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An Economic Analysis of Optimal University Licensing Strategies

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Abstract

This paper examines the determinants and welfare implications of university licensing strategies. A licensing strategy may be based on varying degrees of exclusivity granted to firms, from non-exclusive licensing to exclusive licensing. Depending on the context, the choice of a given strategy yields different revenues both for firms and universities but also leads to different levels of social welfare. Licensing strategies must hence be tailored to the context. In this paper, we particularly explore how the nature of the technology invented by the university might affect the performance of the transfer. We consider a model with one university and four firms in two different sectors. The university seeks to transfer an invention to industry and must choose its valorization strategy (publication, exclusive license, non-exclusive license, exclusive license per field of use). We show that if the invention is embryonic and specific, exclusive licensing is the only strategy allowing transferring it to industry. Further, if the invention is generic and embryonic we show that exclusive licensing per field of use is the best way of transferring the invention. Finally, we show that when the invention is mature, publishing is the optimal strategy. An important result of the model is that at the equilibrium of the game, universities may not always automatically choose the best strategy from a social welfare point of view.

Key words: University licensing, technology transfer, patent, embryonic invention, generic invention

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An Economic Analysis of Optimal University Licensing Strategies[1]

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1. Introduction

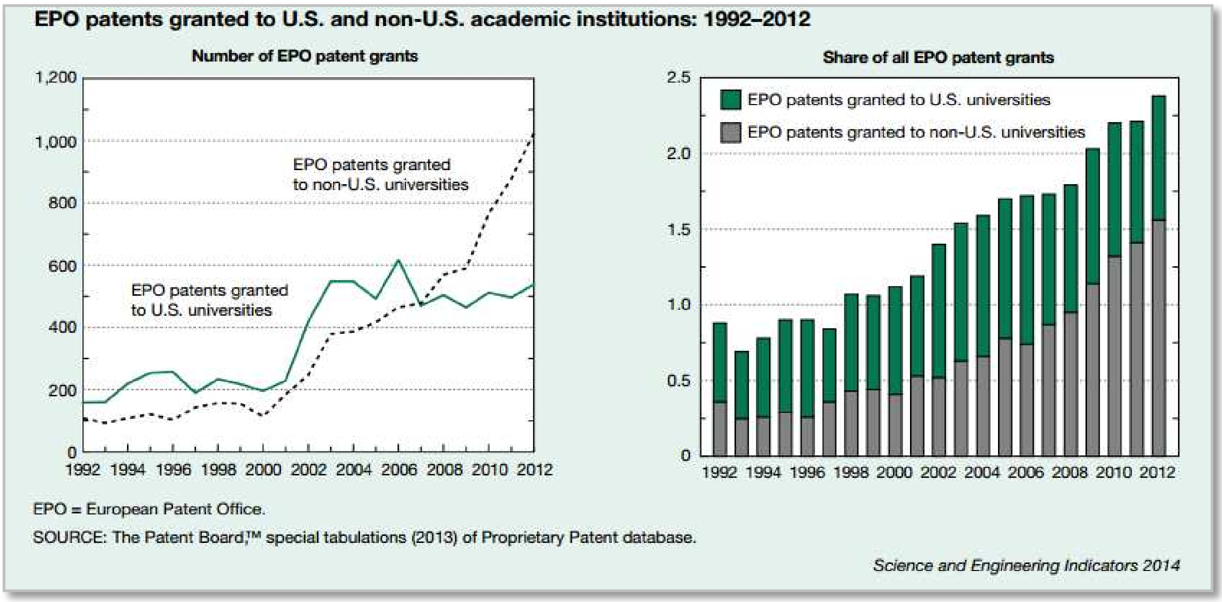
With the aim of making public research organizations (PROs) to contribute more to economic development, in the last three decades universities all around the world have been encouraged to valorize their research results by national and regional governments. This is perfectly illustrated by the Bayh-Dole act passed in 1980 in the US but also by the law on research and innovation passed in 1999 in France. University basic research is valorized once it attracts the industry attention and is developed into new technologies for commercial and industrial use (Ho et al., 2013). There exist many channels through which a university invention can be transferred to the industry, some formal and other more informal. Depending on the sector and the technology characteristics, the relative importance of these transfer channels may vary; the channels may replace or complement each other (Cohen et al.1998; Cohen et al.,2000; Agrawal and Henderson, 2000; Colyvas et al., 2002; Mowery and Shane, 2002; Siegel et al., 2003; Grimpe and Fier, 2010; Grimpe and Hussinger, 2013). Conferences, meetings, education and training of students who will then work in companies are important ways of transferring scientific knowledge from university to industry. Collaborations in joint research project or research consortium and/or informal exchange of knowledge and information are another (Cohen et al., 2000).

However, keeping in mind that social interactions, informal contacts and more formal collaborations should not be neglected, in particular because they also allow transferring tacit knowledge, the main focus of this paper is on technology transfer through formal licensing contracts. Indeed, the model of technology transfer relying on university patenting and licensing has been largely privileged by policy makers and universities and many of the institutional changes observed in the last decades focus on this particular aspect of research valorization. In this model universities protect their intellectual property (mostly via patents but also copyrights for software) and then transfer it to the industry through the use of contractual mechanisms such as licensing.

The attention paid by public research organizations and universities to this formal model of technology transfer is perfectly illustrated by the boom of university patenting and licensing (often exclusive licenses) observed worldwide since the 1980s. Although this trend has started in the US, universities and public research organizations all over the world now routinely patent the results of their research (Mowery et al., 2001; Cesaroni and Piccaluga, 2002; Mazzoleni and Sampat, 2002; Mowery and Ziedonis, 2002; Sampat, 2006; Azagra-Caro et al., 2006; Geuna and Nesta, 2006;

Carayol, 2007; Lissoni et al., 2007)[3]. Figure 1, for instance, shows the increase in number and share of EPO patents granted to U.S. and non-U.S. universities within the period of 1992-2012.

Figure 1: EPO Patents Granted to U.S. and Non-U.S. Academic Institutions: 1992-2012



This evolution in research valorization strategy of universities went hand in hand with the creation or reinforcement of structures dedicated to technology transfer and the evolution of national legal frameworks towards higher financial returns for university research. Most universities in developed countries are now equipped with technology transfer offices (TTOs) whose role is to lower transaction costs in order to ease the industry licensing of university inventions. According to Jensen and Thursby (2001; p. 242) TTOs "are responsible for soliciting reports (disclosures) on faculty inventions, assessing commercial potential of inventions, filing patent applications, finding potential licensees, and executing and monitoring license agreements.". An important question, yet beyond the scope of this paper, deals with the objective of these TTOs, which are increasingly faced with political pressures requiring them to be profitable, although this profitability may come at the detriment of social welfare.

[3] In the USA, according to Science and Engineering indicators (2014) of National Science Foundation (NSF) based on AUTM surveys, during the period of 2001-2011, invention disclosures received by technology transfer offices (TTOs) increased from 11,259 to 19,732; patent applications filed by U.S. universities increased from 5,784 to 12,090 and U.S. patents granted increased from 3,179 to 4,296. Net royalties from university licensing activities grew from $ 753,8 millions to $1.486,0 and active licenses increased from 18,845 to 33,284.
Also, in France for instance, most public research organizations are now engaged in an active patenting policy. In the last decade, the CNRS was systematically ranked in the top 10 of French patent applicants, INSERM and INRA reaching high rankings too. French universities also patent intensively their research and there is much evidence that this trend is growing (Azagra-Caro et al., 2006; Carayol, 2007; Lissoni et al., 2007).

The main rationale of these changes is that the technology transfer would be facilitated if universities patent their researches and license these patents to companies (Nelson, 2001). In particular, exclusive licenses are often perceived as necessary in order to induce firms to invest in the development of the invention coming out of the university. Indeed, scientific inventions are often embryonic (Jensen and Thursby, 2001) and firms have to further invest before they can make money out of them. Granting an exclusive license to firms may hence be necessary in order to induce them to invest. On the other hand, exclusive licenses have been also seen as an important income opportunity by the universities (Nelson, 2001). Yet, this growing involvement of universities in the technology transfer process has raised many concerns. It has been argued whether this involvement has shifted scientists' attention away from basic research or has hindered and delayed the publication of research outcomes (Azoulay et al., 2009; Pénin, 2010b) or caused a decrease in quality of patents while size of university patents growing (Henderson et al. 1998). Further, the use of exclusive licensing has been criticised as it may create monopoly position, thus reducing social welfare (Mowery et al., 2004).

