ESSAYS ON INNOVATION

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A thesis submitted for the degree of Doctor of Philosophy

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2017

Dedicated to my beloved husband, Jose Luis, my parents and my brother.

Thank you to my supervisors, Dr Katharine Rockett and Dr Helen Weeds, who where always there to guide me.

Abstract

One of the top priorities of any policymaker is to ensure long-term economic growth, where one of the main components is technology. A major driver for technology advancements is innovation that increases productivity and promotes economic growth.

This dissertation serves as further understanding of the innovation process. Specifically, this thesis focuses on three different aspects: i) how to incentive research (Chapter 1 and 2), how to organise it (Chapter 3 and 4), and how decision making occurs (Chapter 5).

In Chapters 1 and 2, I examine how research responds to different incentives. I analyse whether university research is more basic than the one of the private firms. Using a unique patent database using GM crops technology, where I can track the development of the technology since I identify the first patent issued in this field. One significant finding is that university patents generate broader use at the beginning of the technology cycle, while private firms research is as complement later.

In Chapter 3 and 4, I study how research is organised within a firm, focusing

on the degree of third-party involvement in new product development. I use the aircraft industry where each firm has a different innovation path due to the inherent structure of each one. One main result is that major involvement of third agents in the R&D process can save time and money, but requires effective monitoring and coordination to avoid delays and unexpected costs.

In Chapter 4, I provide a unique case study using empirical evidence of the different innovation attitudes of Boeing and Airbus by tracking the careers of the inventors that have been present in at least one patent owned by any of these firms. I use a unique database where I can track the patent profile of the inventors and make inferences of each company's innovation attitude.

In Chapter 5, I use real options analysis to provide a tool to decision-makers where businesses in a duopoly face uncertainty in the outcome of the R&D phase. This chapter provides a broader approach to the real options analysis under strategic competition, and I find that a higher probability of success does not mean higher value for the firm since the preemption behaviour lowers the value of the investment opportunity.

Contents

List of Figures

List of Tables

Chapter 1

Role of universities in innovation

1.1 Introduction

Many of the science and technology breakthroughs haven been achieved due to the first intervention of government-funded projects, mainly research done within universities and non-profit organisations (Aghion et al., 2008).

One fundamental reason in support of public funding directed at universities and public centres R&D activities has been that in the absence of such intervention, the private market would not adequately supply certain types of research. Those types unlikely to provide substantial economic rewards to the patent owner (low appropriability), mainly because the new knowledge can be replicated or disseminated at low cost (Nelson, 1959).

According to Calvert (2006), basic research is usually associated to unpredictably and generality, not only in the potential outcome but also in the future economic profits received from the invention. Unpredictability is the main feature of basic research that has justified public funding for many years (Arrow, 1962) since it can lead to inventions that could potentially initiate paradigm shifts and produce radical technological changes that otherwise if left alone to private firms, would never occur.

In this sense, Nelson (1959) and Arrow (1962) argue that one possible explanation for the underinvestment is that profit motivates private firms and basic research carries uncertainty implicitly in the future economic benefits. Thus, natural candidates to fill this gap are universities and other non-profit research bodies where creators can pursue their interest more freely.

In this context, there are two central concerns to be tackled by policymakers: appropriability, that is usually attacked by granting intellectual property, such as patents; and underinvestment, that has been approached mainly through government funding (Trajtenberg, 2012).

Moreover, government support for R&D is a way to keep pace with technological advances in other countries, for instance, spending on R&D has increased dramatically in some emerging market economies, mainly in China and India (Bernanke, 2011).

The issue of public R&D funding becomes more relevant in the light of the most recent economic crisis since it has been documented that business innovation and R&D was negatively affected by the crisis in both developed and developing countries (OECD, 2012).

Undoubtedly, universities have been the cornerstone of many science/technology breakthroughs throughout history, but the question becomes how much money should the government allocate to these activities in a world where there are pressing economic and financial problems, and once the money is allocated, to ensure it is well employed.

In this context, the issue becomes whether private funding is a complement or a substitute to universities public research funding. For instance, Aghion et al. (2008) argue that the role of universities is fundamental in the early stage of a technology cycle, but on the path towards the commercial finished product there should be a transition from academia to private firms.

Moreover, one may argue that one single directive, usually present in private companies, could ensure that all resources are efficiently poured towards the completion of a research project to obtain more rapidly the legal protection and in turn the economic benefits of the money spent on the total project (Aghion et al. 2008).

The aim of this chapter is to provide an insight into the role of universities in innovation. This analysis serves as a background for the next chapter where I present an empirical case study to examine whether there is a significant difference between universities and private firms research positive externalities, measured through forward patent citations, and using a particular technology area.

I analyse whether not only universities are carrying out basic research that is later used by third agents, but also whether private firms are engaged in basic research. If this is the case, one should not expect a difference between universities and private enterprises patents. On the contrary, if as suggested by some authors, universities are the primary source of basic research, their patents should be of much wider use and in turn, much more cited by future patents.

1.2 Rationale for public R&D subsidies

According to the National Science Foundation (NSF), basic research is defined as "systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind[1]", while applied research is "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met[2]."

Therefore, the main difference between basic and applied research is that the first one is done without specific future applications, while the second one focuses on a particular need. In this context, much of the debate on the direction of R&D government policies is whether basic or applied research is the one that provides more positive externalities for the society and long-term growth for the country. Nevertheless, most of the industrial policies have allocated the majority of public resources to basic research activities (Akcigit et al., 2012).

Academic consensus has remained that basic research is the part of the R&D that provides more benefits to the society, mainly because it can be used by a great variety of knowledge fields and be transformed into applied research (Nelson, 1986, Arrow, 1962, Bernanke, 2011). Empirically, many authors have estimated a positive effect of basic research on the innovation systems of different sectors

[1] http://www.nsf.gov/statistics/randdef/fedgov.cfm
[2] Ibid.

(Nelson, 1986; Jaffe, 1989; Adams, 1990; Mansfield, 1991).

Arrow (1962) presented the main argument in support of publicly funded research. The author shows that since the output of basic research is used for other inventive fields, it will only be economically rewarding if other agents can be prevented from using it. Otherwise, there will be an underinvestment allocated to basic research, compared to the social optimum.

Therefore, the role of the government is essential to ensure that the scientific/technological breakthroughs keep appearing by making sure that sufficient funds are allocated to basic research. However, if public funds are allotted to these creative activities, the question becomes how much money is enough and how to ensure an efficient use of these resources.

According to Nelson (1959), the social benefit for basic research expenditure should be the present value of the future benefits derived directly or indirectly from it, and the social cost is defined as the sum of resources directed towards basic research diverted from other activities. In this way, the optimal quantity to allocate to basic research is the one that maximises the social profit defined as social benefit minus social cost.

The above is important since taxpayers support most of the basic research. In the U.S., in 2012, 50 percent of the federal basic research funding was allocated to universities [3].

The appropriability problem of basic research also provides a strong argument supporting government intervention. Since the output of basic research is not im-

[3] http://www.nsf.gov/statistics/fedfunds/

mediately applicable, scientists are frequently not able to obtain immediate legal protection to ensure economics rewards from the invention(Nelson, 1959; Dasgupta and David, 1994).

Due to the features of basic research, private firms are less likely to engage in it. However, some businesses are involved in basic research. The question is why private companies would want to spend their money when there is an uncertainty of future legal protection and successful completion to begin commercialisation?

Possibly, the answer is that because the potential payoff of basic research is long-term that could give a firm a first-mover advantage for an extended period and potentially a monopoly in a particular field, provided the successful completion of the innovation and the legal protection (Rosenberg, 1990). Thus, not only firms with sufficient resources to potentially maintain inventions *on the shelf* will engage in basic research, but also companies with sufficiently diversified products would have the same incentive since they are confident that the new knowledge has applicability to any of their branches (Rosenberg, 1990).

More recently, the trend has moved towards collaboration research agreements, where private firms, government and universities are collaborating more closely.

1.3 Impact of universities in the economic development

Endogenous innovation is the main contributor to economic growth according to the new neoclassical growth theory; and since the incentive to invest in R&D is to ensure private financial returns, it gives place to monopolistic market structures and a sub-optimal equilibrium (Verspagen, 1992).

Aghion and Howitts (1992) presented an endogenous growth model where all the stages of the innovation process are patentable, and the accumulation of knowledge takes the form of industrial innovation that improves the quality of the products, and thus, the growth rate of the economy depends directly on the R&D total expenditure. In this model, an agent has the incentive to innovate since the successful completion of new invention results in legal protection, namely a patent, that would provide a monopoly to enable the agent rent-extraction until a new invention replaces it. The motion of this model is that technological change increases productivity in the production of intermediate goods and thus promotes economic growth.

