ($m \leq n$) or the standard one ($n - m$). So, the total output can be written as:

$$Q = m \, q^h + (n - m)q^s$$

where h and s stand for *high* quality and *standard* quality, respectively.

From the maximization of expression (2.2), the equilibrium output levels for the two types of firms are:[5]

$$q^h = \frac{\delta - w(2 - \alpha(n - m + 1))}{n + 1} \tag{2.3}$$

$$q^s = \frac{\delta - w(2 + m \, \alpha)}{n + 1} \tag{2.4}$$

where q^h is the output level of the manufacturers that adopt the high quality capital input, while q^s is the output level of those that choose the standard one. Using these

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[5]See the appendix for the formal details.

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two expressions, the profits of the two types of manufacturers are:

$$\Pi^h = \frac{\left(\delta - w(2 - \alpha(n - m + 1))\right)^2}{(n+1)^2} - F(\alpha) \qquad (2.5)$$

$$\Pi^s = \frac{\left(\delta - w(2 + m\,\alpha)\right)^2}{(n+1)^2} \qquad (2.6)$$

In what follows, I focus on the case where the quality improvement of the capital input is a non-drastic innovation - i.e., it does not imply the market exit of the non adopters. Here, I limit the analysis to small innovations as it allows a clear discussion of the relationship between the wage rate and the incentives to invest in quality of the capital input.[6] The innovator can influence the choice of the manufacturers by varying the price of the high quality capital input, and in particular the fixed fee $F(\alpha)$. The optimal fixed fee set by the supplier must depend on the chosen quality level, for reasons that are straightforward. First, if α increases, the investment $I(\alpha)$ increases too, and the innovator must raise the price in order to recover the initial investment. Second, the higher the quality of the capital input, the smaller the amount of labour that the manufacturers need to produce the final good. Employing less labour makes marginal costs to fall and revenues to rise. This positive effect is stronger, the higher the size of the innovation α produced by the supplier.

Let us analyse the maximum fixed fee the innovator can set in order to elicit the adoption of the new technology for m firms. The licensing fee F is such that, for the mth manufacturer it must be indifferent whether to keep producing with the standard technology or to adopt the new one. Thus, the mth manufacturer would adopt the new technology if and only if the following conditions are satisfied:

$$\Pi^h_{d,m} \geq \Pi^s_{d,(m-1)} \quad \text{and} \quad \Pi^s_{d,m} > \Pi^h_{d,m+1}.$$

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[6]See section 2.5.1, for an extension where k-drastic innovations are taken into consideration.

Using the definition of firms' profits, these two inequalities boil down to:

$$F \leq \frac{\left(\delta - w(2 - \alpha(n - m + 1))\right)^2}{(n+1)^2} - \frac{\left(\delta - w(2 + (m-1)\,\alpha)\right)^2}{(n+1)^2} \qquad (2.7\text{a})$$

$$F > \frac{\left(\delta - w(2 - \alpha(n + 1 - (m+1)))\right)^2}{(n+1)^2} - \frac{\left(\delta - w(2 + m\,\alpha)\right)^2}{(n+1)^2} \qquad (2.7\text{b})$$

If condition (2.7a) applies, then none of the m adopters has incentives to deviate and produce with the standard technology, as they would not be able to gain any extra profits on top of what they earned with the new one. Also, when condition (2.7b) applies, none of the firms producing with the standard technology wants to adopt the new one, as it would guarantee less profits than the standard one. One can see that condition (2.7a) is sufficient for the equilibrium to be stable, and it is the highest fee that the inventor can set.[7] Therefore, the fixed fee that induces m firms to adopt the new technology is:

$$F(\alpha) = \frac{\alpha\,n\,w\left(2(\delta - 2w) + \alpha\,w(n - 2(m-1))\right)}{(n+1)^2} \qquad (2.8)$$

By setting the fixed fee, the upstream firm decides how many firms m adopt the innovation, given a certain quality α. As the marginal benefits of adoption are decreasing in the number of adopters - i.e., $C2.7a > C2.7b$ - the equilibrium number of licensees m is unique for any given $F(\alpha)$. The following corollary states under which conditions all downstream firms adopt the innovation:

Corollary 2.1. *When the number of downstream firms is not too large, the innovator sets the adoption fee so that all the firms buy the new technology. Formally,*

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[7]See Appendix A.1 for the mathematical proof.

the equilibrium number of contracts signed by the innovator is n if:

$$n < \frac{2(\delta - w(2 - \alpha))}{3w}$$

which is satisfied for $\gamma > \frac{n^2(n+2)w^2}{2(n+1)^2} = \tilde{\Gamma}$

Proof. See the appendix. □

Going backward, we are now in the position to find the equilibrium level of investment of the upstream firm. For the sake of simplicity, we solve the model by assuming that the condition in Corollary 2.1 holds ($\gamma > \tilde{\Gamma}$) and $m = n$. therefore, using eq. (2.8) into eq. (2.1), we derive:

$$\Pi_u = n\,F(\alpha) - \gamma\,\alpha^2$$
$$= \frac{\alpha\,n^2\,w(2(\delta - 2w) - \alpha(n-2)w)}{(n+1)^2} - \gamma\,\alpha^2. \tag{2.9}$$

The innovator chooses α to maximize this expression. Simple differentiation reveals that the upstream supplier chooses $\alpha = \alpha^*$, where:

$$\alpha^* = \frac{n^2 w(\delta - 2w)}{\gamma(n+1)^2 + (n-2)n^2 w^2}.$$

It is useful to rewrite α^* as:

$$\alpha^* = \frac{n(\delta - 2w)}{n+1} \frac{n(n+1)w}{\gamma(n+1)^2 + (n-2)n^2 w^2} = f(w)\,\bar{Q}_d(w), \tag{2.10}$$

where $\bar{Q}_d(w) = n\bar{q}_d(w) = n(\delta - 2w)/(n+1)$ is the total output sold downstream when all the manufacturers produce with the standard capital input. I refer to $\bar{Q}_d$ and $\bar{q}_d$ as "the benchmark". From expression (2.10) the following proposition follows immediately:

Proposition 2.1. *The equilibrium level of investment undertaken by the upstream innovator depends on the wage rate; there exists a critical wage rate $\bar{w} > 0$ such that*
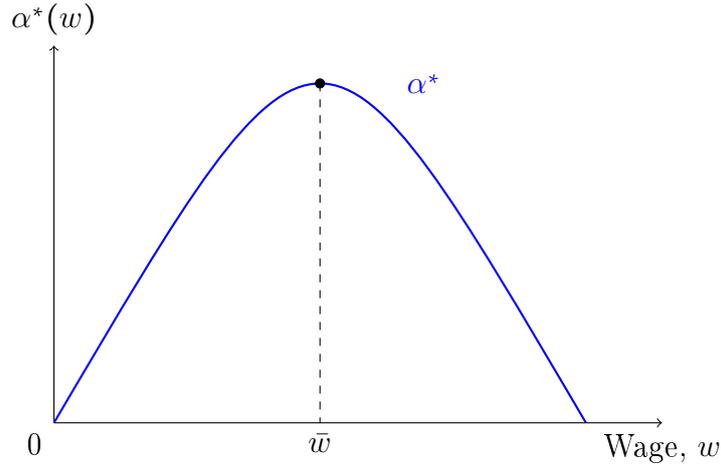
Figure 2.1: equilibrium size of innovation, $\alpha^\star$, depending on the wage rate w. An increase (decrease) in δ shifts the threshold $\bar{w}$ on the right (left).

$\alpha^\star(w)$ *increases for* $w < \bar{w}$ *and decreases for* $w > \bar{w}$. *Moreover,* $\alpha^\star(0) = 0$ *and the critical wage* $\bar{w}$ *is increasing in the market size* δ.