However, exclusive licenses are not the only option for universities. Different licensing strategies are possible, going from exclusive license to non-exclusive or even open-source licenses (Pénin, 2010a). Depending on the context, each choice will affect the revenues of both firms and universities but also may lead to different levels of social welfare. Choosing the most appropriate licensing strategy is hence not an easy task for universities. In particular because it depends heavily on different parameters, such as the nature of the invention, the type of companies, the technological regime of the sector or its competition regime (Pénin, 2010a).

The aim of this paper is therefore twofold: (1) We analyse how the nature of the invention developed by universities affects the licensing strategy and the performance of the transfer; (2) we explore whether or not university licensing practices are always in line with the social interest. Our focus is thus not on all the determinants of university licensing strategies but only on the nature of the invention which is transferred. In particular we focus on two important dimensions of the invention: it can be embryonic versus mature and it can be specific versus generic.

We consider a model with one university and four firms operating in two different sectors. The university seeks to transfer an invention to the industry and must choose its valorization strategy (publication, exclusive license, non-exclusive license, exclusive license per field of use). Depending on the nature of the invention each strategy yields very different outcomes. We then investigate in which context universities should grant exclusive licenses and in which ones they should grant non-exclusive licenses or use more open strategies. One of the main results of this model is that university licensing strategies must be tailored to the context and, in particular, to the nature of the invention that is transferred. We also show that universities may not always automatically adopt the licensing strategy that maximizes social surplus.

The remainder of the article is organized as follows. In the following section, we discuss the welfare implications of licensing strategy with varying degrees by referring to two historical examples of exclusive and non-exclusive licensing in order to figure out whether or not there is a systematic licensing scheme that guarantees successful technology transfer. Section 3 categorizes and discusses the parameters that a university should take into account while choosing a particular licensing strategy. Section 4 presents the model to analyse the effect of nature of invention on technology transfer performance. Section 5 concludes by discussing the implications of our findings as well as limitations and further research.

2. Licensing of University Inventions and Its Welfare Implications

2.1. Different Degrees of Exclusivity and Their Implications on the Performance of the Transfer

World Intellectual Property Organization (WIPO) defines licensing agreement as "[A] partnership between an intellectual property rights owner (licensor) and another party (licensee) who is authorized to use such rights in exchange for an agreed payment (fee or royalty)" (Licensing of Intellectual Property Rights, 2014)[4]. Thus, in our context, a license can be considered as a contract between the owner of IPR (university) and licensee (firm), under which the firm is given a right to use, reproduce and commercialize the invention developed by the university under specified conditions in the contract.

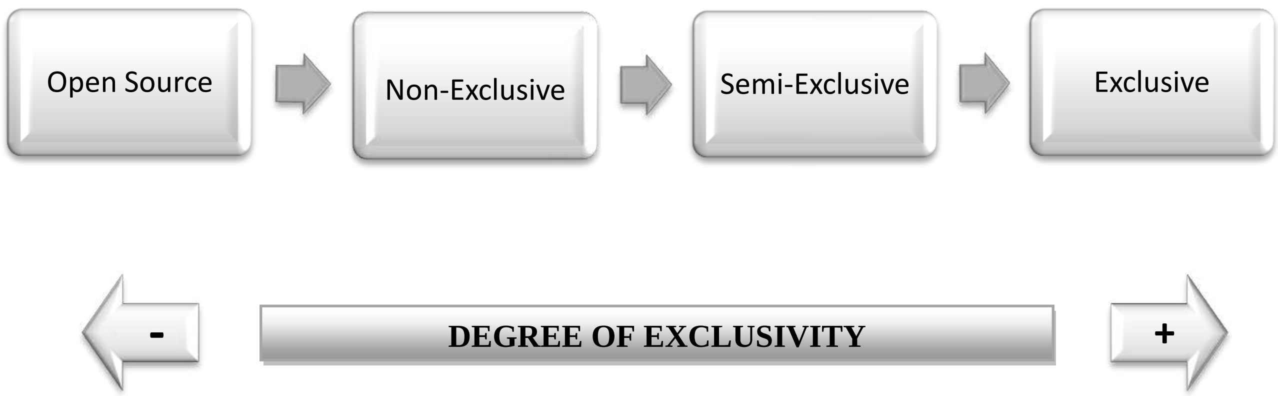
Among many things that must be specified in licensing contracts, a specific attention must be devoted to the degree of exclusivity granted to the licensee. The licensor (university) can indeed grant a license with varying degrees of exclusivity (Cameron, 2010) (see Figure 2). At one extreme of the spectrum an exclusive license gives the highest degree of exclusivity to the licensee. It indeed excludes everyone, even the licensor, from the use of an IPR (often the licensor includes a clause in

[4] The payment can also be non-monetary, as in the form of equity shares, especially when the licensee firm is a start-up whose monetary resources are limited in compare to an incumbent firm (Di Gregorio and Shane, 2000).

the contract which states that it can continue to perform research after the grant of the exclusive license). In this sense, an exclusive license is therefore very similar to the sale of a patent (the main difference is that in the case of an exclusive license the licensor retains the ownership of the patent but cannot use it anymore). An important consequence of the exclusive license is that, since the university grants a license to only one firm, this firm will enjoy a monopoly position over the use and commercialization of the invention.

At the other extreme of the spectrum open source licenses represent the less exclusive form of licensing. Here, everyone can use the licensed invention and contribute to the improvement of that invention provided that the others can also use or modify these improvements without any permission (Hall and Gambardella, 2006). We usually see open source licensing in software technologies (LINUX, for instance, is one of the most prominent examples of open source license). Yet, since open source licensing is very specific and still rare in the case of patents we will not consider it in this paper.

Figure 2: Degrees of Exclusivity of Licensing



In between those two extremes, many different degree of exclusivity can be envisaged. Universities can, for instance, grant non-exclusive license, which means that they can grant a license to many different firms at the same time. This type of licensing contract grants no exclusivity to companies which may therefore allows competitors also obtain a license, hence increase competition on the market.

University may also grant licenses which are exclusive per field of use or exclusive per territory (this is what is called semi-exclusive license in Figure 2). In the first case the company is granted exclusivity for one specific use or one specific sector and the university can still grant license to other companies for other uses or sectors. This is often the case if the technology is a generic technology, where several possible applications exist in different sectors. Limiting the use of software licenses to a particular machine or limiting the sale of a drug that has several therapeutic indications, to the pre-determined indication can be given as an example to this type of restriction (Cameron, 2010). In the second case the company is granted exclusivity for particular territory but the university can still grant license to other companies in other places. The territory may be limited to particular country, region or specified location. In this case, the firm that is restricted by territory cannot sell the product outside of the pre-determined geography. Finally, university can also grant exclusive license but for a limited time. At the end of the license the university can thus decide to grant licenses, exclusive or not, to other companies. In all these cases an invention can therefore be exclusively licensed multiple times (Lemley, 2007; Thursby and Thursby, 2007; Pénin, 2010a).

The decision to grant an exclusive versus non-exclusive or semi-exclusive license may have important implications on the performance of the transfer of the technology. On the one hand exclusive licenses may be required in order to induce firms to invest in the development of embryonic invention. But on the other hand non-exclusive licenses foster competition and the use of the technology by many firms whereas exclusive license induce monopoly deadweight loss. Non-exclusive license may also avoid the risk that the technology is never transferred, risk which is high in the case of an exclusive license. In this latter case, and even if some clauses in the contract can state an obligation of use for the licensee, there is always a risk that the firm decides not to use the technology (Colyvas et al., 2002). As to the revenue for the university, an exclusive license usually yields higher royalty rates in the short run. But non-exclusive licenses, if they are sufficiently numerous, can yield higher total amount (even if less per license). In any case, as showed by the following examples, according to the context, both exclusive and non-exclusive licenses can lead to successful technology transfer.