It is true that innovation is one of the most important aspects to consider to any industrial policy agenda; however, many issues arise from this, for instance, how to allocate the limited government resources and how to measure the social return on them. The net impact of academic research on innovation has proven difficult to measure since its output disseminates easily and its scope is broad.

One early empirical analysis is the one of Mansfield (1991), were the author investigated the link between academic research and industrial innovation using a random sample of 76 American firms from seven different manufacturing industries. The author finds that between 1975 and 1985 around 11 percent of all the new products and 9 percent of all the new processes introduced in these industries could not have been developed without further delay in the absence of academic research, and that the average time lag between the original innovation and the industrial application was 6.4 years. Moreover, the author also suggests that academic research is not homogeneous in its evolution of the importance of industrial innovation and that some industries such as pharmaceuticals, instruments, and information processing are more reliant on it.

Academic research is necessary for industrial innovation, but it is not clear whether the role of universities is mainly as the only source of new and radical research or as partners of private firms in the development of new ideas.

One paper that analyses this issue is the one by Mansfield (1995) where each of 66 firms across different industries was asked to cite some of their primary academic researchers in their field whose work resulted vital for the company. The answers indicated that the majority of the citations correspond to leading science/technology universities, such as MIT, Berkeley or Stanford. Moreover, the results suggest a direct link between a universities R&D expenditure and its contribution to the industry. Around two-thirds of all the cited academic researchers received in some form government financial support, and 66 percent of their total research budget was publicly funded.

Adams (1990) provided a set of indicators to assess the effect of academic research on productivity gains of manufacturing industry, assuming that expansion of basic knowledge is what generates technical change and growth both in R&D and inputs. In this case, the measure of knowledge is the worldwide annual counts of academic publications in nine sciences. The industrial composition of each author is the link between the origin of knowledge and the industry. The author finds that although there is a lag between 20 and 30 years elapsed from the original academic research to the industrial application, there is evidence that it strongly increases the industry productivity.

Universities attitude towards patenting and the commercialisation of their innovations has changed over the years. In this context, Henderson et al. (1998) examined whether the basicness of patented university research changed after the legislation of the early 1980s in the United States, using a random sample from all patents assigned to universities between 1965 and 1992. The authors conclude that while the difference between the degree of basicness of universities and private firms patents has narrowed over time, university patents were still more basic and more important than the corresponding corporate patents. These estimations indicate that there is indeed a real effect of universities research and the advancement of applied technology and that many of the new products and processes used within certain industries rely heavily on it.

Although universities do help to move forward applied technology, it may well be the case where universities and academic institutions have different incentives to reward fast production and rapid dissemination of their inventions compared to the private sector; for instance, universities annual federal budget may be conditioned to tangible evidence of positive externalities to society (Dasgupta and David, 1994).

More recently, Prettner and Wegner (2016) presented a R&D-based model with a basic research sector as the main growth contributor. The main feature is that the wage of academic researchers is partially paid through governmental funding.

Therefore, basic research is considered to be a pure public good, while applied research is deemed to be patentable and commercialised. The authors find that an increase in basic research public funding results in a negative shock to the GDP per capita in the short-run, but raises it in the long run.

The latter result can be explained by the gap between basic research and its application (Adams, 1990), but could also serve as an argument for policymakers to stand against the increase in R&D expenditure, since it represents a short-run loss, despite the well-known long-term benefits (Prettner and Wegner, 2016).

1.4 Are governmental R&D and private R&D complements or substitutes?

In increasingly competitive markets, firms and universities have recently begun to look away from their R&D departments, making agreements with other businesses, government research bodies and other universities (Etzkowitz and Leydesdorff, 1998).

These complex relationships give place to the so-called 'Triple Helix' model, where the origin and transmission of knowledge are analysed regarding university-industry-government. This model is different from the linear model, where basic research only begins in academia, funded by the government, and is later applied by the industry (Etzkowitz and Leydesdorff, 1998).

One early example of this 'Triple Helix' is found in Japan, where since the 1980s several R&D programmes for basic research were founded intended to promote basic research in universities, government research institutes and private sector, without decreasing the budgets of existing programmes (Hayashi, 2003).

There are two main approaches to the question of the relationship between public and private R&D funding. On the one hand, many of the empirical studies have found a complementary effect where the public financing stimulates additional private financing, while on the contrary, some authors have shown a 'crowding effect' where government funding seems to offset private funding (Alonso-Borrego et al., 2014).

David et al. (2000) survey the econometric evidence of 35 years around this complementarity question and find that even though R&D investments of private firms are found to have a high return rate both privately and socially. However, it has also been the case where the evidence suggests that industry R&D that is publicly funded has an even greater rate of return.

There is also proof that even if the majority of universities research funding comes from the government, some industries also provide significant and continuous funding to universities research projects. For instance, Mansfield (1995) found that academic researchers complement their government wage with their industry funding, mainly by using the first one to engage in basic research and the second one to extend or deepen it. Also, many of them continue their relationship with the private sector, even when the formal funding programmed expires, in the form of external consultancy.

In this sense, Etzkowitz (2003) explains the recently observed transition to the entrepreneurial university. In the paper, the development of universities is illustrated, from their original role of preserving and disseminating knowledge (teaching), to their next research engagement, and to their more actual entrepreneurial character.

This entrepreneurial role arises as natural since managers in all public and private R&D organisations are in need to balance incentives for pure basic research to research that would most certainly result in patents and licenses (Banal-Estaol and Macho-Stadler, 2010).

Banal-Estaol and Macho-Stadler (2010) theoretically analyse the impact of economic incentives on the choice of research projects for a risk-neutral researcher. The authors find that these incentives affect not only the time spent in research but also the inclination towards riskier projects which are closely related to basic research.

One may also argue that academic researchers can choose between applied or basic research and that the economic incentives are not only at the organisational level but also at the individual one, so that each researcher may split his time between basic or applied topics.

Gupta-Mukherjee et al. (2007) present a life-cycle model where a faculty member decides how much to spend in applied and (or) basic research based on his current salary and the potential future license income. They find that junior staff spend significantly more time than senior members in basic research, regardless of the licensing option and that the option of license income inclines top researchers time from basic to applied activities

R&D governmental funding is not only directed to universities, but also private firms are actively involved in public research projects. Some evidence suggests that companies with intensive R&D departments are more likely to apply for and receive a subsidy (Aerts and Schmidt, 2008).

Using data from the private sector in Germany and Flanders, Aerts and Schmidt (2008) investigate whether public R&D subsidies completely replace private R&D investment. Not only do they find that there does not exist a complete crowding-out effect, but also that German-funded firms are, on average, 76 to 100 percent more R&D intensive than non-funded companies. In the case of Flanders, a similar result is found (64–91 percent).

According to recent surveys (David et al., 2000, Alonso-Borrego et al., 2014), there is no academic consensus on the question of whether public R&D funding, either in the form of direct research grants or subsidies, is a complement to private financing or a substitute. The results seem to depend on the empirical approach (OLS, pooled OLS, weighted OLS, fixed effects, IV, GLS, researchers), unit of measurement (laboratory, firm or industry), time span of the sample, countries, field of science, among other variables explanatory variables (sales, cash flows, geography, R&D expenditure, etc.).

1.5 Public funding towards R&D

There are several policy instruments that could be used to support R&D, including grants to university or private-sector researchers, direct financing of government research facilities, contracts for particular projects, and tax incentives; however, the challenge is to encourage research while simultaneously guaranteeing that an efficient peer-review process is in place (Bernanke, 2011).

The American government directly support scientific and technical research, through different mechanisms (AAU, 2011):

(a) Grants: provide money, equipment, or both. The granting agency has little involvement in the work.

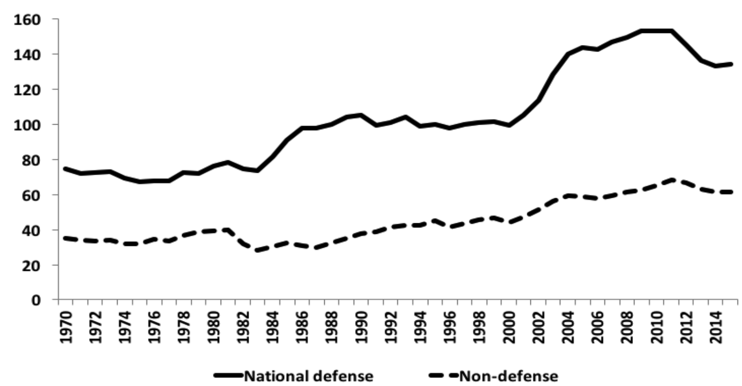
(b) Cooperative Agreements: the federal agencies have substantial participation in the research project. For instance, the National Science Foundation uses cooperative agreements to manage user facilities.