Proof. See the appendix.[8] $\square$

Proposition 2.1 represents one of the crucial results of the paper; see Figure 2.1 for a visual representation. Formally, it follows from simple differentiation of eq. (2.10):

$$\frac{\partial \alpha^\star}{\partial w} = f'_w \bar{Q}_d + f(w) \bar{Q}'_w. \tag{2.11}$$

The effect of w on the level of investment undertaken by the innovator can be easily interpreted by looking at $\alpha^\star(w)$ as the interaction of two terms: the cost-reducing effect of an increase in w, f'_w, which is always positive, and the output contraction effect Q'_w, which is always negative. When the wage rate increases, the manufacturers react by replacing labour with high quality capital input. Thus, the higher the wage level in the downstream sector, the more the manufacturers are willing to pay in order to replace their current production technology with a less labour-intensive one; this clearly stimulates the innovator to invest in R&D and to increase α. However, when the wage rate increases, the manufacturers face higher

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[8]The critical wage rate is defined as $\bar{w} \equiv \frac{\sqrt{\gamma(n+1)^2 \left(\delta^2(n-2)n^2 + 4\gamma(n+1)^2 \right)} - 2\gamma(n+1)^2}{\delta(n-2)n^2}$
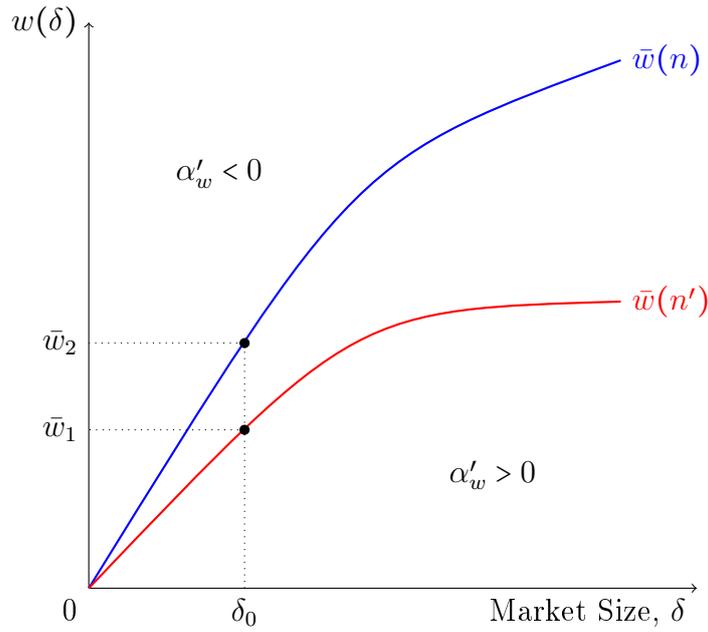
Figure 2.2: The wage effect on the equilibrium quality of capital input $\alpha^\star$. The effect is positive (negative) whenever $w < \bar{w}$ ($w > \bar{w}$). Consider a demand function with an intercept $\delta_0 > 0$: for any wage rate $\bar{w}_1 < w < \bar{w}_2$, the wage effect is positive (negative) if competition is soft (intense), where $n' > n$.

marginal costs and lower the output level. This, in its turn, lowers the profits earned by the manufacturers and the availability to pay for high licensing fee. This is what I refer to as the output contraction effect. Depending on the initial level of the minimum wage w, the cost-reducing effect dominates the output contraction effect ($w < \bar{w}$) or vice versa ($w > \bar{w}$). Moreover, the critical wage rate $\bar{w}$ depends on the size of the market. The interaction between these two forces is influenced by the level of competition in the downstream sector. On the one hand, firms in a concentrated market have fewer incentives to reduce their costs, as they already earn large profits with the backstop technology - i.e., the opportunity cost of adopting the innovative technology increases as the market becomes more concentrated. Therefore, the cost-reducing effect is stronger in competitive markets. On the other hand, when competition is intense, each firm produces fewer units of the final good and the impact of an increase in costs of production is lower. Consequently, the output contraction effect is stronger when the competitive pressure is low (figure 2.2).

Corollary 2.2. *The size of the cost-reducing effect is larger when the market is competitive, while the size of the output contraction effect is larger in concentrated markets. Therefore, the wage effect on innovation is more likely to be positive in competitive markets.*

Proof. See the appendix. □

2.3.2 Price of capital input and innovator's profits

Once determined α^*, we can use it to find the equilibrium outcomes of the game. Let us start from the adoption fee and the upstream innovator's profits. Using eq.(2.10) in (2.9) and (2.8), we obtain:

$$F^* = \frac{n^3 w^2 (\delta - 2w)^2 \left(\gamma(n+1)^2 + (n-2)n^2 w^2\right)}{(n+1)^2 \left(\gamma(n+1)^2 + (n-2)n^2 w^2\right)^2},$$

and

$$\Pi_u^* = n\, F^* - \gamma\, \alpha^{*2} = \frac{n^4 w^2 (\delta - 2w)^2}{(n+1)^2 \left(\gamma(n+1)^2 + (n-2)n^2 w^2\right)}.$$

It is useful to rewrite Π_u^* as:

$$\Pi_u^* = \left(\frac{n\,w}{n+1}\right)\left(\frac{n^2 w(\delta - 2w)}{\gamma(n+1)^2 + (n-2)n^2 w^2}\right)\left(\frac{n(\delta - 2w)}{n+1}\right) = g(w)\,\alpha^*(w)\,\bar{Q}_d(w) \quad (2.12)$$

From expression (2.12) we obtain the following proposition:

Proposition 2.2. *The innovator's equilibrium profits depend on the wage rate; there exists a critical wage rate $\tilde{w} > 0$ such that $\Pi_u^*(w)$ increases for $w < \tilde{w}$ and decreases for $w > \tilde{w}$. Moreover, $\Pi_u^*(0) = 0$, $\tilde{w} > \bar{w}$ and the critical wage $\bar{w}$ is increasing in the market size δ.*
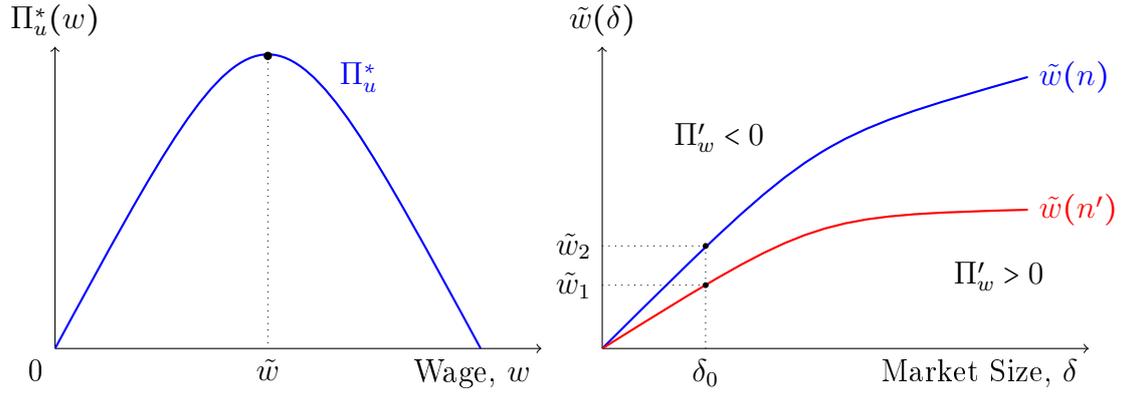
Proof. See the appendix. □

Figure 2.3: in the left panel, the profits of the innovator, Π_u^* depending on the wage rate w. An increase (decrease) in δ shifts the threshold $\tilde{w}$ on the right (left). In the right panel, the relationship between the critical wage rate $\tilde{w}$ and the market size δ, in case of n and $n' > n$ firms.