2.2. A Successful Example of Exclusive License

Although exclusive licensing may induce monopoly deadweight loss and block future innovations, in some cases they are necessary in order to transfer the invention, i.e. without exclusivity the invention may never be transferred and remain on the shelves of the university. The promise of a monopoly profit may indeed encourage firms to invest in order to develop an embryonic invention. Also, a short-term exclusivity may shorten the time to market, as the exclusive licensee would urge to get the monopoly profits as soon as possible. In this case both firms and consumers may be better off.

In general exclusive licenses are considered as absolutely necessary in the case of pharmaceutical products for instance. Indeed, a new drug invented by a university must still go through a big number of tests; pre-clinical, clinical, etc., and those tests are very costly. No firm would hence like to perform them without the guaranty of having a monopoly on the drug market, i.e. without having received an exclusive license (Mansfield, 1986; Levin et al., 1987). As an illustration, a recent survey on French public scientists has showed that, in the case of drugs, scientists who have had one of their invented drug transferred to a company all consider that without an exclusivity this transfer would not have been made possible (Pénin, 2010b). This unanimity must be compared with the case of other sectors, engineering science for instance, in which most scientists do not believe that exclusivity is necessary to transfer their invention.

The historical example of the invention of insulin by the University of Toronto illustrates the role of exclusive license (even if limited in time) in order to induce firms to invest in the transfer of the technology. In 1922, University of Toronto got a patent on insulin and its manufacturing methods (Cassier and Sinding, 2008). Insulin is an invention with an important social value and the University of Toronto did not want to give a monopoly over this invention to a single firm. At the end they decided to opt for non-exclusive license (with grant-back mechanisms which makes this licensing scheme very close to open-source licenses). Yet, conscious about the fact that industrialists needed incentives to invest in this still uncertain technology they first granted an exclusive license for one year to Eli Lilly by considering the company's scientific and industrial experience. Given the embryonic state of the invention, which was still in experimental phase and industrial scale tests were needed, this one year exclusivity was necessary for Eli Lilly to undertake and develop the invention. However, in this specific case, exclusive license was not a mean to establish a monopoly but rather a mean allowing the technological learning between Eli Lilly and the University of Toronto. This technological learning and early investment helped Eli Lilly to retain its competitive advantage even after the end of exclusive term (Cassier and Sinding, 2008).

2.3. A Successful Example of Non-Exclusive License

A famous example where a non-exclusive license enabled the wide diffusion of a technology is Cohen-Boyer technology on recombinant DNA (rDNA) products. In 1973, Stanley Cohen (Stanford

University) and Herbert Boyer (University of California in San Francisco) developed the rDNA technology and a patent was quickly applied for by Stanford University in 1974 and was granted in 1980 (other patents did follow on some extensions of the technology). Given the generic nature of the technology, which had many applications in most of the life science sectors (biotechnology, pharmaceutical, chemical, agriculture, food, energy etc.), the University of Stanford decided to adopt a non-exclusive licensing strategy, i.e. they decided to grant a license to any firm which would like to get at a modest price.

This strategy did not prevent the transfer of the technology to the industry, on the contrary. Nor did it imply lower revenue for Stanford. Actually, during the 17 years where the different patents held by Stanford were in force Cohen-Boyer technology was non-exclusively licensed to 468 companies and to the end of 2001 Stanford University generated US$254 million. Furthermore, 2442 new products were developed based on rDNA technology by the time patent expired and commercial products developed by licensees generated US$35 billion (Feldman et al., 2005; Feldman et al., 2007). According to Feldman et al. (2007), Stanford's decision to rely on a non-exclusive strategy was decisive to explain the large diffusion of the technology. Would the technology have been licensed exclusively to a single company, it is likely that the rise of biotechnology industry would have been delayed for years.

3. The Choice of Licensing Strategy: Context Matters

As seen in section 2 there is no systematic licensing scheme that guarantees successful technology transfer. The success of a given strategy depends largely on the context, i.e. on the nature of the invention, the type of firms, the technological regime, etc. The most prominent parameters[5] that should enter into the choice of a license are summarized in Table 1.

[5] Of course it is possible to add more parameters into this table. For instance cumulative versus science based technology, that are discussed in the seminal work of Nelson and Winter (1982) should enter into the list of determinants under technological regime category. In this case, we expect that non-exclusive or more open licensing strategies might be more appropriate for the case of a cumulative technology as the more open strategies allow the cumulative progress of technology and hence prevent blocking of future innovations whereas an exclusive licensing strategy might be an option for science based technologies, where the technological progress is non-cumulative. Further, we can examine the effect of institutional factors on licensing strategy by introducing it as a new category.

Table 1: The Determinants of Socially Optimal University Licensing Strategy (based on Pénin, 2010a)

		Exclusive licensing strategy if	Non-exclusive licensing or more open strategies if
Nature of Invention	Specificity	Specific	Generic
	Distance to the market	Embryonic	Mature
Technological Regime	Appropriability	Weak	Forte
	Complexity	Simple (discrete)	Complex
	Speed of technical progress	Slow	Rapid
Competition Regime	Size of market	Small	Large
	Intensity of competition	High	Low
Type of the Licensee Firm	Firm size	Small	Large
	Firm life stage	Start-up	Incumbent

Note: This table must be understood ceteris paribus. The sign given for each variable is determined in order to maximize social welfare, not necessarily universities' licensing revenues.

3.1. Nature of the Invention

An invention can be characterized along too important dimensions: (1) Distance to the market and (2) Specificity. Distance to the market indicates whether the invention is embryonic (far from the market) or mature (close to the market). An embryonic invention means that firms must still invest in its development before they can make money out of it. A mature invention means that it is immediately usable by firms without further investments. Hence, ceteris paribus, exclusive licensing may be more desirable in the case of embryonic inventions in order to incentivize firms to invest in the development of the invention. On the other hand, exclusivity may be less desirable for mature technologies, for instance engineering technologies, as exclusivity leads to costly monopoly and is not necessary to induce the transfer. According to Thursby and Thursby (2001), most university inventions are at embryonic stage, i.e. either are proofs of concepts or lab-scale prototypes, thus justifying the grant of exclusive licenses to firms. They conducted a survey on 62 U.S. research universities which showed that over 75 percent of the university inventions were at embryonic stage and only 12 percent were ready for commercial use at the moment of the patent. Also, 31 percent of these inventions were licensed either exclusively or exclusively per field of use whereas only 10 percent non-exclusively licensed.

An invention can also be specific versus generic. A generic (platform) technology may have many different applications and may be used in various sectors. Conversely, a specific technology can only be used for a particular application or in a particular sector. As showed by Colyvas et al. (2002), who examined the case of 11 technologies in Stanford and Columbia Universities, licensing a generic technology non-exclusively leads many firms to develop different technologies based on this invention whereas the choice of an exclusive licensing strategy may limit the use of the technology, i.e. has a high social cost. Hence, ceteris paribus, the more generic the technology, the less exclusive the license should be.

3.2. Technological Regime

The technological regime of an industry should also affect the choice of the license. Technological regimes can be defined along several dimensions (Nelson and Winter, 1982). In our case, three dimensions are important: (1) Degree of appropriability, (2) Complexity and (3) Speed of technical progress. Degree of appropriability refers to firms' ability to capture profits generated by an invention. Since Teece (1986) one distinguishes between natural appropriability, which refers to the ability to be protected even without patents, and legal appropriability, which refers to the efficiency of patents to prevent imitation. Ceteris paribus, exclusive licenses may be more appropriate in sectors where natural appropriability is low (imitation is easy) and legal appropriability high (patents are efficient). This is typically the case of the pharmaceutical sector for instance. Yet, in other sectors such as engineering, where natural appropriability is often stronger (imitation is more difficult even without patents), an exclusivity may not be necessary to induce the transfer of the invention.