(c) Contracts: Agreements between an institution and an awarding agency that involve the creation of a particular product or service.

In the U.S., since the 1970s, federal R&D funding as a share of the GDP has declined, while the private funding has increased. For instance, in 2008, the federal share of total U.S. R&D spending was 26 percent and the industry's share was 67 percent (Bernanke, 2011).

Mowery (1998) identified different trends in the structure of the U.S. national innovation system. Among them: i) a decline in the federal government R&D expenditure, mainly explained by a cut in the defence field; ii) a reduction in the proportion of basic research funded by private firms; iii) increasing emphasis on the collaboration research between universities, industry and federal laboratories; and iv) more severe domestic and international legal protection.

However, after 2001 in the U.S., federal funding directed towards national defence activities has increased significantly, while the funding towards non-defence areas remained steady and more recently has shown a slight decrease (Fig. 1.1). Thus, in the past ten years universities have not only competed for funding, but also non-defence fields within each university have had to compete. This trend is relevant when one considers the fact that allocation of federal funding within non-defence activities has evolved differently for each branch of research.



Source: AAAS, based on OMB Historical Tables in Budget of the United States Government FY 2016. Constant dollar conversions based on GDP deflators.

Figure 1.1: Federal funding for research and development (in billions of constant 2015 U.S. dollars): 1970 to 2015

Although public investment has been essential to foster innovation in academia and the private sector, most of the recent success of the American innovation system is explained by the intense market competition, where private firms have had the incentive to innovate while having access to venture capital (E.C., 2002).

The 'European Paradox' arises from the fact that universities in the European

Union do generate significant amounts of new knowledge, but they fail to commercialise it or to get economic rewards compared to the U.S. (E.C., 2002).

In 2002, in response to this weakness, the European Union set a goal of devoting 3 percent of the GDP to R&D activities by 2010; however, in 2010, when the target was not reached, the goal was maintained to be achieved by 2020[4].

In 2002, the European Commission published the 'Report on Research and Development', where the main observation was that "Member states ought to look further at ways of addressing identified market failures by stimulating early-stage investment through creating an adequate financial and regulatory framework".

According to the European Commission (E.C., 2001), in contrast to the American innovation system, the European Union faces challenges to use basic research efficiently. Among the differences are:

- Undersupply of venture capital for basic research where the investors seem to be more risk averse than in the U.S.
- Costly administrative burden on start-ups.
- Severe bankruptcy laws that discourage risky projects.
- European Patent Office is slower, more expensive and more complicated in its procedures than the U.S. Patent Office.
- Duplication of research efforts in research bodies within the European Union.

[4]http://ec.europa.eu/europe2020/europe-2020-in-a-nutshell/targets/index_en.htm

- Universities intellectual property rules are unclear on the share of the economic rewards a researcher may expect to receive for his innovations.

1.5.1 University patenting in the U.S.

University patenting can promote technology transfer to the private sector and serve as a source of revenue through licensing and commercialization of the innovations; at the same time, patenting can help to minimise the time each piece of research remains on-the-shelf (Verspagen, 2006). However, there is concern that by patenting, universities may fall into a double objective of producing basic research while maximising future economic rewards from patents (Verspagen, 2006)

Academic researchers usually work in a cooperative environment, but given the possibility of financial rewards from their inventions, they may fail to cooperate and could be tempted to operate as if they were in a competitive environment, hiding their discoveries and delaying the disclosure of them until they are confident they can get the legal protection (Verspagen, 2006).

Moreover, at the organisational level, universities may change their behaviour by pouring more resources into projects where they can quickly obtain patents and abandoning those projects whose output is less sure and thus, less patentable (Verspagen, 2006). Uncertainty on the research puts financial constraints on the time and material resources injected into a project, the appropriability issue serves as an ex-ante drawback to a project where the results are not entirely legally protected.

The dilemma becomes if basic research provides small public returns, why would society support it, and if there are potentially high private returns for some forms of basic research, they would eventually appear without the intervention of the government (Trajtenberg, 2012).

The majority of American universities did not become actively involved in patenting and licensing their intellectual property until the Bayh-Dole Act of 1980 which gave colleges and universities a common legal framework for claiming ownership of income from patented discoveries that resulted from their federally funded research (Mowery et al., 2001).

It is worth noting that not only universities showed an unprecedented jump in patenting after the 1980s, but this change in patenting behaviour was observed in general within the U.S.

Kortum and Lerner (1999) investigates the motives behind this sudden surge, and find that this phenomenon is particular to American inventors while foreign patenting was already increasing before the 1980s. The authors conclude that this increase in patenting was triggered mainly by changes in the management of innovation towards more applied innovations in a wide variety of technologies and not due to the change in legislation.

The World Intellectual Property Office (WIPO) [5] defines a patent license as "legal contract, and so it will set out the terms upon which the exploitation rights are granted, including performance obligations that a licensee must comply with".

Table 1.1 shows the number of patents received by academic institutions with the highest 1993 $R\&D$ federal funding. It is evident that after the introduction

[5] http://www.wipo.int/export/sites/www/sme/en/documents/pdf/license_assign_patent.pdf

of the Bayh-Dole Act, the number of issued patents to academic institutions increased significantly, going from 196 patents in 1979 to 1004 patents in 1989. Academic institutions showed a significant increase in their patenting profile after the Bayh-Dole of 1980.

Year	Number of patents
1974	177
1979	196
1984	408
1989	1004
1994	1486

Source: Mowery et al (2001)

Table 1.1: Number of U.S. patents issued to 100 U.S. academic institutions with the highest 1993 $R\&D$ funding: 1974 to 1994

Commercial activities of universities include different tools (Kemp and Thursby, 2002): industry sponsored research, licensing, invention disclosures and new patent applications.

If universities are receiving more patents, one may expect that they are also receiving the economic benefits of them, royalties and licenses. In 2009, from 153 institutions that responded to the Association of University Technology Managers (AUTM), the number of active licenses increased significantly from 2004 to 2013 (Table 1.2) going from 23,269 to 37,445. In the same period, the revenue-generating licenses rose from 9,543 in 2004 to 15,925 in 2010.

The Association of University Technology Managers (AUTM) survey provides information about invention disclosures filed with university offices-prospective inventions submitted before a formal patent application. These disclosures have increased from 15,002 in 2004 to 21,596 in 2013 (Table 1.2).

Activity indicator	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Invention disclosures received	15,002	15,371	16,855	17,677	17,694	18,163	18,635	19,732	21,353	21,596
New U.S. patent applications filed	9,462	9,306	10,748	10,899	11,197	11,222	11,075	12,090	13,034	13,573
U.S. patents granted	3,268	2,944	2,895	3,291	2,933	3,088	4,018	4,296	4,635	5,220
Startup companies formed	425	418	500	510	549	555	613	617	655	759
Operational startups	2,451	2,652	2,960	3,148	3,076	3,175	3,339	3,573	3,747	3,948
Active licenses	23,269	23,896	26,070	26,094	26,816	28,763	33,309	33,284	34,417	37,445
Revenue-generating licenses/options	9,543	10,251	10,733	12,467	13,231	13,927	13,995	14,754	15,797	15,925
New licenses/options executed	4,087	4,201	4,192	4,419	4,416	4,624	4,735	5,398	5,567	5,865
Equity licenses/options	318	278	357	377	382	354	357	387	445	428

Source: AUTM Licensing Survey (various years). Science and Engineering Indicators 2016

Table 1.2: Academic patenting and licensing activities in the US:
2004 to 2013

All the activity indicators of innovation reported by the AUTM rose from 2004 to 2013. However, the measurement of universities commercialization outputs is not straightforward, since they consider paid not only royalties and sponsored research, but also the number of patents received and disclosures, regarded as proxies of commercialisation efforts (Kemp and Thursby, 2002).

Table 1.3 shows that universities are seeking legal protection of around two-thirds of all the formal invention disclosures. Also, around one-third of all the patent applications result in a patent granted by the USPTO.

Ratio	**2004**	**2013**
Patent applications filed to invention disclosures	63	68
Patent applications grantes to patents filed	35	38
Patents granted to invention disclosures	22	24

Source: AUTM Licensing Survey (various years). Science and Engineering Indicators 2016

Table 1.3: Academic patenting and licensing activities in the U.S.: 2004 and 2013

The above may indicate that the departments within a University are filing disclosures of an invention to their legal departments, probably because they need to justify funding allocation. In 2013, only 24 percent of the total invention disclosures received a patent. (Table 1.3).