Proposition 2.2 follows from simple differentiation of expression (2.12):

$$\frac{\partial \Pi_u^*}{\partial w} = g_w' \, \alpha^*(w) \, \bar{Q}_d + \alpha_w' \, g(w) \, \bar{Q}_d + \bar{Q}_w' \, g(w) \, \alpha^*(w)$$

The analysis follows a similar logic as for $\alpha^*(w)$. The effect of a wage rate increase on the innovator's profits, in fact, is given by the interaction of different forces of opposite signs. First, there is a clear positive rent expansion effect, g_w'. If the wage rate rises, manufacturers are willing to pay more in order to adopt the innovation as it not only increases productivity but also becomes relatively cheaper. Indeed, the gains from the adoption of the innovative input are higher, the higher the price of the displaced input is. The rent expansion effect is reinforced (or mitigated) by the effect that a wage rate increase has on the quality of the innovation, $\alpha^*(w)$. As $\alpha_w' > 0$ (resp. < 0), the rent generated by the innovation in the downstream segment rises (resp. falls) and so do the innovator's profits. Finally, a negative output contraction effect, $\bar{Q}_w'$, operates as described in the previous paragraph. Figure 2.3 shows the relationship between supplier's profits and the wage rate.

2.3.3 Downstream manufacturers

Let us now turn to the downstream segment of the industry. As long as Corollary 2.1 applies, asymmetric equilibria are not possible: all the manufacturers choose the new technology. Thus, we can rewrite the expressions (2.3)-(2.6) as:

$$q^h = q^* = \frac{\delta - w(2 - \alpha^*)}{n + 1}, \tag{2.13}$$

$$q^s = \varnothing, \tag{2.14}$$

$$\Pi_d^h = \Pi_d^* = \frac{\left(\delta - w(2 - \alpha^*)\right)^2}{(n + 1)^2}, \tag{2.15}$$

$$\Pi_d^s = \varnothing. \tag{2.16}$$

By substituting eq. (2.10) into expressions (2.13) and (2.15), we obtain:

$$q^* = \frac{\gamma(n + 1)^2 + (n - 1)n^2 w^2}{\gamma(n + 1)^2 + (n - 2)n^2 w^2} \frac{\delta - 2w}{n + 1} = \psi \, \bar{q}_d \tag{2.17}$$

$$\Pi_d^* = \frac{\left(\gamma(n + 1)^2 - n^2 w^2\right)^2}{\left(\gamma(n + 1)^2 + (n - 2)n^2 w^2\right)^2} \frac{(\delta - 2w)^2}{(n + 1)^2} = \vartheta \, \bar{\Pi}_d, \tag{2.18}$$

where $\psi > 1$, and $\vartheta < 1$, and where, as previously defined, $\bar{q}_d$ indicates the downstream firms' output when innovation is not considered - i.e., $\gamma = \infty$. Consequently, $\bar{\Pi}_d = (\delta - 2w)^2/(n + 1)^2$ is the corresponding level of profits. From equation (2.17), we can state:

Proposition 2.3. *The equilibrium level of output produced by the manufacturers depends on the wage rate; there exists a critical market size $\check{\delta} > 0$ such that $q^*(w)$ increases for $\check{w}_1 < w < \check{w}_2$ and decreases otherwise. Moreover, $q^*(0) = \bar{q}_d$ and the range $w \in (\check{w}_1, \check{w}_2)$ widens (narrows) as the market size δ increases (decreases).*

Proof. See the appendix. □

Corollary 2.3. *The manufacturers are forced into a prisoner dilemma alike situation, where the adoption of innovation is the only equilibrium, although it is not the*
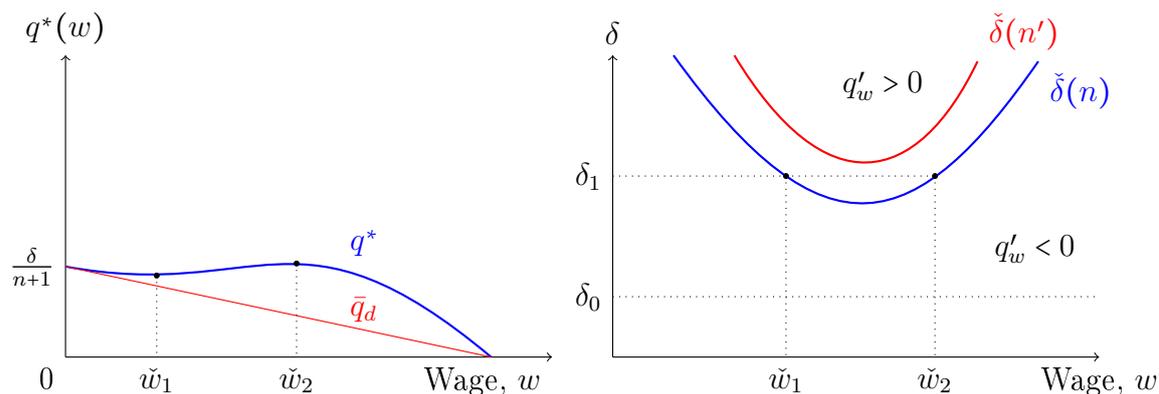
Figure 2.4: in the left panel, the equilibrium output per-firm q^*, depending on the wage rate w. An increase (decrease) in δ widens (narrows) the range $w \in (\check{w}_1, \check{w}_2)$ for which the output level increases as a reaction to an increase in the wage rate. In the right panel, the relationship between the critical market size δ and the wage rate, in case of n and $n' > n$ firms.

efficient outcome: $\Pi_d^* < \bar{\Pi}_d$.

Proof. Proof of Corollary 2.3 follows immediately from expression (2.18). □

Proposition 2.3 follows from simple maximization of expression (2.17) and shows that, under some conditions, the higher the wage rate faced by manufacturers, the higher their output level. This counter-intuitive result is essentially driven by the effect of increasing the wage rate on the quality of the innovation.

When the wage rate is such that $w \in (\check{w}_1, \check{w}_2)$, given a sufficiently large market size δ, raising the wage rate represents a good incentive for innovation, as it increases the manufacturers' willingness to pay for the technology (i.e., they want to change their technology with a less labour-intensive one). As the incentives to purchase the innovative capital input increase, the supplier's incentives to invest in R&D increase as well and this, in its turn, raises the quality of the input. Finally, the consequent adoption of the new input by the downstream manufacturers pushes the industry output upwards and lowers the equilibrium price of the final good. Figure 2.4 provides a graphical representation of the relationship between the wage rate and the per-firm output level (left panel), as well as the condition for a feasible range $w \in (\check{w}_1, \check{w}_2)$ to exist (right panel). Instead, Corollary 2.3 states that the

manufacturers are worse off after the adoption of the innovative capital input. This means that the inventor does not extract only the value generated by the invention, but also some extra share of the Producer surplus from the manufacturers. This extra share is a quasi-rent which is due to a combination of the monopoly position guaranteed by the patent, and the full bargaining power of the supplier of the innovative input in setting the price of the innovation.