Technological regime also distinguishes between simple and complex technologies. A complex technological regime refers to sectors in which products are made of several components, each of which can be patentable, that must be combined in order to bring the product into the market (for example electronics). On the other hand, a simple technological regime refers to sector in which products are mono-components (e.g. a molecule to produce a drug). In the case of complex technologies firms usually are concerned primarily with issues of freedom to operate, i.e. they use their patents defensively. This is not the case in simple technologies where patents can more easily be used offensively (Kingston, 2001). Hence, ceteris paribus, the more complex the technology the less desirable it may be to grant exclusive license to firms since this may result in situations where many patents are overlapping thus preventing the development of new products in the market, i.e. tragedy of the anticommuns (Heller and Eisenberg, 1998).

Speed of technical progress refers to how fast the technology is progressing in a given sector. In an environment where the technology is rapidly evolving, in which new products and technologies are released very regularly, granting exclusivity to a single firm may impede innovation dynamics and retards new inventions coming to the market. In this case, first mover advantage can be largely sufficient in order to incentivize firms to develop inventions originated in university. Hence, ceteris paribus, the faster the technological progress in a sector, the less desirable the exclusivity is.

3.3. Competition Regime

The optimal licensing strategy for university should also pay attention to the nature of competition in the licensee's industry. For instance if the market has an important size, if few firms are present in this market due to important entry barriers, granting an exclusivity may not be necessary in order to induce firms to transfer the invention. Granting exclusivity to a company which already enjoys a monopoly position may clearly not be necessary. On the other hand, exclusivity may be needed, ceteris paribus, in case of the market is small, existence of a demand is uncertain and licensee is susceptible to face fierce competition.

3.4. Type of the Licensee Firm

Finally, optimal licensing strategy should adapt to the type of the licensee. A small size firm or a new born start-up may not have the capacity to capture the benefits of its invention without having an exclusivity on it (among others because it cannot rely on complementary assets such as production capacity, distribution capacity, branding, etc.). Conversely, a big size firm or an incumbent firm which has been in the market for a long time usually have the ability to capture the benefits of an invention even if it does not have exclusive license. Hence, ceteris paribus, the smaller and the younger the company, the more desirable exclusive license is.

To summarize, in this section we have put forward a list of determinants that should enter into the choice of universities licensing strategies. In the next section we develop a formal model in order to understand better how those different determinants interact with each other. In particular, as a first step, we focus on the nature of the invention.

4. A Model to Analyse the Effect of the Nature of the Invention on the Performance of Technology Transfer

Let us consider a sequential game with 5 players consisted of 1 university and 4 firms. Furthermore, assume that two firms are operating in an industry A and the other two in an industry B. Firms can therefore be denoted by F_{1A} and F_{2A} in sector A and F_{1B} and F_{2B} in sector B. Assume also that the university has made a product invention that she would like to transfer to the firms so that they can sell it. The timing of the game is as follows: In the first stage, university decides either to publish or patent the invention. If university decides to patent, in the second stage, it must decide to license the invention either exclusively, non-exclusively or exclusively per field of use (in case of an exclusive license we assume by convention that the licensee is firm 1, i.e. firm F_{1A} in sector A and in case of an exclusive license per field of use, firm F_{1A} in sector A and F_{1B} in sector B). Then, at the last stage of the game, firms must decide whether or not to invest in order to be able to sell the invention and make money out of it. Firms will decide to invest in the invention and to commercialize it (**C**) if and only if it yields them positive profits. In the other case, firms decide not to commercialize the invention ($\not{\mathbf{C}}$).

Hence we have four possible outcomes of the game: 1) the invention is not commercialized in the two industries (all of the four firms do not want to invest, i.e. the technology is not transferred); 2) the invention is exclusively licensed to one firm in one sector (global monopoly case); 3) the invention is commercialized by firms F_{1A} in industry A and F_{1B} in industry B (exclusive licensing per field of use leads to monopoly case in the two sectors) and; 4) the invention is commercialized by all the firms (non-exclusive licenses or publication lead to duopoly in each of the two industries). In this latter case we assume that the firms compete *à la Cournot* in their respective sector.

In case the invention is patented by the university and licensed to firms we consider the following licensing fee: Total fee (TF) is a function of the royalty rate (t), i.e. the fee per unit of output (q) where $0 < t < 1$. For simplicity we assume that there is no fixed fee. Royalty rate is exogenous and differs when the license is exclusive, non-exclusive or exclusive per field of use. We assume that: $0 < t_{ne} < t_{efu} < t_e < 1$, where t_e is the royalty rate for an exclusive license, t_{ne} for a non-exclusive license and t_{efu} for an exclusive license per field of use[6]. In addition, we assume that t_{ne}, t_{efu}, and

[6] The fact that $t_{efu} < t_e$ may be justified by some degree of permeability between industries A and B. If the two industries were perfectly impermeable, i.e. if an exclusive license per field of use was enforceable at no cost, then we

t_e are such that licensees' profits are always positive. Similarly, in order to make sure that licensee's monopoly profit is always higher than the duopoly profit we posit that $t_e < \frac{1+2t_{ne}}{3}$.

When university patents the invention it bears a cost (e.g. patent application fee, labour cost etc.) associated with patenting, denoted by c_p. University decides to patent the invention only if its net income (i.e. royalty revenues minus patenting costs) is positive. In the other case it decides to publish. In other words, we assume that the objective function of the university is to maximize its net income, not social welfare[7].

Finally, we consider the following inverse demand function in the two possible markets for the invention developed by the university: $p_{A=} 1 - q_A$ in the market A and $p_{B=} 1 - q_B$ in the market B. Furthermore, we also assume for simplicity that firms' marginal costs (MC) are zero, but when the firm buys a license, the marginal cost equals the royalty rate of the license to the university.

In this model, we are specifically interested by two parameters which refer to the "nature of invention". The first parameter I, indicates the distance of the invention to the market. It hence affects the cost functions of the licensees and their commercialization decisions. For simplicity we assume that I is a fixed cost, i.e. if the invention is embryonic, the total cost (TC) function of the firm becomes $TC = tq + I$. If $I = 0$ then the invention is mature and firms can commercialize the invention without any additional cost. But the higher I (i.e. the more embryonic the invention), the more costly it is for the firm to commercialize the invention. The second parameter of the game, G, refers to the specificity of the invention, that is to say whether the university invention can be used in the two markets A and B or only in market A.

4.1. The Case of a Specific Technology

By convention a specific invention can be used only in industry A. The game is hence reduced to three players (university and firms 1 and 2 in industry A). The extensive form of the game is represented in Appendix 1. In this case it is immediate to stress the first result:

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should have $t_{efu} = t_e$. But, when the enforcement of an exclusive license per field of use is costly, firms may be willing to pay more in order to have a global exclusive license.

[7] If this assumption may be too strong in some cases, it is undisputable that universities increasingly face pressures from policy makers in order to be more "profitable". Also, recent reforms in most developed countries tend to delegate the mission of technology transfer to independent TTOs (example SATT in France) whose objective is more or less explicitly to be profitable. It is therefore not exaggerated to assume that the revenues generated by technology transfer are an important issue either for universities, for TTOs or for both.

Proposition 1a: If the invention is too embryonic (where $I > \frac{(1-t_e)^2}{4}$), then there is no Subgame Perfect Nash Equilibrium (SPNE) in which the invention is commercialized. In this case the only SPNEs are when the university publishes the invention and both firms decide not to commercialize it.

Proposition 1b: If the invention is moderately embryonic (where $\frac{(1-t_{ne})^2}{9} < I < \frac{(1-t_e)^2}{4}$) then the only SPNE of the game which enables the invention to be commercialized is when the university delivers an exclusive license. This equilibrium is reached if and only if $t_e \frac{(1-t_e)}{2} > c_p$.

Proposition 1c: If the invention is mature, i.e. close to the market (where $0 \leq I < \frac{(1-t_{ne})^2}{9}$), then there always exists a SPNE in which the invention is transferred.