Universities in the U.S. have shown an increasing patenting trend since the change in legislation in 1980 (Mowery et al., 2001). The USPTO has issued in total more patents to universities and colleges passing from 1,250 in 1990 to 4,547 in 2010. In particular, the biotechnology area, which includes GM crops, has increased from 181 patents in 1990 to 1,364 in 2010. In 2010, the biotechnology sector accounted for 30 percent of all the U.S. universities patents.

Kemp and Thursby (2002) explain that although the goal of patent licensing is usually thought to ensure revenue inflows, this may not be the case for all universities, in particular for public universities that are socially considered to be the core source of basic research.

Universities and academic institutions that receive public funding are required to provide evidence of the effective use of this funding. One measure of good achievement is to patent their innovations and to commercialise them.

The process of patent commercialisation within universities contrasts to forwarding private firms (Kemp and Thursby, 2002): i) faculty members may undertake research, regardless of its potential economic benefits in the majority of the cases; ii) if the researcher believes that his research may subject to legal protection, he contacts the universitys transfer technology office (TTO) to disclose the results; iii) TTO evaluates the innovation and decides whether it is a candidate for legal protection and could be commercially exploitable; iv) if the patent can, the TTO seeks private sector firms that could be interested in the innovation; if the matching with a business is successful, the TTO negotiates a licensing agreement or seeks further private resources to expand the development of the innovation that may lead to other marketable innovations.

The matching of universities patents and private firms represents an important challenge for many TTOs, and many of them have reported it as a major problem from the simple detection of a firm interested in the innovation (Kemp and Thursby, 2002).

University-researcher royalty sharing arrangements can provide different incentives to individual researchers. There is evidence that universities that give a larger share of the patent royalties to employees receive more revenue from licensing; universities can reward researchers for their work either in cash or research support material; therefore, the share of each one serves as incentive to them, these incentives have a real effect on the number of licenses executed for private universities, but no for public ones (Lach and Schankerman, 2008).

In Table 1.4, one can observe that ten universities accounted for more than one-third of the total patents granted to universities in the U.S. It is worth noting that from these top-ten patenting universities, six of them are private and four are public or academic institutions. We observe that the number of patents granted to the University of California decreased from 2000 to 2010, but still in 2010, it accounted for almost 9 percent of all patents awarded to all universities. This observation could be explained by Mansfield (1995), where the author concludes that there exists a cluster of universities that are more important in their role as basic researchers compared to others.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Top 10 Universities	36.48	35.50	36.00	37.49	38.91	41.57	37.95	36.84	35.90	34.12	33.52
University of California	13.49	12.46	13.13	13.28	13.74	14.02	12.54	11.61	8.53	8.41	8.71
Massachusetts Institute of Technology	3.53	3.99	4.27	3.85	4.25	4.99	4.05	4.54	4.60	4.31	4.18
California Institute of Technology	3.15	3.60	3.29	4.10	4.16	3.83	3.48	3.66	3.53	2.88	3.03
University of Texas	2.95	2.84	3.07	3.13	3.52	3.45	3.34	3.13	3.00	3.58	3.10
Stanford University	3.24	2.56	3.15	2.48	2.57	3.28	3.00	2.97	4.37	3.76	3.83
University of Wisconsin	2.04	2.14	2.31	2.54	2.26	2.70	3.00	3.10	3.07	3.76	3.19
Johns Hopkins University	2.60	2.45	2.73	2.31	3.09	2.74	2.80	2.16	2.37	1.90	1.87
University of Michigan	2.19	1.66	1.60	2.14	2.32	2.94	2.29	2.13	2.67	2.11	1.89
Cornell University	1.55	2.03	1.12	1.82	1.38	1.57	1.84	1.72	1.90	1.87	1.85
Columbia University	1.72	1.77	1.32	1.85	1.62	2.05	1.61	1.82	1.87	1.53	1.87

NOTES: Data include institutions affiliated with academic institutions (university and alumni organizations, foundations, and university associations).
Source: National Science Foundation http://www.nsf.gov/statistics

Table 1.4: Top 10 U.S. patenting universities (% with respect to total U.S. universities patents)

In Chapter 2, I use patent information from the USPTO, where the majority of the universities that appear in the database are based in the U.S. However, it is important to mention that, in contrast to the American case, in the European

Union, patenting laws are not homogeneous among the countries. For instance, in Italy, Finland, Italy and Sweden, academic researchers are legally entitled to own their work and in turn, to own the patents that could derive from their work (Verspagen, 2006).

In Europe, university licensing is, generally, not profitable for universities, but a small number of them successfully receive substantial revenue from their patents (Geuna and Nesta, 2006).

Finally, there exists a fundamental difference between the treatment of federal funding in U.S. and the European Union. Even though the European Commission provides direct funding to research projects, it does not claim any rights to the output of them, in contrast to the American federal government that has legal rights to all the projects they sponsor (Verspagen, 2006).

1.6 Patents as indicators of innovation

Patents have played a pivotal role in the empirical research on innovation because they provide a dynamic format, where new linkages among them are continuously formed, and also the information is publicly and freely available in many countries (Gittelman, 2008). In this way, by looking at patents, one can follow the development of technologies, to track individuals and firms behaviour, and to identify university-industry-government collaborations.

Legally, new patent applications are obliged to cite all prior art used, and in turn, more forward citations for a patent may indicate the importance of it. However, there could also be the case that one patent is being more cited by others only because it is older not necessarily because it is more important.

Gittelman (2008) provides some important features of patents as indicators of innovation:

- The use of patents hides information about the structure and environment in which the primary innovation was conceived, and most likely, the original inventor(s) have little involvement in the actual writing of the patent.
- When one patent cites a previous one, some knowledge transfer is assumed from the older to the newer one, but some patent citations may be due to other reasons rather than this. For instance, it may serve as a strategy 'to fence' a core innovation.
- The majority of empirical studies treat patents as homogeneous, causing potential problems of omitted variable bias. For instance, access to different financial resources, government funding, the number of researchers involved or time spent in the innovation.

Patents can be used for different objectives such as commercialisation of a product, to establish a first-mover advantage within a field, to discourage future entrants to an industry or to build a patent portfolio (Gittelman, 2008).

Even with the inherent limitations, patents have been used for different purposes, such as the measurement of creative output and its impact on economic development, of the incentive effect on researchers, universities and private firms, and of their influence on a company's value (Bessen, 2008). Burhan et al. (2016) present a summary (Table 1.5) of the different motives for patent filing.

Motive for filling patent	Literature review
(Protect) — protection from imitation	Arrow (1962), Arundel et al. (1995), Shane (2001)
Vary with experience	Morgan et al. (2001), Mathew and Bhaduri (2012), Buenstorf and Geissler (2012), Azoulay et al. (2007)
Vary with technological complexity	Cohen et al. (2002), Roberts (1999) and Reitzig (2004)
Vary with organizational size	Blind et al. (2006)
(License) — licensing/negotiation	Blind et al. (2006)
(Incentive) — incentive/reward/performance indicator	Blind et al. (2006), Kortum and Lerner (1999), Arundel et al. (1995), Bussy et al. (1994), Hussinger (2006), Janz et al. (2001), Narin et al. (1987), Ernst et al. (2000), Breitzman and Thomas (2002), Narin and Breitzman (1995), Blind and Thumm (2004), Shapiro (1990)
(Fame) — fame/recognition	Ernst et al. (2000)
(Signal) — signal to potential licensees/collaborators/ investors/consulting/research firms — of value/applied orientation of their research/need for their further involvement in developing the product	Blind et al. (2006), Higgins et al. (2011), Agrawal (2006), Owen-Smith and Powell (2001)
(PeerP) peer/Organizational pressure	Owen-Smith and Powell (2001), Tartari et al. (2014)
Varies among sectors/Areas of research	Owen-Smith and Powell (2001)
Freedom to operate/Right to use	Henkel and Jell (2011), Henkel and Pangerl (2008), De Rassenfosse and de la Potterie (2007), Blind et al. (2006), Veer and Jell (2012), Baker and Mezzetti (2005)
Blocking competition	Cohen et al. (2002), Schneider (2008), Reitzig (2004), Veer and Jell (2012), Blind et al. (2006), Duguet and Kabla (1998)

Source: Burhan et al. (2016)

Table 1.5: Patent filing motives

The number of forward citations, times a patent is cited by succeeding patents, can provide a good measure of the technological importance of a patent rather than the R&D expenditure alone since the last one can potentially over or underestimate the evolution of the knowledge of a particular field (Griliches, 1990).