Finally, I try to evaluate the effect of a minimum wage policy on the market outcomes. First, it is important to correctly compare the critical wages in propositions (1)-(3). It is relatively easy to show that $\bar{w} < \tilde{w}$, for any $\gamma > \tilde{\Gamma}$.[9] Instead, the comparison of $\bar{w}$, $\tilde{w}$, and the extremes of $\{\check{w}_1; \check{w}_2\}$ is more complicated. It is easier to look at the size of the market (δ): let us consider a given wage rate w_0, and define $\bar{\delta}$, $\tilde{\delta}$, and $\check{\delta}$ as the critical size of the market above which $\alpha_w > 0$, $\Pi_w^u > 0$, and $q_w > 0$, respectively. We can see that:

$$\check{\delta} \geq \bar{\delta} \qquad \text{if} \quad \gamma \geq \frac{(n-1)n^2 w^2}{n+1} \equiv \bar{\Gamma}, \tag{2.19a}$$

$$\check{\delta} < \bar{\delta} \qquad \text{otherwise.} \tag{2.19b}$$

Moreover, $\bar{\delta}, \check{\delta} > \tilde{\delta}$. From conditions 2.19a and 2.19b, it is possible to derive the following proposition:

Proposition 2.4. *Given the parameter of the model, an increase of the minimum wage:*

   i) *increases the equilibrium size of innovation, the profits of the innovator and the Social Welfare in A;*

   ii) *increases the equilibrium size of innovation and the profits of the innovator, but decreases the Social Welfare in B;*

   iii) *increases the profits of the innovator and the Social Welfare, but decreases the*
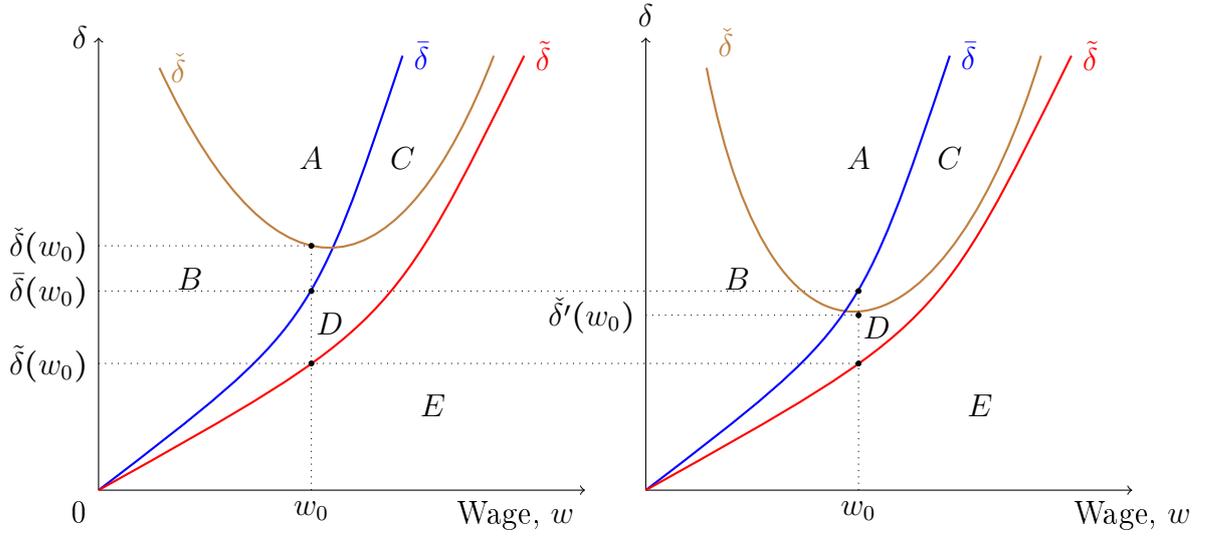
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[9]See the appendix.

Figure 2.5: effects of an increase in w on innovator's profits Π_u^*, size of innovation α^* and output of adopters q^{*h}, when $\gamma > \bar{\Gamma}$ (in the left panel) and otherwise (in the right panel).

equilibrium size of innovation in C;

iv) increases the profits of the innovator, but decreases the equilibrium size of innovation and the Social Welfare in D;

v) decreases the equilibrium size of innovation, the profits of the innovator and the Social Welfare in E.

Figure 2.5 shows this proposition graphically. Moreover, if we focus on a particular case, it is possible to predict the effect of a minimum wage policy, given δ and w_0:

Corollary 2.4. *Consider $w_0 > 0$ and $\gamma > \bar{\Gamma}$. Increasing the minimum wage leads to:*

i) *increases the equilibrium size of innovation, the profits of the innovator and the Social Welfare, if $\delta > \check{\delta}$;*

ii) *increases the equilibrium size of innovation and the profits of the innovator, but decreases the Social Welfare, if $\check{\delta} > \delta > \bar{\delta}$;*

iii) *increases the profits of the innovator, but decreases the equilibrium size of innovation and the Social Welfare, if $\bar{\delta} > \delta > \tilde{\delta}$;*

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iv) decreases the equilibrium size of innovation, the profits of the innovator and the Social Welfare, if $\tilde{\delta} > \delta$.

2.4   Welfare analysis

One may wonder whether the level of the innovation undertaken by the upstream firm is also efficient from the social point of view. It is easy to see that this is not the case. To show this, let us consider the Social Welfare SW, defined, as usual, as the sum of Consumers and Private surplus. Using the above findings:

$$SW = \frac{1}{2}\left(\delta - \left(\delta - n\frac{\delta - w(2-\alpha)}{n+1}\right)\right)\frac{\delta - w(2-\alpha)}{n+1} + n\left(\frac{\delta - w(2-\alpha)}{n+1}\right)^2 - \gamma\,\alpha^2$$

It is easy to see that this function is concave in α; its maximization reveals that the socially optimal level of the innovation is:

$$\alpha^w = \frac{n(n+2)w(\delta - 2w)}{\gamma(n+1)^2 - n(n+2)w^2} > \alpha^* \tag{2.20}$$

It is apparent that the upstream firm underinvests compared to the socially optimal level: $\alpha^w > \alpha^*$. This result has a clear interpretation if one thinks to the standard theory of non-linear wholesale pricing; this theory suggests that by setting a two-part tariff wholesale price, i) an upstream firm is able to fully appropriate the downstream firms' profits and ii) this pricing scheme maximizes Social Welfare. In our setting, the upstream firm can only partially extract the downstream firms' profits; as a matter of fact, even if we assume (as I do) that the supplier has full bargaining power in setting the price of the license, nevertheless, the presence of the standard technology puts some competitive pressure on the innovator who cannot fully extract the surplus of downstream firms (namely, the standard technology represents an exit option for the manufacturers). Due to this inappropriability

problem, the innovator is induced to underinvest compared to the social optimum.

Remark 2.1. *The innovator's investments in innovation are below the optimal level promoted by the policy maker. This is so, because i) the innovator does not internalise the Consumer surplus in his maximisation problem, and ii) the presence of an alternative that prevents full appropriation of the Producer surplus technology triggers the hold-up problem.*

2.5 Extensions

2.5.1 Large and K-drastic innovations

Let us now relax the assumption that n satisfies the condition in Corollary 2.1. If this is the case, then the maximisation problem of the innovator becomes:

$$\max_{m;x} \Pi_u = m\,F(\alpha) - \gamma\,\alpha^2$$

$$s.t. \quad F(\alpha) \le \frac{\alpha\,n\,w\left(2(\delta - 2w) + \alpha\,w(n - 2(m-1))\right)}{(n+1)^2}$$

By embedding the Participation Constraint (eq. 2.8) into the innovator profit function, we derive:

$$m^* = \frac{2\gamma(n+1)^2}{n(n+2)w^2}$$

$$\alpha^* = \frac{2n(n+2)w(\delta - 2w)}{8\gamma(n+1)^2 - n(n+2)^2 w^2} = \phi(w)\,\bar{Q}(w)$$

with $\phi'_w > 0$, and $Q'_w < 0$.