Indeed, in the case of proposition 1a, if $I > \frac{(1-t_e)^2}{4}$ then at the last stage of the game, firms will never decide to commercialize the invention because it would always yield them negative profits (even the monopoly profit, $\frac{(1-t_e)^2}{4}$ is always negative in this case). Knowing this, the university decides not to patent at the first stage of the game because in this case it receives a 0 payoff while if it patents, it will receive a negative payoff (it will have to pay c_p).

Furthermore, in the case of proposition 1b, if $\frac{(1-t_{ne})^2}{9} < I$ then firms' duopoly profits are always negative (i.e. firms never accept to commercialize the invention if it is not exclusively licensed). Conversely, if $I < \frac{(1-t_e)^2}{4}$, because the monopoly profit is positive (i.e. under exclusive licensing scheme), firm 1 accepts to commercialize the invention (provided that $0 < t_e < \frac{1+2t_{ne}}{3}$) . Furthermore, the university accepts to patent and delivers an exclusive license to firm 1 if and only if $t_e \frac{(1-t_e)}{2} > c_p$.

Finally, in the case of proposition 1c, if $I < \frac{(1-t_{ne})^2}{9}$ then both monopoly and duopoly profits are positive and firms always accept to commercialize the invention. Hence under both cases, the technology is transferred. University may choose either to patent or publish depending on its net income. Hence, if the cost of patenting is lower than the licensing revenue, that is to say either $c_p <$

$t_e \frac{(1-t_e)}{2}$ or $c_p < 2t_{ne} \frac{(1-t_{ne})}{3}$, then at the SPNE of the game university patents and grants either an exclusive or a non-exclusive license. But, on the other hand, if cost of patenting is higher than the licensing revenue, that is to say both $c_p > t_e \frac{(1-t_e)}{2}$ and $c_p > 2t_{ne} \frac{(1-t_{ne})}{3}$, then at the SPNE of the game university publishes the invention.

This first proposition is therefore in line with the discussion in section 3. The more embryonic the university invention the more likely it is to see exclusive licensing. Indeed, since duopoly profits are lower than monopoly profits, it is possible that publishing the invention or granting non-exclusive licenses to firms do not provide them with enough incentives to invest in the development of the technology. Yet, when the invention is too embryonic even the grant of an exclusive license is not sufficient to induce firms to invest in the development of the invention.

If the technology is mature it will be transferred in any case. Whatever the choice of the university, firms decide to commercialize the invention. Yet, all the SPNEs may not be in the public interest. This is clearly stated by proposition 2.

Proposition 2: Assume $I = 0$ (invention is mature). In this case the social surplus is the highest when the invention is published. But, if $c_p < t_e \frac{(1-t_e)}{2}$ or $c_p < 2t_{ne} \frac{(1-t_{ne})}{3}$ then the university decides to patent the invention, i.e. the SPNE of the game is not socially optimal.

In order to show that publishing gives the highest social surplus when the invention is mature, we should compare social welfare (SW), under each licensing regime. Table 2 summarizes these findings.

Table 2: Social Welfare under Different Licensing Strategies (Specific Invention)

	Social Welfare	**Firms' profit**	**Consumer Surplus**	**University Net Income**
Exclusive Licensing	$\frac{3}{8}(1-t_e)^2 - I + t_e\left(\frac{1-t_e}{2}\right) - c_p$	$\frac{1}{4}(1-t_e)^2 - I$	$\frac{1}{8}(1-t_e)^2$	$t_e\left(\frac{1-t_e}{2}\right) - c_p$
Non-exclusive Licensing	$\frac{4}{9}(1-t_{ne})^2 - 2I + 2t_{ne}\left(\frac{1-t_{ne}}{3}\right) - c_p$	$\frac{2}{9}(1-t_{ne})^2 - 2I$	$\frac{2}{9}(1-t_{ne})^2$	$2t_{ne}\left(\frac{1-t_{ne}}{3}\right) - c_p$
Publishing	$\frac{4}{9} - 2I$	$\frac{2}{9} - 2I$	$\frac{2}{9}$	0

From Table 2 it is thus immediate that SW under publishing is higher than SW under non-exclusive and exclusive licensing if the invention is mature ($I = 0$). However, if $c_p < t_e \frac{(1-t_e)}{2}$ or if $c_p < 2t_{ne}\frac{(1-t_{ne})}{3}$, the university net income will be higher under patenting than under publishing, i.e. the university will decide to patent and to deliver an exclusive or non-exclusive license, although it is socially under optimal.

4.2. The Case of a Generic Technology

In the case of a generic technology the university invention can be used in the two industries A and B and can thus be commercialized by the 4 firms in those two industries. The extensive form of this game is given in Appendix 2. A first result is stated in proposition 3 below.

Proposition 3: If the invention is generic and mature ($I = 0$) and if $2t_{efu}\frac{(1-t_{efu})}{2} > t_e\frac{(1-t_e)}{2}$ or $4t_{ne}\frac{(1-t_{ne})}{3} > t_e\frac{(1-t_e)}{2}$, then there always exist a SPNE in which the invention is commercialized in the two sectors.

Indeed, if the invention is mature, then both monopoly and duopoly profits are positive in each sector. Hence firms always accept to commercialize the invention whatever the strategy of the university (patenting or publishing) is. If the university decides to patent, provided that

$2t_{efu}\frac{(1-t_{efu})}{2} > t_e\frac{(1-t_e)}{2}$ or $4t_{ne}\frac{(1-t_{ne})}{3} > t_e\frac{(1-t_e)}{2}$, the university always chooses not to give a global exclusivity to a single firm, thus leading to the commercialization in both sectors.

The decision to patent or publish depends on university's net income. If the cost of patenting is lower than the licensing revenues, that is to say either $c_p < 2t_{efu}\frac{(1-t_{efu})}{2}$ or $c_p < 4t_{ne}\frac{(1-t_{ne})}{3}$, then university patents and we have a SPNE with patent and exclusive license per field of use or non-exclusive licence and commercialization (i.e. commercialization in both sectors). If the cost of patenting is higher than the licensing revenues, that is to say both $c_p > 2t_{efu}\frac{(1-t_{efu})}{2}$ and $c_p > 4t_{ne}\frac{(1-t_{ne})}{3}$, then university publishes and we have a SPNE with publication and commercialization in both sectors.

Proposition 3 states that if the invention is mature and generic there always exist a SPNE which allows the transfer of the invention in all sectors of the economy. However, this SPNE may not always be socially desirable, as stated in proposition 4.

Proposition 4: If the invention is generic and mature, the SPNE which yields the highest social surplus is when the invention is published. But, if $c_p < t_e\frac{(1-t_e)}{2}$, $c_p < 2t_{efu}\frac{(1-t_{efu})}{2}$ or $c_p < 4t_{ne}\frac{(1-t_{ne})}{3}$), then the university decides to patent the invention, i.e. the SPNE of the game is not socially optimal. The less efficient SPNE is when $t_e\left(\frac{1-t_e}{2}\right) > 2t_{efu}\left(\frac{1-t_{efu}}{2}\right)$ and $t_e\left(\frac{1-t_e}{2}\right) > 4t_{ne}\left(\frac{1-t_{ne}}{3}\right)$, i.e. when the university choses to grant an exclusive license only to one firm in one sector.

In order to show that publishing gives the highest social surplus when the invention is generic and mature we must again compare social welfare (SW) under each licensing regime. Table 3 summarizes these findings.