Basic research should generate higher level of forward citations than applied research since it can be path-breaking with radical new ideas (Trajtenberg, 1990). Patents can also provide information about an agent's inventive behaviour, and by looking at an agent's pattern of patenting one is able to infer its position within the scientific/technology field or it could shed light on the process of strategic interactions with other firms (Griliches, 1990).

Despite the inherent limitations of the use of patents to evaluate either the transfer of technology from the academia to the industry or the measurement of R&D's economic impact, they can still as a good proxy for empirical studies.

For instance, Burhan et al. (2016) examine different motives for patent filing in researchers of India and find that they are indeed driven by various motives (protect, signal, fame, economic incentive, license or peer pressure), and not only the traditional patent use as legal protection to further licensing. Moreover, Bessen (2008) estimates that patents issued to small agents are much less valuable than those owned by large corporations and that litigated patents are approximately six times more valuable than non-litigated patents and more forward cited.

In a different example of the use of patents, Acs et al. (2002) compare the impact of two different measures of technological progress, patents and innovations, on the regional spillover activity in the U.S. by using patents as the explanatory variable. The authors conclude that patents provide almost the same econometric results than using explicit known innovations instead, noting that patents tend to overestimate the effects of local interactions and underestimate the contribution of local academic research.

In summary, private firms research seems to work as a complement to universities research; however, it is not clear whether this relationship is static throughout the technology cycle of a particular field. It is not straightforward that universities are the only agents involved in basic research and that private firms focus mainly on the applied side.

In the next chapter, I will use a unique database within a specific field to examine whether there are indeed greater externalities, measured as the number of future citations per patent, for university patents compared to private firms within a particular technology field (genetically modified crops). The central question is whether private firms and universities act as complements or substitutes and whether this relationship is the same throughout the technology cycle. One aspect to consider is that if private firms foresaw a high economic return of this technology, they would engage on it regardless of the universities and government role.

Chapter 2

Are university patents different from patents of private firms? The genetically modified crops case

2.1 Introduction

According to Verspagen (2006), a patent is a legal monopoly for the use of a specific piece of knowledge awarded to an individual, institution or corporation that first develops it. Almost all well-organised economies have put in place a patent regime, although there are still significant discrepancies from one to another. Current patent systems are complex pieces of machinery since they not only involve the particular government office in charge of assessing and issuing patents, but also courts, private attorneys, corporations and public institutions.

Patent law is designed to deter the incentive of an inventor trying to keep his innovation in secret and in turn, reducing the stock of knowledge available to society. In many countries, once the patent is granted, the patent application becomes public (Landes and Posner, 2003).

As discussed in the previous chapter, basic research usually done in universities and academic institutions is assumed to have inherently low appropriability and high uncertainty on the outcome of it. Public funding of university research is supported because in the absence of such intervention the private sector would underinvest in certain types of research highly needed by society (Arrow 1962). Moreover, basic research, thought to be mainly performed within universities, is less likely to provide substantial economic rewards to the inventor (Nelson, 1959).

The goal of this chapter is to compare knowledge externalities generated by university patents compared to the ones of private firms. There are three important aspects to consider: i) if basic research does indeed produce greater knowledge to a wider variety of technology fields, those patents associated with basic research should have more future citations; ii) if basic research is mainly done in academia, patents owned by universities should receive more future citations compared to the ones belonging to private firms; and iii) the degree of involvement of private firms and universities may not be the same throughout the technology cycle.

To empirically examine these aspects, I use a different patent database of the Genetically Modified Crops field obtained from the United States Patent and Trademark Office, where the externalities measurement is the net citations a patent receives during the first four years after its issue date. This database presents some advantages since only I am not only able to identify the very first patent granted in this field and in turn to track the technology cycle, but also both universities and corporations were involved from early stages of this cycle.

The main result of this chapter is that university patents are not associated generally with greater knowledge externalities than the corresponding patent of private firms with the exception of those at the beginning of the technology cycle. This major conclusion persists when we control for some variables that could affect future use of patents by third parties (e.g. examiner, agent). This result supports the idea that not all knowledge fields should be treated the same way, there are some areas where the academia is the source of a new branch of knowledge, but private firms engage later on when the economic returns are considered high enough, acting as complements of universities research.

The structure of the chapter is as follows: state 2 provides a summary of basic research concept and its relationship with patents; Section 3 explains in detail the database and the main econometric approach to be used; Section 4 provides a background of the genetically modified crops field; Section 5 illustrates the link between basic research in genetically modified crops case and patents; in Section 6, I present the results of the estimation; and finally, I provide the conclusions.

2.2 Patents and basic research

In this chapter, I refer to "*basicness*" as a fundamental feature of innovation, representing originality and closeness to science, while "*appropriability*" refers to the ability of inventors to harvest the economic benefits from their innovations. As discussed in the previous chapter, the more basic the research is, the lower the proportion of total surplus that can be secured by the inventor (Henderson et al., 1997).

The number of forward citations[1] a patent generates has been considered as a proxy of the importance of a patent by different authors (Griliches, 1990; Trajtenberg, 1990; Henderson et al., 1997; Fogarty et al., 2000; Hall and Ziedonis, 2001; Gittelman, 2008). Since patent applications are legally required to list all relevant sources of prior art, one would expect that patents that represent a significant advancement in the knowledge will be more widely cited (Trajtenberg, 1990). For instance, Henderson et al. (1997) consider self-citations, i.e. cites found in following patents obtained by the same agent, as an indication that the innovator is internalising the benefits of his first innovation.

Another advantage of patent information is that it represents a dynamic environment, where new links are formed continuously over time, and provides a wider and more detailed coverage as well (Trajtenberg, 1990).

Patents do not always represent true knowledge transfer, for instance, Hall and Ziedonis (2001) study the 'patents paradox' of the semiconductor industry in

[1] Number of times that each patent has been cited by subsequent patents

the U.S. where there has been an increase of patents in the semiconductor industry since the early 1980s, but at the same time firms within this industry prefer other tools (lead time, secrecy, and manufacturing or design capabilities) to recover their R&D investment instead of relying solely on patents. Hall and Ziedonis (2001) conclude that although firms in this type of industry, where there is cumulative innovation, do not rely entirely on patents to protect their intellectual property, they can still be used to reduce the hold-up problem of competitors and strategically build a ’patent portfolio’ in case they need it in the future.

When considering university patents, only a cluster of academic institutions own the majority of them, and there is a direct relationship between their R&D budget and their number of patents (Henderson et al., 1997). Henderson et al. (1998) find that the importance of universities patents has been decreasing from the mid-1980s compared to a random sample of all U.S. patents.

Patent data has intrinsically two limitations(Henderson et al., 1997): only successful R&D efforts are patentable, and since patenting is the result of strategic behaviour, not all innovations are patented.

In this chapter, I analyse whether not only universities are carrying out subsidised basic research that is later used by third agents, measured as forward net citations, but also whether private firms are engaged in basic research. If the last hypothesis is correct, one should not expect a positive difference towards universities compared to private firms patents (Henderson et al., 1997). On the contrary, if as suggested by some authors, universities are the primary source of basic research, their patents should be of a much wider use and much more cited by future patents.

2.3 Data and econometric approach

The patent data was obtained from the United States Patent and Trademark Office (USPTO) and is focused on patented innovations of the GM crops field. The data begins in 1983 with the first GM crop patent and stops at the end August of 2009, resulting in 3428 patents in total.

The use of GM results convenient for the main goal of this paper, mainly because:

- It allows for better control compared to the three-digit patent classes traditionally used in a cross-sectional database.
- I am able to identify the start and develop of an innovation cycle. As citation patterns might vary along cycles, universities might be more or less involved in different phases.
- Public policy towards dependent research can be focused to specific research areas.

In Table 2.1, I present the description of the variables I consider in the analysis. It is important to note that all the information contained in the database comes from the USPTO website. Only, type of assignee is own recorded as a dummy using the *Assignee* character, while *Self Citations* is counted comparing the *Assignee* of the patent in question with the corresponding *Assignee* of all its *Total citations received*.

I do not consider in the analysis 214 patents whose assignees correspond to a combination of the type of assignees, to be able to capture the difference among isolated types.

I focus on the first four years after the patent was issued to count the Net Forward Citations: all citations a patent received during the first four years after it was published by the USPTO that are not from the same patent owner (original assignee)[2].

The use of the first four years is to avoid bias towards older patents, where patents that have been exposed more time are more prompt to be used by later innovations. If all patents are measured in the same time span, we will only observe the effect of their relative position in the technology cycle.