Remark 2.2. *Relaxing the condition on n in Corollary 2.1 does not alter the quality of the results. To increase the minimum wage rate generates a positive cost-reducing effect and a negative output contraction effect also when competition large.*

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Finally, let us now look more carefully at the case in which the innovator is so efficient that his innovation has drastic effect on the market - i.e., the innovation is k-drastic. This is defined as a quality improvement of the innovative capital input sufficiently large that, if the number of adopters is at least $k < n$, the $n - k$ firms producing with the standard quality input cannot survive on the market (see Sen and Tauman [2007] for a formal definition). Formally, this assumption requires:[10]

$$\gamma < \Gamma^*(w,n) = \frac{3(n+1)^2}{8n(n+2)w} \qquad \Rightarrow \qquad \alpha^* \geq \frac{\delta - 2w}{(n-1)\,w} \qquad (2.21)$$

When assumption 2.21 is satisfied, the inventor, given his type γ, sets F in order to elicit exactly $m = k$ manufacturers. As the innovation is such to prevent non adopters from producing positive output, all the production is concentrated among adopters. Formally, we have:

$$m = \frac{\delta - 2w}{\alpha\,w}$$

$$q^h = \frac{\delta - w(2-\alpha)}{m+1}$$

$$q^h = \frac{\delta - w(2-\alpha)}{\frac{\delta - w(2-\alpha)}{\alpha\,w}}$$

$$q^h = \alpha\,w \qquad (2.22)$$

$$\pi^h = \alpha^2\,w^2 \qquad (2.23)$$

Condition 2.7a becomes:

$$F \leq \alpha^2\,w^2 - \frac{\delta - w(2 + \frac{\delta - 2w}{\alpha\,w}\alpha)}{n+1}$$

$$F \leq \frac{n(n+2)\alpha^2\,w^2}{(n+1)^2} \qquad (2.24)$$

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[10]See the previous chapter of this thesis for a detailed analysis of the conditions for an innovation to be k-drastic.

Using Condition 2.24 into the innovator's objective function, we derive:

$$\max_{\alpha} \Pi_u = \frac{\alpha\, w(n+2)n(\delta-2w)}{(n+1)^2} - \gamma\,\alpha^2$$

$$\alpha^{**} = \frac{n(n+2)(\delta-2w)w}{2\gamma(n+1)^2} \tag{2.25}$$

Eq. (2.25) can be written as:

$$\alpha^{**} = \phi(w)\bar{Q}_d(w) \tag{2.26}$$

Thus, the effect of an increase of the minimum wage can be decomposed into:

$$\frac{\partial \alpha^{**}}{\partial\, w} = \phi'_w \bar{Q}_d(w) + \phi(w)\,\bar{Q}'_w \tag{2.27}$$

Eq. (2.27) is very similar to eq. (2.11) and highlights the same two opposite forces operating on the innovator's incentives to invest in quality. As the minimum wage increases ($w\uparrow$), the manufacturers are willing to pay more (individually) to replace the old technology with a less labour-intensive one (cost-reducing effect). On the other size, as the costs of production increase, manufacturers shrink the output and demand fewer inputs, reducing the potential effect of a more productive labour factor (output contraction effect). One can see that, whenever the wage rate is below the critical level $\bar{\bar{w}} \equiv \frac{\delta}{4}$, the first positive effect dominates the latter. Otherwise, the opposite is true.

Remark 2.3. *Proposition 2.1 holds also in case of k-drastic innovations.*

Finally, let us discuss the effect of an increase of the wage rate on the market outcomes q^{**}, Π_u^{**}, and m^{**}.

$$q^{**} = \alpha^{**}\, w = \frac{n(n+2)(\delta-2w)w^2}{2\gamma(n+1)^2} \tag{2.28}$$

$$\Pi_u^{**} = \frac{n^2(n+2)^2(\delta-2w)^2 w^2}{4\gamma^2(n+1)^4} \tag{2.29}$$

$$m^{**} = \frac{2\gamma(1+n)^2}{n(2+n)w^2} \tag{2.30}$$

A similar analysis as for eq. (2.27) applies to the manufacturers' individual output $\left(\tilde{\tilde{w}} \equiv \frac{\delta}{3}\right)$ and the innovator' profits $(\bar{\bar{w}})$. Instead, concerning the number of adopters, apparently, an increase in the minimum wage generates only negative effect. The explanation for this may come from the fact that, as w increases, it is easier that the innovation has a drastic effect on the market as it becomes more difficult to produce with the standard technology - i.e., the condition $\alpha^* > \frac{\delta-2w}{(n-1)w}$ is less strict. Thus, if the minimum wage is large, an innovation has a larger impact on the market structure and reduce the number of active firms.

2.5.2 Linear Pricing

So far, we have assumed that the innovator was charging its technology according to a two-part tariff scheme. However, one may wonder how the findings above change if this assumption is removed and we assume that the innovator sets a linear price $r > w$ per unit of the high quality capital input. In this section, I follow Kamien and Tauman [2002] on patent licensing.

The upstream innovator sets the optimal price r solving the following maximisation problem:

$$\max_r \quad \Pi_u = n \cdot \frac{\delta - r - w(1-\alpha)}{n+1}(r-w) - \gamma\alpha^2, \tag{2.31}$$

$$s.t. \quad w(1-\alpha) + r \leq 2w$$

The condition in 2.31 is the Participation Constraint of the innovator's maximisation problem and it states that the marginal costs of the manufacturers that adopt the innovation should not exceed the marginal costs of producing by means of the standard input. Also, the assumption of linear pricing implies full adoption

as optimal licensing strategy (See Kamien and Tauman [1986]).[11]

The result is easily derived:

$$r(\alpha) = (1 + \alpha)w. \tag{2.32}$$

Remark 2.4. *The equilibrium royalty rate is a linearly increasing function of the size of innovation and the wage rate.*

Going backward to t=1, we can now find the optimal level of innovation. Plugging equation 2.32 into the innovator's profits, and maximising it with respect to the level of quality α of the innovative capital input, we can write the innovator's investment decision as:

$$\alpha^+ = \frac{nw(\delta - 2w)}{2\gamma(n+1)} < \alpha^*, \tag{2.33}$$

while the upstream innovator gains:

$$\Pi_u^+ = \frac{n^2 w^2 (\delta - 2w)^2}{4\gamma(n+1)^2} < \Pi_u^*. \tag{2.34}$$

We can see that, if the innovator charges a linear price, the equilibrium quality level is lower than under a two-part tariff scheme. This is due to the fact that the price of the innovation compensates the reduction in the labour costs following the adoption of the innovative technology. Therefore, it is not possible for the manufacturer to expand their output and increase the private surplus, which in turn implies that the innovator can extract a lower rent from the downstream segment. However, the results in Proposition 2.1 hold with minor differences. In fact, if we rewrite expression (2.33) as:

$$\alpha^+ = h(w) \, \bar{Q}_d$$

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[11]Lapan and Moschini [2000] show that incomplete adoption of an innovative input can be an equilibrium solution, if choosing such an input alters the price of other inputs of production, by lowering the demand of them. However, here I am assuming that the price of labour is determined by a given minimum wage that does not react to variation in the demand of labour.

where, $h'_w < f'_w$. This means that the cost-reducing effect is lower under linear pricing scheme than in the scenario where the supplier sets a two-part tariff, while the output contraction effect is the same. Thus, the following proposition applies:

Proposition 2.5. *The equilibrium level of investments undertaken by the upstream innovator depends on the wage rate; there exists a critical wage rate w^+ such that $\alpha^+(w)$ increases for $w < w^+$ and decreases for $w > w^+$. Moreover, $\alpha^+(0) = 0$ and the critical wage w^+ is increasing in the market size δ.*

Proof. See the appendix. $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\square$

Instead, the results in Proposition 2.3 cannot be replicated with a linear pricing scheme, as manufacturers do not reduce their costs of production $(w(1-\alpha)+r = 2w)$ after the adoption of the innovative technology. Let us write down the output function of the downstream manufacturers:

$$q^+ = \frac{\delta - r(\alpha^+) - w(1-\alpha^+)}{n+1}$$

$$q^+ = \frac{\delta - w(1+\alpha^+) - w(1-\alpha^+)}{n+1} = \frac{\delta - w(1-\alpha^+ + 1 + \alpha^+)}{n+1}$$

$$q^+ = \frac{\delta - 2w}{n+1}$$

The optimal output of the manufacturers does not depend on the level of innovation. Therefore, any positive effect of a minimum wage policy on the quality of the innovative technology does not apply to the output level. This is so because, from an economic perspective, the wage rate policy and the price of innovation are strategic complements and an increase of the former generates an increase of the latter. Thus, although a higher wage rate makes the innovation more convenient for the manufacturers, the rise in the innovation's price prevents them from obtaining any cost reduction. Consequently, we can state that, under linear pricing scheme, the innovation has no effect on the Consumers surplus (the price of the final good

does not change), while it increases the Private surplus by transforming part of the wage bill into profits for the upstream innovator.