Table 3: Social Welfare under Different Licensing Strategies (Generic Invention)

	Social Welfare	**Total profit**	**Consumer Surplus**	**University Net Income**
Exclusive Licensing	$\frac{3}{8}(1-t_e)^2 + t_e\left(\frac{1-t_e}{2}\right) - c_p$	$\frac{1}{4}(1-t_e)^2$	$\frac{1}{8}(1-t_e)^2$	$t_e\left(\frac{1-t_e}{2}\right) - c_p$
Exclusive Licensing per Field of Use	$\frac{3}{4}(1-t_{efu})^2 + 2t_{efu}\left(\frac{1-t_{efu}}{2}\right) - c_p$	$\frac{1}{2}(1-t_{efu})^2$	$\frac{1}{4}(1-t_{efu})^2$	$2t_{efu}\left(\frac{1-t_{efu}}{2}\right) - c_p$
Non-exclusive Licensing	$\frac{8}{9}(1-t_{ne})^2 + 4t_{ne}\left(\frac{1-t_{ne}}{3}\right) - c_p$	$\frac{4}{9}(1-t_{ne})^2$	$\frac{4}{9}(1-t_{ne})^2$	$4t_{ne}\left(\frac{1-t_{ne}}{3}\right) - c_p$
Publishing	$\frac{8}{9}$	$\frac{4}{9}$	$\frac{4}{9}$	0

In Table 3 we can see that SW under publishing is higher than SW under exclusive licensing, exclusive license per field of use and non-exclusive licensing. However, if either $c_p < t_e\frac{(1-t_e)}{2}$ or $c_p < 2t_{efu}\frac{(1-t_{efu})}{2}$ or $c_p < 4t_{ne}\frac{(1-t_{ne})}{3}$, university decides to patent (i.e. publishing cannot be a SPNE), leading hence to inefficiency. Furthermore, it is possible that the invention is not commercialized in both sectors if university exclusively and globally license the invention to firm 1 in sector A. University may choose to give a global exclusivity if both $t_e\left(\frac{1-t_e}{2}\right) > 2t_{efu}\left(\frac{1-t_{efu}}{2}\right)$ and $t_e\left(\frac{1-t_e}{2}\right) > 4t_{ne}\left(\frac{1-t_{ne}}{3}\right)$. Intuitively, the inefficiency is higher under global exclusivity since the quantity produced decreases and the invention cannot be commercialized in both sectors.

Now, let us examine what may happen in the game when the invention is generic and embryonic. In this case, as stated by proposition 5, some degree of exclusivity may be necessary in order to induce firms to invest in the technology. However, it is also possible that universities do not chose the most desirable licensing contract, as stated by proposition 6.

Proposition 5: If the invention is generic and moderately embryonic then the only SPNE which allows the invention to be commercialized in both sectors is when the university decides to patent and to deliver exclusive license per field of use. This SPNE is reached if $2t_{efu}\frac{(1-t_{efu})}{2} > c_p$ and $2t_{efu}\left(\frac{1-t_{efu}}{2}\right) > t_e\left(\frac{1-t_e}{2}\right)$.

Indeed, if $\frac{(1-t_{ne})^2}{9} < I$ then firms' duopoly profits, whether university publishes or delivers a non-exclusive license, are always negative and firms never accept to commercialize the invention. Although global exclusivity may allow commercialization in sector A, it will not be possible to have a SPNE which allows the invention to be commercialized in both sectors. When $I < \frac{(1-t_e)^2}{4}$ firms' monopoly profits in sector A and sector B are positive, because $\frac{(1-t_{efu})^2}{4} > \frac{(1-t_e)^2}{4} > I$. In this case both firms accept to commercialize the invention. Furthermore, the university accepts to patent and deliver exclusive license per field of use if and only if $2t_{efu}\frac{(1-t_{efu})}{2} > c_p$ and $2t_{efu}\left(\frac{1-t_{efu}}{2}\right) > t_e\left(\frac{1-t_e}{2}\right)$.

Proposition 6: If the invention is generic and moderately embryonic, then there is a risk of inefficiency if $t_e\left(\frac{1-t_e}{2}\right) > 2t_{efu}\left(\frac{1-t_{efu}}{2}\right)$. In this case the only SPNE is when the university delivers a global exclusive license and the invention is commercialized only in sector A.

Non-commercialization of the invention in both sectors will create inefficiency if university decide to give a global exclusivity to firm 1 in sector A. This outcome is possible if university obtains higher income by giving global exclusivity that is if $t_e\left(\frac{1-t_e}{2}\right) - c_p > 2t_{efu}\left(\frac{1-t_{efu}}{2}\right) - c_p$. And this situation cannot be excluded as illustrated by the following numerical example: Assume that $t_e = 10\%$ and $t_{efu} = 4\%$ (this important gap might be justified by the perceived difficulty by companies to enforce an exclusive license per field of use). In this case the net income of university under global exclusivity equals $0.045 - c_p$ while it equals $0.0384 - c_p$ under exclusive license per field of use. In this case the university would therefore decide to grant a global exclusive license only to firm F_{1A}.

The main results of the model are summarized in Table 4. If the invention is too embryonic and either specific or generic, there is no SPNE in which the technology can be transferred. If the invention is moderately embryonic and specific, giving exclusivity is the only way of transferring technology. If the invention is moderately embryonic and generic, then the only way of transferring technology in both sectors is giving exclusive license per field of use. If university decides to give a global exclusivity, this may lead to inefficiency. This case cannot be excluded under some reasonable conditions. If the invention is mature and specific or generic, there exist always a SPNE in which the technology is transferred in both sectors. In this case the optimal strategy is always publishing. However university may choose to patent if c_p is lower than its licensing revenue. Finally, if the invention is mature and generic, it is possible (under some extreme conditions) that the university choses to grant a global exclusive license, thus leading to an under commercialisation of the technology as compared to the optimum.

Table 4. Summary of Results

NATURE OF INVENTION	**Specific**	**Generic**
Too Embryonic	<u>Proposition 1a:</u> The only SPNEs are publishing and no transfer.	The only SPNEs are publishing and non commercialization (No transfer).
Moderately Embryonic	<u>Proposition 1b:</u> The only SPNE which allows commercialization is exclusive licensing.	<u>Proposition 5:</u> The only SPNE that allows commercialization in both sectors is exclusive licensing per field of use. <u>Proposition 6:</u> Risk of inefficiency if university grants a global exclusivity.
Mature	<u>Proposition 1c:</u> All SPNEs allow commercialization. <u>Proposition 2:</u> Risk of inefficiency if university does not publish.	<u>Proposition 3:</u> Most SPNEs allow commercialization in both sectors. <u>Proposition 4:</u> Risk of inefficiency if university does not publish and even worse if it grants a global exclusivity.

5. Conclusion

The growing interest of the “ivory tower” in valorising its research through patenting and licensing has raised many questions. In this paper we have investigated how the nature of the invention (embryonic versus mature; generic versus specific) may affect the degree of exclusivity of the licensing contract. We have also shown that it may be possible that universities choose to grant licensing contracts which are not in the public interest. In particular, this may be the case when the objective of universities and TTOs is to maximize their revenues but not the social welfare.

Some of the findings of our model are clearly in line with recent policy evolutions. For instance, in line with the Bayh Dole argument, we find out that some degree of exclusivity may be desirable when the invention is embryonic (and clearly many university inventions are embryonic). Also, we find out that even exclusive licenses may not be sufficient to transfer the technology if the invention is too embryonic and hence too costly. Thus, in this case policy measures that favour academic entrepreneurship, creation of start-up, and/or the collaboration between the academic inventor and the firm might help to develop the technology and transfer the invention (Jensen and Thursby, 2001).

However, our model also points out some possible source of inefficiency if universities decide to rely systematically on exclusive licenses. In particular this may be detrimental to social welfare when the invention is mature and/or generic. In this case, an important finding of the model is that publishing the research outcomes (releasing them for free) may be the most desirable solution. This result must be emphasized, in particular since budget constraints that apply to countries all around the world may induce governments to increasingly require universities to “sell” their technologies rather than giving them away for free. This short run strategy might hence reduce publications and be detrimental on the longer run to social welfare.

At the end, this paper contributes to the existing literature in two ways: First, it offers a conceptual understanding of the determinants that should be considered by universities when they choose their patenting and licensing strategy; second, it formalizes the role of the nature of the invention on optimal university licensing strategy.