Also, this measurement is supported by the findings of Pakes (1986), where the author uses renewal information of patents to analyse the actual value of each patent; as time passes, the real value of each patent is gradually uncovered. His estimates indicate that most of the uncertainty on the value of a patent is resolved during the first three or four years of its life, and as a patent ages it is unlikely that in future years it will provide more returns to justify the payment of renewal fees.

A patent's position in a technology cycle may be relevant, and by using the GM crops field, I can capture the possible effect of an invention depending on its position in the cycle. To my best knowledge, this represents a unique analysis in

[2]The number of forward citations received by each patent is counted as of August of 2013.

Variable	Description
1. Number of patent	Unique number assigned to applications that have issued as patents
2. Original assignee	Name of the individual or entity to whom ownership of the patent was assigned at the time of issue
3. Application date	Date when a complete application was received by the USPTO
4. Publication date	Date the patent was officially issued by the USPTO
5. Total references cited	Backward references: patents cited as prior art
6. Total citations received	Forward references: include those other patents which cite the subject patent as prior art on their front pages
7. Self-citations	Forward references made by the same patent owner
8. Examiner	Name of the primary examiner responsible for examining the patent application
9. Agent/Attorney	Name of the legal representative of the patent applicant
10. Country of the original assignee	Country of the patent assignee at the time of patent issue
13. Type of assignee	Four different types of owner are considered depending on the original patent owner: University, Government, Individual and Private firm

Table 2.1: Variables of GM patents

the basic research literature using patents where the standard has been to use a pool of patents of different maturities and a broad range of technologies.

I capture the position of a patent in the technology cycle in the variable "Distance", measured as years passed from the beginning of the period (March 13th, 1983) to August 30th, 2013.

The basic equation to estimate is:

$$\ln(\text{Net citations first four years}_i) = \beta_1 \ln(\text{Distance}_i) + \beta_2 \ln(\text{University}) + \beta_3 \ln(\text{Government}) + \beta_4 \ln(\text{Individual}) + \beta_5 \ln(\text{University*Distance}_i) + \beta_6 \ln(\text{Goverment*Distance}_i) + \beta_7 \ln(\text{Individual*Distance}_i) + \ln(\eta_i) \quad (2.1)$$

Assuming that more valuable patents were approved at the start of the cycle where radical innovations were conceived, we should expect that more recent patents represent only incremental innovations. In this case, the variable "Distance" would have an adverse effect on the dependent variable.

The focus of this chapter is to determine whether universities patents are more widely used throughout the whole span of the database compared to private firms patents; we expect a positive sign in the coefficient of the dummy variable "University" and also in the interaction term 'University*Distance'. We should consider the net effect of being a University patent as $\beta_2 + \beta 5 * Distance$.

However, if universities are the cornerstone of the technology at the beginning of the cycle, but private firms got involved in radical innovations later in the period, we expect the coefficient of the variable "University" to have a positive sign, but the interaction term ″University*Distance″ a negative one. As ″Distance″ increases, the positive effect of a university assignee on the Net Citations would decrease and may even become negative.

There are other important characteristics to consider from this database. To prove the robustness of the results, I later control for dummies of ″Examiners″, ″Countries″ and ″Agents″.

(a) From 182 different examiners, 19 of them accumulate 80 percent of the total patents (Figure 2.2).

Examiner	Number of patents	Percent	Cumulative percentage
Fox, D	667	19.5	19.5
McElwain, E	221	6.5	25.9
Benzion, G	218	6.4	32.3
Mehta, A	214	6.2	38.5
Kruse, D	168	4.9	43.4
Robinson, D	139	4.1	47.5
Bui, P	136	4.0	51.4
Baum, S	128	3.7	55.2
Kallis, R	127	3.7	58.9
Nelson, A	122	3.6	62.4
Chereskin, C	115	3.4	65.8
Collins, C	103	3.0	68.8
Kubelik, A	96	2.8	71.6
Ibrahim, M	65	1.9	73.5
Smith, L	60	1.8	75.2
Wax, R	54	1.6	76.8
Moody, P	49	1.4	78.2
Campbell, B	37	1.1	79.3
Ketter, J	32	0.9	80.2

Table 2.2: Main USPTO examiners

(b) From 31 different countries, 6 of them accumulate almost 90 percent of the patents (Table 2.3).

Country	Number of patents	Percent	Cumulative percentage
USA	2,352	68.6	68.6
Germany	211	6.2	74.8
United Kingdom	206	6.0	80.8
Japan	187	5.5	86.2
Canada	80	2.3	88.6
France	71	2.1	90.6

Table 2.3: Top countries of origin

(c) From 437 different assignees, 17 of them accumulate 50 percent of the total patents, excluding those that correspond individual assignees (Table 2.4).

Assignee	Number of patents	Percent	Cumulative percentage
Pioneer Hi-Bred	490	14.3	14.3
Monsanto	176	5.1	19.4
Stine & Monsanto	127	3.7	23.1
Syngenta	121	3.5	26.7
Calgene	100	2.9	29.6
University of California	93	2.7	32.3
Cornell University	74	2.2	34.4
Novartis	63	1.8	36.3
BASF Plant	63	1.8	38.1
DuPont	62	1.8	39.9
Mycogen	62	1.8	41.7
Zeneca	60	1.8	43.5
Mertec	59	1.7	45.2
Plant Genetic	53	1.6	46.8
Bayer	50	1.5	48.2
Hoeschst	44	1.3	49.5
DeKalb	42	1.2	50.7

Table 2.4: Top assignees

(d) From 430 different agents, 23 of them accumulate around 50 percent of the total patents, excluding those that did not register an agent.

Table 2.5 shows distributional statistics of Net citations in the first four years, and we observe a considerable proportion of zeros in the dependent variable, for all the types of assignee considered. More than 70 percent of all the patents have zero net citations in the first four years (Figure 2.1).

	Number of patents	Mean	Median	Std. Dev.	Quantiles				
					25%	75%	90%	95%	99%
Total	3428	0.65	0.00	1.76	0	1	2	3	8
University	662	0.73	0.00	1.93	0	1	2	4	8
Private firms	2448	0.66	0.00	1.79	0	1	2	3	8
Government	198	0.25	0.00	0.72	0	0	1	2	4
Individual	120	0.64	0.00	1.36	0	1	2	3	7

Table 2.5: Descriptive statistics: net forward citations in the first four years

In Figure 2.1, I show the distribution of the dependent variable, where a remarkable skewness is present. This characteristic will be important to cinder in the econometric analysis of this chapter.

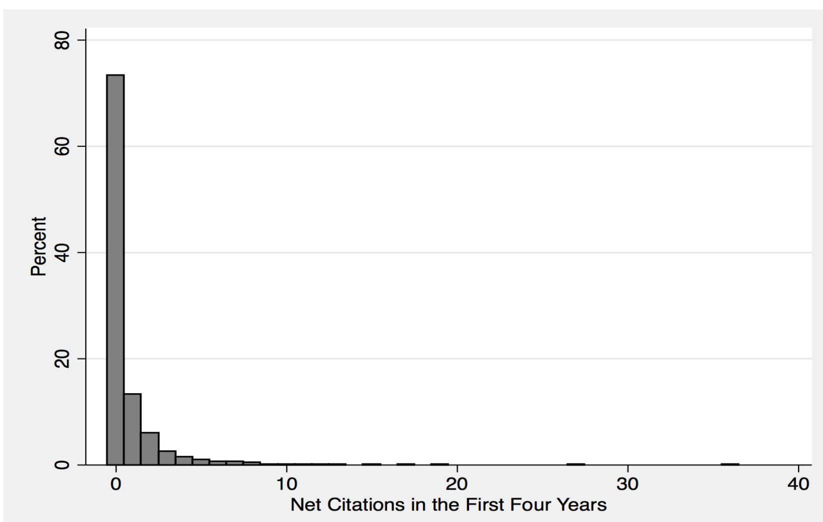


Figure 2.1: Distribution of dependent variable: net citations in the first four years

Forward patent citations present a distributional skewness, where only a few patents result very successful. Thus, there have only a few patents using them ex-post, and the majority of them receive zero forward citations while they are active. Nevertheless, when using forward citations, one should be careful in interpreting patents as a mix of creative effort and genuine innovation output (Griliches, 1990; Henderson et al., 1997).

Almost 70 percent of all patents have received zero net citations in the first four years, and the maximum number is 36 citations; considering the five patents with more net citations in the first four years, only one belongs to a University (Rutgers University), while the other four belong to a private firm.