2.5.3   Total wage bill and profits

In this section, I analyze the impact of the innovation on the remuneration of input factors, namely, the total wage bill and profits. We already know that the main impact of the innovation is to lower the requirement of labour input in the production of the final good. Moreover, the manufacturers that adopt the innovative technology reduce the necessary amount of labour input, in order to produce one unit of final good, from 1 to $(1-\alpha)$. However, from eq. (2.17), we know that, when all firms adopt the innovative technology, the total output increases and so does the demand for labour. Also, since one unit of capital input is required to produce one unit of final good and the capital input is produced by labour, to increase the output means also to increase the demand for the labour necessary to produce more units of capital input. Thus, it is not immediate to understand the net effect of the innovation on the total wage bill. If the productivity increasing property of the innovation dominates the expansion of output, we say that introducing the innovative technology would harm labour remuneration. Vice versa, when the output expansion effect dominates on the productivity effect, the displaced workers are hired back to expand the production.

In formula we have that:

$$LW = n\left((1-\alpha)\frac{\delta-(2-\alpha)w}{n+1}\,w + \frac{\delta-(2-\alpha)w}{n+1}w\right)$$

$$LW = n\,\frac{\delta-(2-\alpha)w}{n+1}\,(2-\alpha)w$$

Let us focus on the effect of innovation on the wage bill. We have that:

$$\frac{\partial LW}{\partial \alpha} = -\frac{n\,w(\delta - 2(2-\alpha)w)}{n+1}$$

which is positive for $\delta < 2w(2-\alpha)$. If we look at the two extremes of this condition, namely $\alpha = 0$ and $\alpha = 1$, we can see that, in the latter case, the condition cannot be satisfied, as with $\delta < 2w$ there is no market at all. Instead, for small value of the quality of innovation, the condition is more easily satisfied. We can interpret this result as we have already mentioned. Small innovations have relatively small effects in increasing the productivity of labour, while they do increase the production of the final good. By combining together a small displacement effect and the output expansion, we obtain a positive net effect on the total wage bill. Instead, if the displacement of workers is large due to a high increase in productivity of labour (α is high), the expansion of the output is insufficient to hire the displaced workers back and the net effect on the wage bill is negative. Interestingly, this result contradicts the one in Acemoglu and Restrepo [2019], according to whom small innovations - or innovations that generate small increase in automation - are the most harmful to the labour demand.

Remark 2.5. *When the quality of the innovation - i.e., the increase in labour productivity that the innovative technology generates - is high, then its introduction engenders a negative net effect on the total wage bill. This is so because, when the innovation is of high-quality, the displacement of workers due to increase in labour productivity is higher than the increase in labour demand due to the output expansion.*

Now, let us define total industrial profits as the sum of the net profits of all active firms, namely, the upstream innovator and the downstream manufacturers. Since the innovator's revenues simply consist of a transfer of private surplus from

downstream manufacturers, we can write:

$$\Pi_{tot} = n \, \Pi_d - \gamma \, \alpha^2$$

$$\Pi_{tot} = n \, \frac{(\delta - w(2 - \alpha))^2}{(n+1)^2} - \gamma \, \alpha^2$$

Simple differentiation reveals $\frac{\partial \Pi_{tot}}{\partial \alpha} > 0$ if $\delta > \frac{\alpha(\gamma(n+1)^2 - nw^2) + 2nw^2}{nw}$. Interestingly, this threshold moves in a similar direction as for total wage bill. More in particular, with little innovations ($\alpha \to 0$) the condition gets close to $\delta > 2w$, which is always satisfied as this is the condition for a market to exist. Instead, as the innovation increases, the condition becomes stricter $\delta > \frac{\gamma(n+1)^2}{nw} + w$ although not prohibitive.

Remark 2.6. *Small innovations tend to have beneficial impacts on both total wage bill and profits. Large innovations are more likely to have a negative impact on the total wage bill than on the total profits.*

2.5.4 Unionization and incentives to adopt the innovation

I finally draw a consideration on unionisation and its effect on incentives to adopt innovation. Hitherto, I have assumed that the wage rate was given and did not vary as the quality of the technology implied in the production process increased. This is not always the case, however. From a theoretical perspective, higher productivity of labour should automatically lead to a higher wage rate, and this is true for all kinds of labour (Aghion et al. [2017]). From an empirical perspective, this mechanism is not so obvious, as automation may have both positive and negative effects on wages (Acemoglu and Restrepo [2019, 2017]). Anyway, evidences suggest that sectors with a better technological equipment are those that face higher increase in wage rate (Pianta and Tancioni [2008]).

Moreover, at least in developed countries, variations in the wage rate are determined by a bargaining process between firms and workers. Although many different

levels of bargaining are generally involved, several European countries have strong unions and very centralized bargaining processes.

In this section, I explicitly address the problem of how the incentives to adopt innovation vary if it directly affects the price of labour at the sector level. Before proceeding, let us just make some slight modifications to the model set up, particularly respecting the wage rate. Let us assume that the industry has a very strong union with full bargaining power. Therefore, the wage rate chosen by the union applies to all firms in the downstream segment. Let us also assume that there are just two manufacturers and that the wage rates in the upstream and downstream segments are w_u and w_d, respectively. Moreover:

$$w_u = 1; \quad w_d(x) = \frac{1}{1-x}$$

where $x = \alpha$ if at least one manufacturer adopts the new technology, and $x = 0$ if the two manufacturers produce with the backstop technology. In other words, the introduction of a new technology in the downstream segment of the industry alters the cost of labour for all firms, regardless of their actual technological equipment. Thus, we can think to the innovation as a means to increase the rival's costs of production (see Salop and Scheffman [1983], Williamson [1968]). Obviously, this is a simplification that does not take into consideration any bargaining process, as the union has full bargaining power, and it therefore represents an unlikely situation. Theoretically, a more realistic assumption would be that the wage level increases to some level $w(x) = \frac{1}{1-x}$, with $x = \frac{m}{n}\alpha$, representing a gradual increase in the wage rate following the rate of adoption of the new technology, $\frac{m}{n}$. However, I believe this is a useful simplification to understand how the incentives to adopt innovation are affected by variations in the wage rate.

Let us define q_0 as the output of each manufacturer when none of them adopts the innovative technology, and q_2 as the output of each manufacturer when both adopt

the innovation. Instead, when just one of the manufacturers adopts the innovative technology, we define q_1^h as the output of the adopter, while q_1^s is the output of the non adopters.

Easy computations show that

$$q_0 = \frac{(\delta - 1) - 1}{3} \equiv \frac{\Delta}{3}$$

$$q_2 = \frac{(\delta - 1) - \frac{1-\alpha}{1-\alpha}}{3} \equiv \frac{\Delta}{3}$$

$$q_1^h = \frac{\Delta}{3} + \frac{\alpha}{3(1-\alpha)} > \frac{\Delta}{3}$$

$$q_1^s = \frac{\Delta}{3} - \frac{2\alpha}{3(1-\alpha)} < \frac{\Delta}{3}$$

where $\Delta = \delta - 2$.

The first thing it is worth remarking is that the innovation does not bring any advantage to the manufacturers when they behave symmetrically ($q_0 = q_2$). This is due to the fact that, even if the innovation increases the productivity of labour, the union is able to raise the wage rate up to the new productivity level. The net effect is, therefore, nil.