Yet, there are some limitations to this paper which might be the subjects of further researches. In this work, we only considered the effect of the nature of the invention on university licensing strategies. In addition to this, the effects of other parameters such as technological regime, size of market, characteristics of licensee firm may also be explored by using a similar game theoretic approach. In this regard, we aim to extend our approach first by introducing different market sizes in the case of a generic technology, especially when there are spillovers between the sectors. It is also possible to add more on the list of aforementioned determinants such as cumulative versus science based technology by placing them under the technological regime (Nelson and Winter,1982) category or by introducing the probability of imitation in a sector to determine the degree of exclusivity that should be granted to the firm operating in that sector. Further, considering the incomplete information case may yield interesting results in terms of licensing strategy especially by affecting the expected profits. The research valorisation analysis may also be extended to other contractual forms such as collaboration or material transfer agreements.

Regarding the methodology, using a combined approach might be more appropriate, i.e. besides applying game theoretic models, conducting empirical tests to explore how aforementioned determinants affect university research valorisation strategies, may give us robust results. Indeed we aim to obtain the data on the nature of invention as well as on some other determinants to run an econometric analysis from the surveys conducted in Grenoble and Strasbourg Universities within the framework of an ongoing project, namely COCON (COhort of CONtracts) which is funded by the French National Research Agency (ANR). The data will be obtained through the examination of various types of research transfer contracts between the universities and firms. Finally, given the increasing political pressure on TTOs requiring them to be profitable, an examination on the primary objective of TTOs, i.e. profit driven or a more socially driven, is needed to shape the university licensing strategies.

References

Agrawal, A., & Henderson, R. (2002). Putting patents in context: Exploring knowledge transfer from MIT. Management Science, 48(1), 44-60.

Azagra-Caro, J. M., Carayol, N., & Llerena, P. (2006). Patent production at a European research university: exploratory evidence at the laboratory level. The Journal of Technology Transfer, 31(2), 257-268.

Azoulay, P., Ding, W., & Stuart, T. (2009). The Impact of Academic Patenting on the Rate, Quality and Direction of (public) Research Output*. The Journal of Industrial Economics, 57(4), 637-676.

Cameron,D. M. (2010). Cameron's Canadian Patent and Trade Secrets Law. Chapter 13: Licensing. Retrieved 06, June 2014 from http://www.jurisdiction.com/patweb13.pdf

Carayol, N. (2007). Academic incentives, research organization and patenting at a large French university. Econ. Innov. New Techn., 16(2), 119-138.

Cassier, M., & Sinding, C. (2008). 'Patenting in the public interest:'administration of insulin patents by the University of Toronto. History and Technology, 24(2), 153-171.

Cesaroni, F., & Piccaluga, A. (2002, March). Patenting Activity of European Universities. Relevant? Growing? Useful?. In conference 'Rethinking Science Policy: Analytical Frameworks for Evidence-Based Policy (pp. 21-23).

Cohen, W. M., Florida, R., Randazzese, L., & Walsh, J. (1998). Industry and the academy: uneasy partners in the cause of technological advance.Challenges to research universities, 171(200), 59.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and impacts: the influence of public research on industrial R&D. Management science, 48(1), 1-23.

Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R. R., Rosenberg, N., & Sampat, B. N. (2002). How do university inventions get into practice?. Management science, 48(1), 61-72.

Di Gregorio, D., & Shane, S. (2003). Why do some universities generate more start-ups than others?. Research policy, 32(2), 209-227.

Feldman, M. P., Colaianni, A., Kang, L., Krattiger, A., Mahoney, R. T., Nelsen, L., ... & Kowalski, S. P. (2007). Lessons from the commercialization of the Cohen-Boyer patents: the Stanford

University licensing program. Intellectual property management in health and agricultural innovation: a handbook of best practices, Volumes 1 and 2, 1797-1807.

Feldman, M., Colaianni, A., & Liu, K. (2005). Commercializing Cohen-Boyer 1980-1997. Kauffman Foundation.

Gambardella, A., & Hall, B. H. (2006). Proprietary versus public domain licensing of software and research products. Research Policy, 35(6), 875-892.

Geuna, A., & Nesta, L. J. (2006). University patenting and its effects on academic research: The emerging European evidence. Research Policy, 35(6), 790-807.

Grimpe, C., & Fier, H. (2010). Informal university technology transfer: a comparison between the United States and Germany. The Journal of Technology Transfer, 35(6), 637-650.

Grimpe, C., & Hussinger, K. (2013). Formal and Informal Knowledge and Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance. Industry and Innovation, 20(8), 683-700.

Heller, M. A., & Eisenberg, R. S. (1998). Can patents deter innovation? The anticommons in biomedical research. Science, 280(5364), 698-701.

Henderson, R., Jaffe, A. B., & Trajtenberg, M. (1998). Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. Review of Economics and Statistics, 80(1), 119-127.

Ho, M. H. C., Liu, J. S., Lu, W. M., & Huang, C. C. (2013). A new perspective to explore the technology transfer efficiencies in US universities. The Journal of Technology Transfer, 1-29.

Jensen, R., & Thursby, M. (2001). Proofs and prototypes for sale: The licensing of university inventions. American Economic Review, 91(1), 240-259.

Kingston, W. (2001). Innovation needs patents reform. Research Policy, 30(3), 403-423.

Lemley, M. A. (2007). Are universities patent trolls. Fordham Intell. Prop. Media & Ent. LJ, 18, 611.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., Gilbert, R., & Griliches, Z. (1987). Appropriating the returns from industrial research and development. Brookings papers on economic activity, 783-831.

Lissoni, F., Llerena, P., McKelvey, M., & Sanditov, B. (2008). Academic patenting in Europe: new evidence from the KEINS database. Research Evaluation, 17(2), 87-102.

Mansfield, E. (1986). Patents and innovation: an empirical study. Management science, 32(2), 173-181.

Mazzoleni, R., & Sampat, B. N. (2002). University patenting: an assessment of the causes and consequences of recent changes in strategies and practices.*Revue d'économie industrielle*, 99(1), 233-248.

Mowery, D. C. (Ed.). (2004). Ivory tower and industrial innovation: university-industry technology transfer before and after the Bayh-Dole act in the United States. Stanford University Press.

Mowery, D. C., & Shane, S. (2002). Introduction to the special issue on university entrepreneurship and technology transfer. Management Science,48(1), v-ix.

Mowery, D. C., & Ziedonis, A. A. (2002). Academic patent quality and quantity before and after the Bayh Dole act in the United States. Research Policy,31(3), 399-418.

Mowery, D. C., Nelson, R. R., Sampat, B. N., & Ziedonis, A. A. (2001). The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh–Dole act of 1980. Research policy, 30(1), 99-119.

National Science Foundation (NSF), (2014). Science and Engineering Indicators 2014. Chapter 5. Retrieved on 15 April, 2014 from http://www.nsf.gov/statistics/seind14/content/chapter-5/chapter-5.pdf

Nelson, R. R. (2001). Observations on the post-Bayh-Dole rise of patenting at American universities. The journal of Technology transfer, 26(1), 13-19.

Nelson, R. R., & Winter, S. G. (1982). An evolutionary theory of economic change, 929-964.

Pénin, J. (2010a). Quelle politique de licence de brevet pour les organismes publics de recherche? Exclusivité versus modèles plus ouverts. Management international/Gestiòn Internacional/International Management, 14(3), 47-58.

Penin, J. (2010b). On the consequences of patenting university research: Lessons from a survey of French academic inventors. Industry and Innovation,17(5), 445-468.

Sampat, B. N. (2006). Patenting and US academic research in the 20th century: The world before and after Bayh-Dole. Research Policy, 35(6), 772-789.