Due to the nature of the dependent variable, I also used Pseudo-Poisson Maximum Likelihood (PPML) in the econometric estimation. Santos Silva and Tenreyro (2006) showed that the PPML estimator "Poisson Pseudo-Maximum Likelihood" is well-behaved even when the number of zeros in the sample is significant, and also, it maintains the original measurement unit. Other count data models, such as the Negative Binomial and the zero-inflated regression models have a major drawback in the interpretation of their estimation; they are not invariant to the scale of the dependent variable.

However, I also present the estimation using Negative Binomial (NB) in order to show the robustness of the results. Recall from Table 2.5 and the analysis of this chapter there is evidence of over-dispersion; thus, PPML and NB analysis result consistent since the counting data is non-negative.

Moreover, since there is a significant amount of observations of the dependant variable with value zero, it is appropriate to consider a Zero-Inflated Negative Binomial (ZINB), and we would expect ”Distance” to be a dominant variable to influence the appearance of a zero.

2.4 Genetically modified crops

According to the World Health Organisation (WHO)[3], the Genetically Modified Organisms (GM) can be defined as ”organisms (i.e. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination”. Such methods are used to create GM plants – which are then used to grow GM food crops.

The WHO[4] explains that the initial objective of developing plants based on GM organisms was to improve the resistance against plant diseases caused by insects or viruses and that GM foods are mainly developed because there are some advantages either to produce or to consume them (lower price and greater durability).

In most cases, these GM technologies are developed and owned by the private sector and commercialised through licensing agreements. For instance, according to information provided by the agricultural private corporation Monsanto, more than 325,000 farmers a year enter into a commercial agreement with them in the United States. In such contract, farmers are obliged to not save and replant seeds

[3]http://www.who.int/foodsafety/areas_work/food-technology/faq-genetically-modified-food/en/

[4]Ibid.

produced from the seed they buy from Monsanto [5].

In 1980, the Supreme Court of the United States ruled that an invention that involves a GM organism remain subject to legal protection [6]. In the case known as *Diamond vs. Chakravarty*, the Supreme Court ruled that "A live, human-made micro-organism is patentable subject matter [...]micro-organism constitutes a 'manufacture' or 'composition of matter' ".

This legal protection was further strengthened in 1995, when the Supreme Court ruled in the case *Asgrow Seed Company vs. Winterboer* [7] where farmers have only the right to sell saved GM seeds if these are planted on their property.

However, it has been widely discussed whether this GM technological progress has restricted the access to new genetic resources and technologies. Private firms involved in GM crops have introduced novel contract agreements to the seed industry, where farmers not able to use crop seeds for future plantings (Harhoff et al., 2001).

On February 19th of 2013, Monsanto Company sued Hugh Bowman, a soybean farmer, for patent infringement. According to documents of the Supreme Court of the United States, Monsanto owns two patents at issue, Patent No. 5352605 and Patent No. RE39247, which involve herbicide resistance technology. Monsanto argues that the farmer replanted second-generation seeds, instead of purchasing new ones. On May 13th of 2013, the Supreme Court of the United States concluded that the farmer was forbidden from replanting them in any form and

[5]http://www.monsanto.com/newsviews/pages/why-does-monsanto-sue-farmers-who-save-seeds.aspx

[6]https://supreme.justia.com/cases/federal/us/447/303/case.html

[7]https://law.resource.org/pub/us/case/reporter/US/513/513.US.179.92-2038.html

ordered the farmer to pay compensation [8].

Granting legal protection on genes alters the incentives for patent filing, moving it from basic research to strategic portfolio management, that could result in the delay of the discovery and introduction to the market of innovations that are socially desirable (Harhoff et al., 2001)

GM crops is a compelling case to analyse since it enjoys remarkable characteristics that help the goal of this paper: i) universities were involved from the very beginning of the technology cycle; ii) private firms became involved early in this period; iii) the legal framework in the U.S. recognises a GM organism as patentable; and iv) the economic benefits for the owners of some of this patents are significant indicating that private returns could encourage not only academic participation, but also private participation.

2.5 Basic research and patents: GM crops

The focus of this section is to analyse whether universities patents generate broader knowledge compared to private firms, since, presumably, academic institutions are more engaged in basic research.

One of the main advantages this database presents is that I am able to track the technology cycle from the first patent that was filed on March 13, 1981, and issued on October 4, 1983.

Figure 2.2 shows the issued patents according to their position in the technology cycle for universities, where the point of origin is the issue date of the first

[8] http://www.supremecourt.gov/opinions/12pdf/11-796_c07d.pdf

patent in the GM crops field. Figure 2.3 shows the same, but for private firms patents.

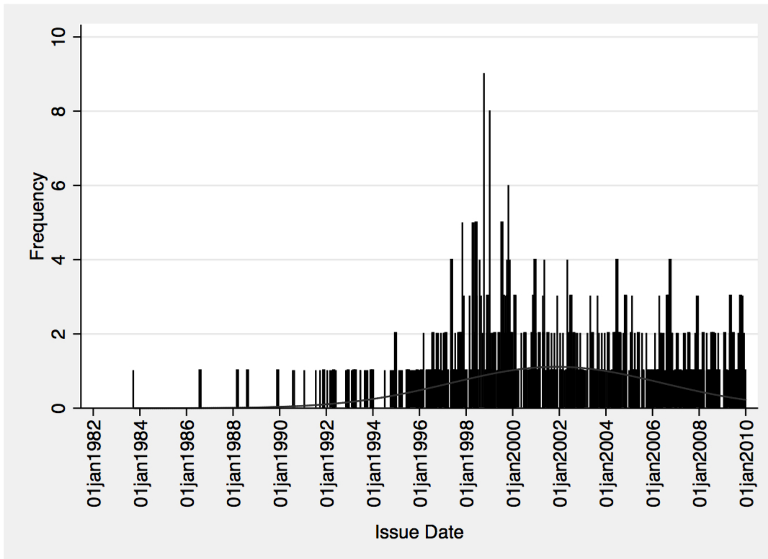


Figure 2.2: Issued patents according to the technological cycle: Universities

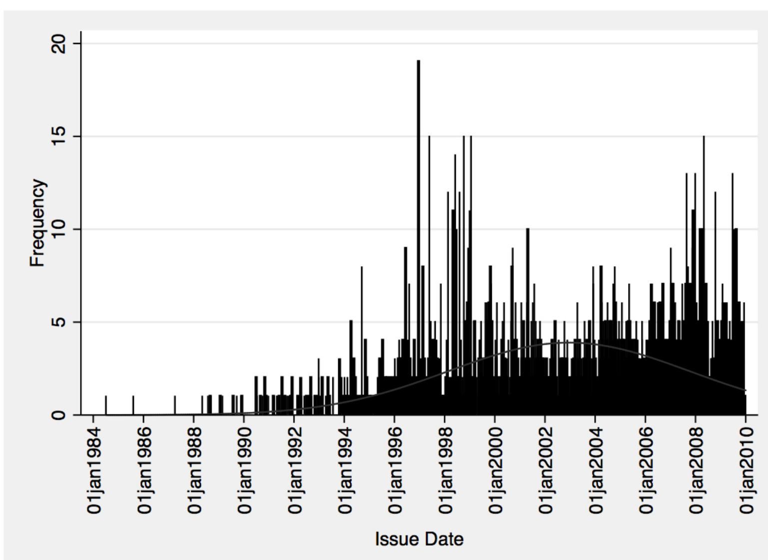


Figure 2.3: Issued patents according to the technological cycle: Private firms

It is important to note that private firms and universities patents were not being issued differently for the first years of the cycle. Issued patents were almost evenly distributed and none received significantly more patents, during the first ten years approximately.

In Figure 2.2, it appears that the technology cycle had a peak within the universities around 1998, while for private firms we observe two peaks, one around 1998 and then another ten years later (Figure 2.3).

We observe a disparity in the number of issued patents from 1994 onwards, where corporations were already receiving more patents than universities (Fig. 2.4). Additionally, while the role of universities in the GM crops fields appeared to be diminished in recent years, corporations continue to patent intensively.