Instead, asymmetric equilibria displays some interesting features. Keeping in mind that, by assumption, the introduction of the new technology by at least one firm induces the union to raise the wage rate up to the new potential level of productivity (the productivity of labour that the firms would obtain by adopting the technology), we can see that innovation is now guaranteeing some advantages to the adopting manufacturer. Moreover, the adopter is now able to expand her output and gain some market share, while the non-adopting rival is forced to reduce its output. Clearly, since the manufacturer that keeps producing with the backstop technology cannot increase labour productivity, the increase in the wage rate operated by the union increases its costs of production. Consequently, the adopter, which does not

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gain anything in terms of costs of productions - as the new higher wage zeros out the boost in labour productivity - can nonetheless expand the output and gain more profits.

This results highlight the fact that, although the presence of a union limits the effect of innovation on the costs of production of the firms, still it provides the manufacturers with a unilateral incentive to adopt the innovation. The innovator, who sets the price of the innovation in order to maximize its total revenues, can exploit this strategic effect of the innovation and charges the manufacturers a price which satisfies conditions (2.7a) and (2.7b), as reported in section 2.3.

Briefly, since the profits of the manufacturers in each scenario are:

$$\Pi_0 = \left(\frac{\Delta}{3} \right)^2$$

$$\Pi_2 = \left(\frac{\Delta}{3} \right)^2 - F$$

$$\Pi_1^h = \left(\frac{\Delta}{3} + \frac{\alpha}{3(1-\alpha)} \right)^2 - F$$

$$\Pi_1^s = \left(\frac{\Delta}{3} - \frac{2\alpha}{3(1-\alpha)} \right)^2$$

we can easily derive the maximum adoption fee F as the one that satisfies $\Pi_2 = \Pi_1^s$:

$$F = \frac{4\alpha}{9(1-\alpha)} \left(\Delta - \frac{\alpha}{1-\alpha} \right)$$

This is the price that sustains complete adoption of the innovation, by exploiting the manufacturers' unilateral incentive to adopt the innovation in order to harm the rival. We do not go backward to previous stages, as the analytical computations become intricate. However, we can see from the analyses above that incentives to adopt the innovation exist also when the wage rate reacts to the introduction of a labour-augmenting innovation. This is possible because of the strategic role of the

innovation to increase the rival's costs and, particularly, the cost of the input the rival mostly relies on. From the considerations above, we can state:

Remark 2.7. *When the innovation can be used strategically to increase the rivals' costs of production, it also generates incentives for technology adoption in the downstream segment. Moreover, strong centralized unions have ambiguous effects on incentives to adoption. On the one hand, a central union decreases the cost-reducing effect of innovation, lowering the appeal of the innovative technology from the manufacturers' perspective; on the other hand, however, by raising the wage rate after the adoption of the innovation by all the manufacturers, it generates a positive strategic effect for the adopters.*

2.6 Discussions and conclusions

Using a model of a vertically related industry, this paper shows the relationship that links the incentives to invest in R&D and adopt a labour-augmenting innovation, and the wage rate. This paper represents a novel attempt to understand the possible implications of a minimum wage policy on the investments in R&D and on the industry performance. The model suggests that, depending on the size of the market and the current level of the wage rate, a policy aimed at increasing the minimum wage may act as an incentive for innovation by an outsider innovator. Moreover, such a policy may have beneficial effects on the level of output and the equilibrium price of the final good. I identify two main forces that make this positive effect possible: first, as the wage rate increases, the downstream manufacturers are willing to pay more in order to replace their technology of production with a less labour-intensive one, because the "cost-reducing" effect of increasing the productivity of labour is larger when labour is more expensive. Second, as the wage rate increases, firms react by lowering their output and their demand of inputs, thus reducing the potential effect of the innovation ("output-contraction" effect). The dominance of

the former (latter) force induces a positive (negative) effect of a minimum income policy on the incentives for innovation.

The results are confirmed when the labour market is dominated by a central union which controls the wage rate. In this case, innovation is not used as a tool to increase the efficiency of the firms, but as a tool to increase the rivals' costs of production. Finally, the model suggests that small innovations are those that are more likely to have a better impact on the distribution of surplus among the factors of production. This result is at odds with the findings in automation literature, where usually larger automation processes are associated to higher returns for the labour share.

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Appendix 2

Appendix B.1

Conditions (2.7a) and (2.7b)

Proof. The price of capital input is determined in order to make the mth manufacturer indifferent between the adoption of the new technology and the standard one. For the sake of simplicity, I drop the subscript d, unless necessary. The payoff of the mth manufacturer if she adopts the new technology is:

$$\Pi_m^h = \frac{(\delta - w(2 - \alpha(n - m + 1)))^2}{(n+1)^2} - F$$

Instead, if she keeps the standard technology, the payoff is:

$$\Pi_{n-(m-1)}^s = \frac{(\delta - w(2 + \alpha(m - 1)))^2}{(n+1)^2}$$

One can see that $\Pi_m^h \geq \Pi_{n-(m-1)}^s$ is Condition (2.7a):

$$F \leq \frac{(\delta - w(2 - \alpha(n - m + 1)))^2}{(n+1)^2} - \frac{(\delta - w(2 + (m-1)\alpha))^2}{(n+1)^2} \equiv C(2.7a)$$

Also, for m to be an equilibrium, it must be that the $m + 1^{th}$ manufacturer has no incentives to adopt the innovative input. This is guaranteed by Condition (2.7b), which gives the condition for the $n - m$ non-adopters to be better off with

the standard technology:

$$\Pi_m^s = \frac{(\delta - w(2 + \alpha \, m))^2}{(n+1)^2}$$

$$\Pi_{m+1}^h = \frac{(\delta - w(2 - \alpha(n+1-(m-1))))^2}{(n+1)^2} - F$$

It is easy to observe that $\Pi_{m+1}^h < \Pi_{n-m}^s \geq 0$ is Condition (2.7b):

$$F > \frac{(\delta - w(2 - \alpha(n+1-(m+1))))^2}{(n+1)^2} - \frac{(\delta - w(2 + m \, \alpha))^2}{(n+1)^2} \equiv C(2.7b)$$

If Condition (2.7a) holds with equality, Condition (2.7b) is always satisfied with strict inequality:

$$C(2.7a) - C(2.7b) = \frac{2 \, n \, \alpha^2 w^2}{(n+1)^2} > 0$$

The opposite is not true. Therefore, Condition (2.7a) is a sufficient condition for the equilibrium in the downstream subgame to be stable, and it shows the most profitable choice for the upstream supplier among all the sufficient conditions. Thus, the profit-maximising choice, given α and m, is to set $F = C(2.7a)$. $\qquad\square$

Proof of Corollary 2.1

Proof. At time 1, the innovator sets the price in order to maximize the total revenues $m \, F$, given the costs of innovations that are considered as sunk. Since the price of the innovation is decreasing in m, the innovator faces a trade-off between the number of contracts signed, and the price charged to each licensee. The solution to this trade-off is to restrain the access to the new capital input to a subset of firms $m \leq n$. The economic intuition behind this solution is that the innovator wants to protect his profits from downstream competition, and it does so by allowing some firms (the licensees) to become more efficient and steal a share of the market from the non-adopters, therefore creating an asymmetry.

We can see that:

$$\max_m \Pi_u = m \, F(m, \alpha) - I(\alpha)$$

$$m^* = \frac{2(\delta - 2w) + w(2\alpha + n)}{4w}$$

Therefore, the optimal number of contracts from the innovator's perspective is $m = \min\{m^*, n\}$. One can see that:

$$n < m^* \qquad \text{if} \quad n < \frac{2(\delta - w(2 - \alpha))}{3\,w}$$

$\square$

Proof of Proposition 2.1

Proof. The equilibrium size of the quality improvement is derived from simple differentiation of eq.(2.9)

$$\frac{\partial \Pi_u}{\partial \alpha} = \frac{2n^2 w(\delta - 2w)}{(n+1)^2} + \frac{2\alpha(n-2)n^2 w^2}{(n+1)^2} - 2\gamma\,\alpha$$

Equalizing marginal revenues and marginal costs, we obtain

$$\alpha^* = \frac{n^2 w(\delta - 2w)}{\gamma(n+1)^2 + (n-2)n^2 w^2}$$

One can see that $\alpha^* \in [0, 1)$ if $\gamma > \frac{n^2 w^2}{(n+1)^2} \equiv \bar{\gamma}$.