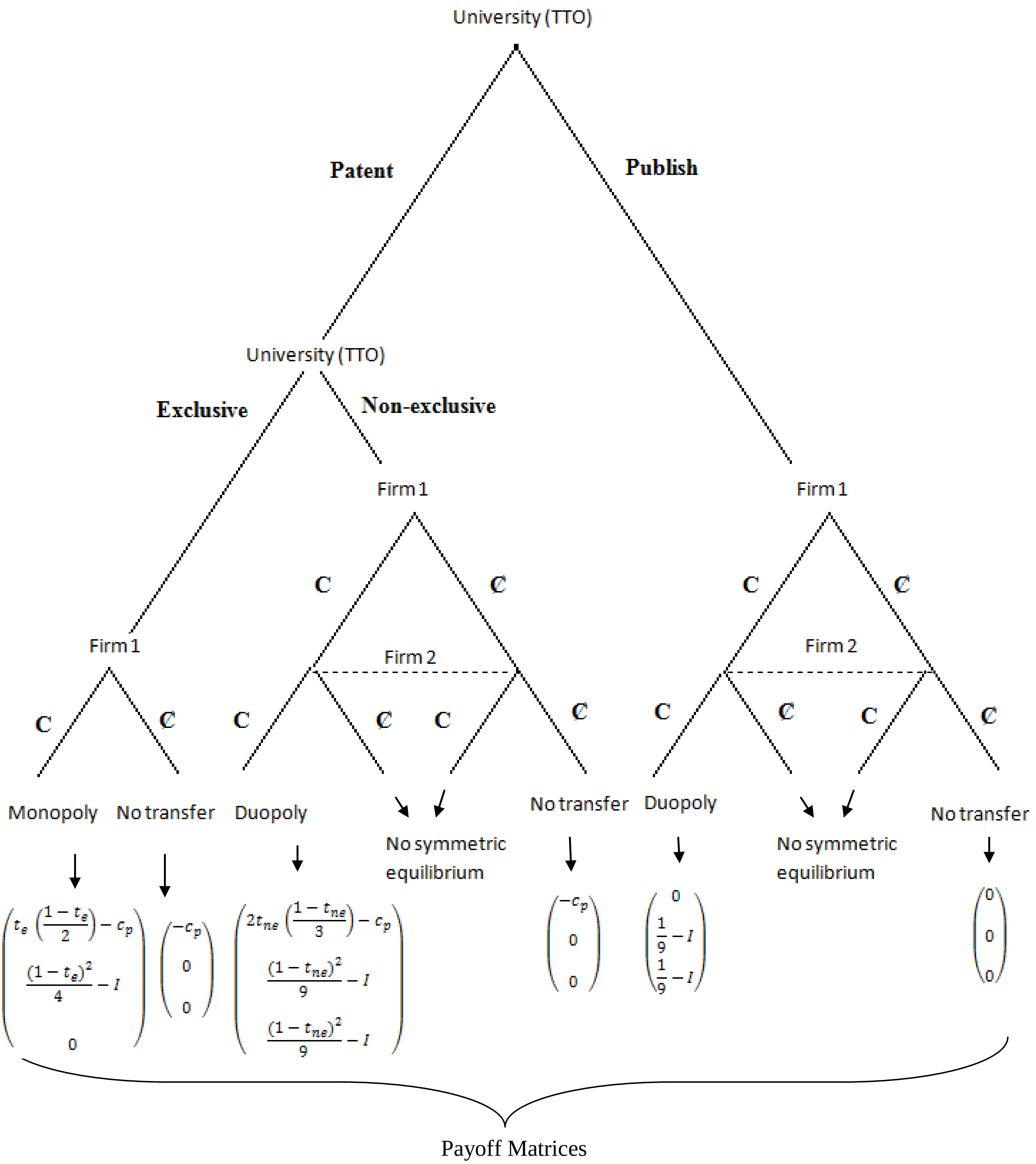
Siegel, D. S., Waldman, D. A., Atwater, L. E., & Link, A. N. (2003). Commercial knowledge transfers from universities to firms: improving the effectiveness of university–industry collaboration. The Journal of High Technology Management Research, 14(1), 111-133.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research policy, 15(6), 285-305.

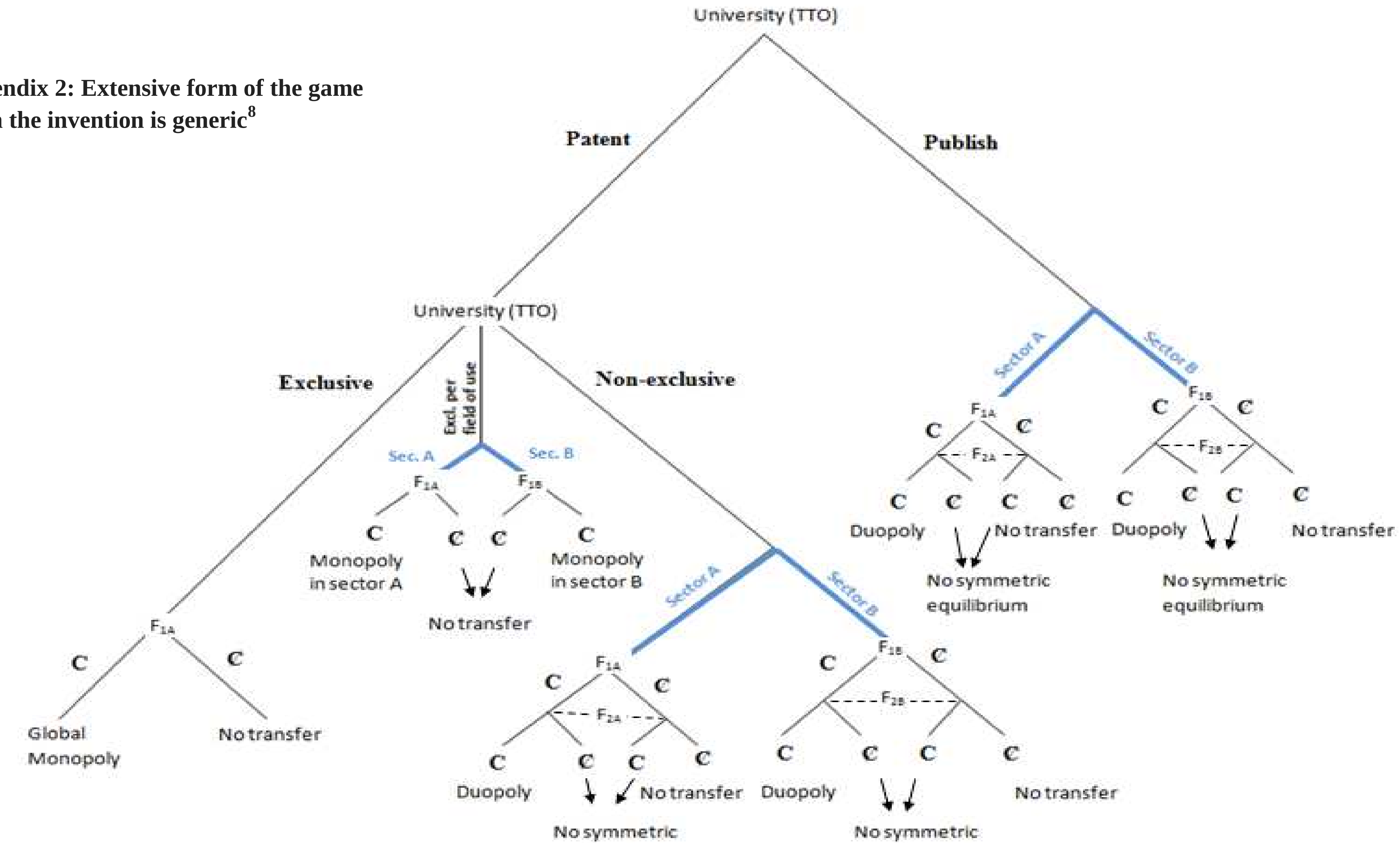
Thursby, J. G., & Thursby, M. C. (2007). University licensing. Oxford Review of Economic Policy, 23(4), 620-639.

World Intellectual Property Organization (WIPO), (2014). Licensing of Intellectual Property Rights; a Vital Component of the Business Strategy of Your SME. Accessed in 21 May, 2014 from http://www.wipo.int/sme/en/ip_business/licensing/licensing.htm

Appendix 1: Extensive form of the game when the invention is specific



Appendix 2: Extensive form of the game when the invention is generic[8]



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[8] Blue colored parts are the cases where university licenses the invention in both sectors, A and B, simultaneously. Therefore these should not be considered as a choice between two sectors.