Proposition 2.1 follows from simple differentiation of expression (2.10):

$$\frac{\partial \alpha^*(w)}{\partial w} = \frac{n^2 \left(\delta \left(\gamma(n+1)^2 - (n-2)n^2 w^2 \right) - 4\gamma(n+1)^2 w \right)}{\left(\gamma(n+1)^2 + (n-2)n^2 w^2 \right)^2}$$

We can see that,

$$\frac{\partial \alpha^*(w)}{\partial w} > 0 \quad \text{if} \quad w < \bar{w} \equiv \frac{\sqrt{\gamma(n+1)^2 \left(\delta^2(n-2)n^2 + 4\gamma(n+1)^2 \right)} - 2\gamma(n+1)^2}{\delta(n-2)n^2}$$

and vice versa. $\square$

Proof of Corollary 2.2

Proof. By taking the first derivative of $\bar{w}$ with respect to the number of downstream manufacturers:

$$\frac{\partial \bar{w}}{\partial n} = -\frac{\gamma(n+4)\left(n^2-1\right)\left(-4\sqrt{\gamma(n+1)^2\left(\delta^2(n-2)n^2+4\gamma(n+1)^2\right)}+2\delta^2(n-2)n^2+8\gamma(n+1)^2\right)}{2\delta(n-2)^2n^3\sqrt{\gamma(n+1)^2\left(\delta^2(n-2)n^2+4\gamma(n+1)^2\right)}} < 0$$

From this relation and the fact that $\bar{w}'_\delta > 0$, and $\bar{w}''_\delta < 0$, it is possible to derive the graph in figure 2.2. $\qquad\square$

Proof of Proposition 2.2

Proof. Proposition 2.2 follows from simple differentiation of expression (2.12):

$$\frac{\partial \Pi_u^*}{\partial w} = \frac{2n^4 w(\delta-2w)\left(\delta\gamma(n+1)^2-2w\left(2\gamma(n+1)^2+(n-2)n^2w^2\right)\right)}{(n+1)^2\left(\gamma(n+1)^2+(n-2)n^2w^2\right)^2}$$

This first derivative is positive if the numerator is positive. One can see, that

$$\frac{\partial \Pi_u^*}{\partial w} > 0 \quad \text{if} \quad w < \tilde{w}$$

$$\tilde{w} = \frac{4\,6^{2/3}\gamma(n-2)\left(n^2+n\right)^2-\sqrt[3]{6}\left(\sqrt{3}\sqrt{\gamma^2 N_1\left(27\delta^2(n-2)n^2+128\gamma(n+1)^2\right)}-9\delta\gamma N_2\right)^{2/3}}{6(n-2)n^2\sqrt[3]{\sqrt{3}\sqrt{\gamma^2 N_1\left(27\delta^2(n-2)n^2+128\gamma(n+1)^2\right)}-9\delta\gamma N_2}} > 0$$

with $N_1 = \left(n-2\right)^3 n^6(n+1)^4$, and $N_2 = n^4\left(-n^2+n+2\right)^2$.

Moreover, it is possible to see that:

$$\tilde{w} - \bar{w} > 0$$

$\qquad\square$

Proof of Propositions 2.3 and 2.4

Proof. Proposition 2.3 follows from simple differentiation of expression (2.17):

$$\frac{\partial q^*}{\partial w} = -\frac{2\left(-\gamma n^2(n+1)^2 w(\delta - 2nw + w) + \gamma^2(n+1)^4 + n^4\left(n^2 - 3n + 2\right)w^4\right)}{(n+1)\left(\gamma(n+1)^2 + (n-2)n^2w^2\right)^2}$$

Due to the complexity to solve this derivative w.r.t. the wage rate, we rather focus on the size of the market δ:

$$\frac{\partial q^*}{\partial w} > 0 \quad \text{if} \quad \delta > \frac{(n-2)(n-1)n^2w^3}{\gamma(n+1)^2} + \frac{\gamma(n+1)^2 + n^2(2n-1)w^2}{n^2w} \equiv \check{\delta}$$

The function $\check{\delta}$ is U-shaped, leading to the right panel in figure 2.4. Finally, let us compare the thresholds for $\frac{\partial \alpha^*}{\partial w} > 0$ and $\frac{\partial q^*}{\partial w} > 0$ to hold simultaneously. It is possible to see that:

$$\check{\delta} - \bar{\delta} = \frac{\left(\gamma(n+1)^2 + (n-2)n^2w^2\right)^2 \left(\gamma(n+1)^2 - (n-1)n^2w^2\right)}{\gamma n^2(n+1)^2 w \left(\gamma(n+1)^2 - (n-2)n^2w^2\right)}$$

which is positive for $\gamma > \frac{(n-1)n^2w^2}{(n+1)^2}$, and where $\bar{\delta}$ is the critical market size at a given wage rate w where $\frac{\partial \alpha^*}{\partial w} > 0$ if $\delta > \bar{\delta}$.

Similarly, one can see that $\check{\delta} > \tilde{\delta}$ $\qquad\qquad\square$

Proof of Proposition 2.5

Proof. Proposition 2.5 follows from simple differentiation of eq. (2.33):

$$\frac{\partial \alpha^+}{\partial w} = \frac{n\,\delta - 4n\,w}{2\gamma(n+1)} > 0$$

$$\Rightarrow w^+ < \frac{\delta}{4}$$

$\qquad\qquad\square$

Conclusion

This research represents an attempt to investigate the nature of the firms' incentives to innovate. I have adopted an Industrial Organization approach with a focus on vertical relations.

In chapter 1, I have addressed the problem of how competition in the product market affects the choice of the licensing contract and, consequently, the optimal number of licensees in equilibrium. I have distinguished between small (non-drastic) and large (k-drastic) innovations and shown that the innovator prefers offering an upfront fee licensing contract when competition is either intense or very soft. Also, I suggested that the optimal number of licensees in equilibrium can be defined as a function of competition in the product market and the innovator's efficiency. From a policy perspective, although innovation is always beneficial to the Social Welfare, I have shown that competition alters the way in which the innovation impacts on Consumer and Producer surplus. In particular, innovation is more beneficial to consumers when the ex-ante competition is low. Instead, if the product market is very competitive, innovation benefits the innovators much more than the consumers and manufacturers. Thus, I have argued that political concerns about the increasing market shares of innovative firms are well-grounded, as the market power accumulation of the innovator seems to be an outcome consistent with the results of this article.

In chapter 2, I have more explicitly addressed the problem of vertical relations and incentives for innovation. I have designed a model in which the manufacturers

produce the final good by means of capital input and labour. Moreover, the amount of labour required in the production depends on the quality of the capital input employed. I have demonstrated that the labour market conditions affect the incentives of an upstream supplier to invest in the quality of the capital input. I have argued that, when the wage rate increases, the incentives to invest in the quality of the capital input are subject to two opposite forces: on the one hand, the manufacturers are more willing to replace the old labour-intensive technology with a new one which makes less use of labour. On the other hand, when the wage rate increases, the marginal costs of production of the manufacturers rise too, and the output level shrinks. Thus, the demand for both capital and labour falls accordingly, and the incentives to replace the old technology diminish. The two forces are defined as the cost-reducing effect and the output contraction effect, respectively. When the wage rate is below a critical level, the cost-reducing effect dominates and an increase in the wage rate leads to a larger investment in R&D by the supplier. Also, under certain conditions, increasing the price of labour may initiate an innovative process that yields an output expansion and an increase in the labour demand.