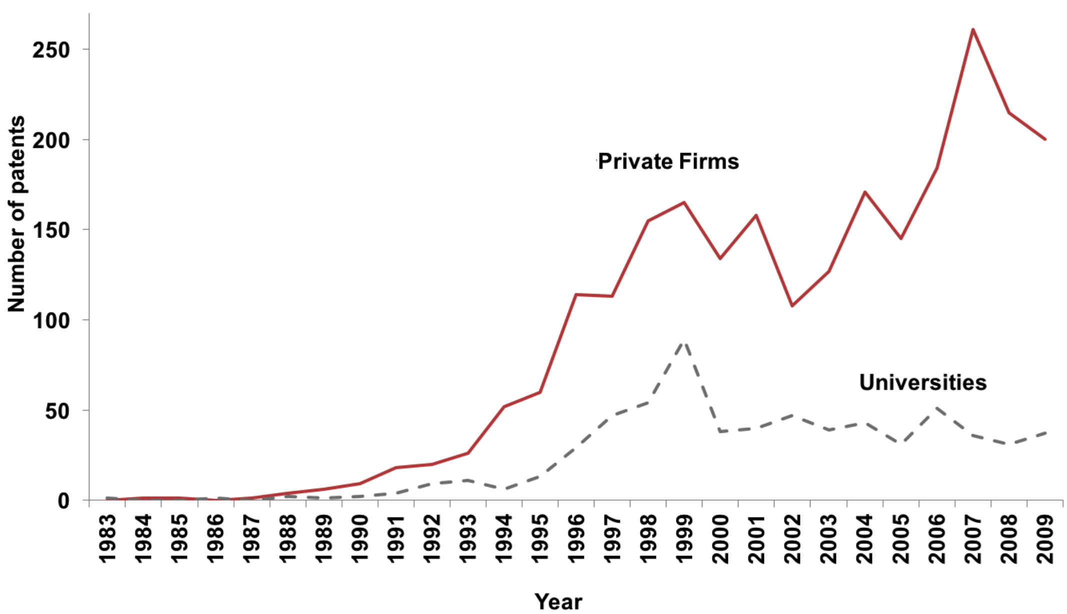


Figure 2.4: Number of patents per application year (1983-2009): universities and private firms

In Figure 2.5, we observe the number of patents per application year for the first years of the technology cycle. Both universities and private firms were being issued almost equally in the first five years, from 1987 onwards private enterprises took the lead.

The above could be an indication that private companies perceived a genuine opportunity to receive future profits in the GM crops field and in turn decided to invest in research to obtain future monopolies.

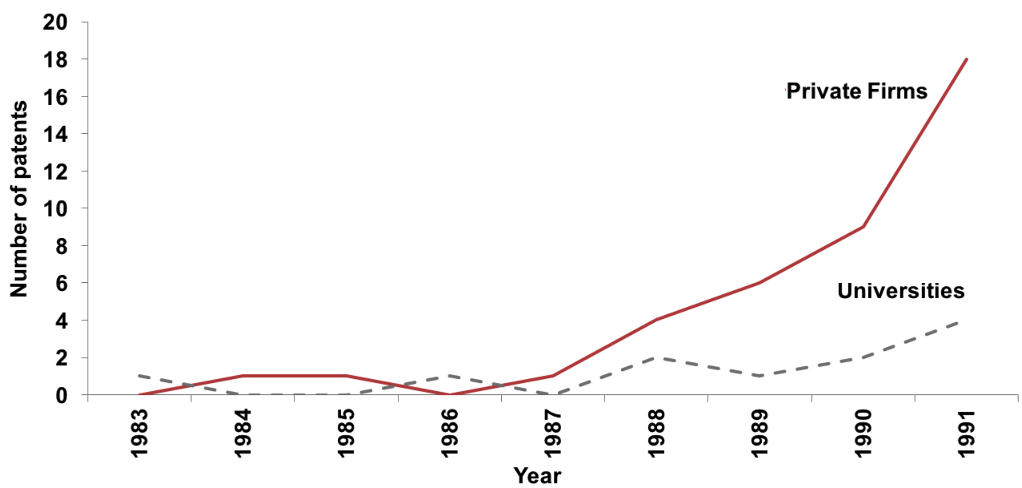


Figure 2.5: Number of patents per application year (1983-1993): universities and private firms

All the above gives ground to assume that universities patents may be more important in generating positive externalities at the beginning of the technology cycle, but private firms appear to take the leadership rapidly. This result may have important policy implications commercialization since policymakers are interested in allocating the limited government resources to those projects where more benefits for the society can be achieved.

The above could defend the idea that, probably, government support is needed to develop a new technology initially, but universities projects can be later funded by alliances with the private sector and this transition can occur quite early in the cycle.

To understand whether the difference in the number of granted patents is due to a lag between the filing and the issue date (Examination Process). One possibility is that private corporations have better resources at their disposal to apply successfully for a patent.

Figures 2.6 and 2.7 show the elapsed years between the application date and the issue date for universities and private firms, correspondingly.

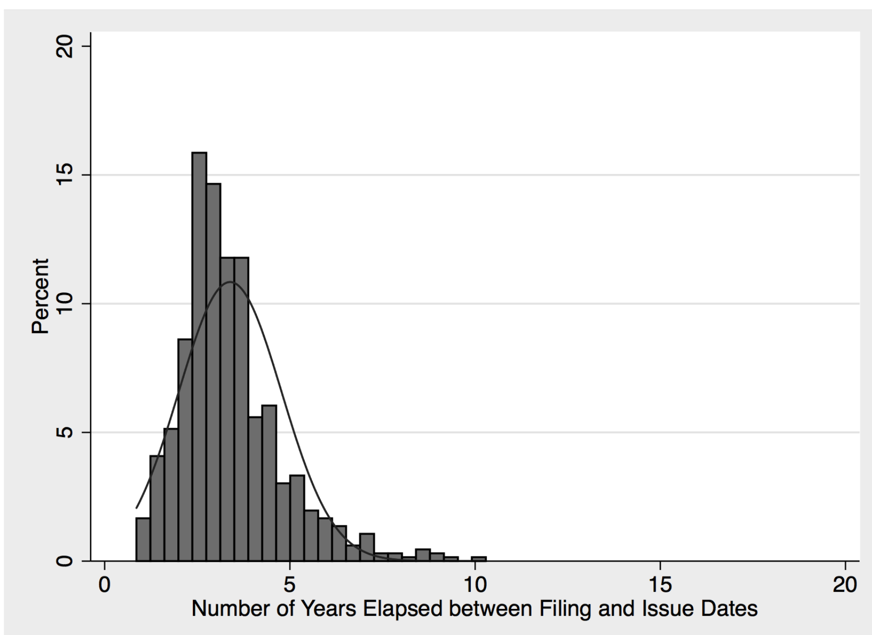


Figure 2.6: Examination process: Universities

We observe that the majority of the patents for both types of assignee are being issued between two and four years after the application. Even more, apparently, corporations have more extreme cases where the application process lasted more than ten years. Thus, the different number of citations is not explained by the assumption that private firms are granted, in general, their patents before universities (Figure 2.7).

For this reason, I decided not to include this information as an explanatory variable in the estimations.

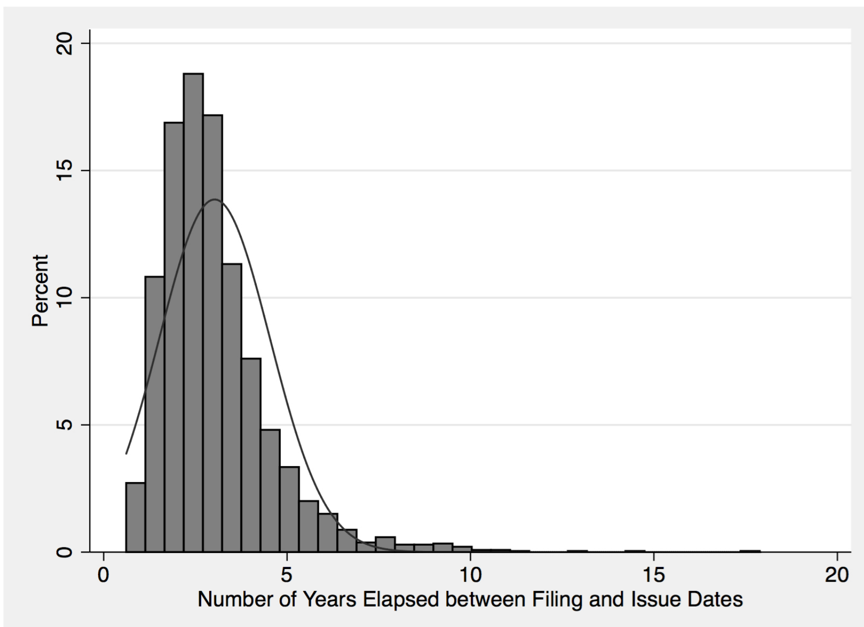


Figure 2.7: Examination process: Private firms

There is a negative relationship between the importance of a patent and the examination time when we consider the review process as the elapsed years between filing and issue date, (Figure 2.8).

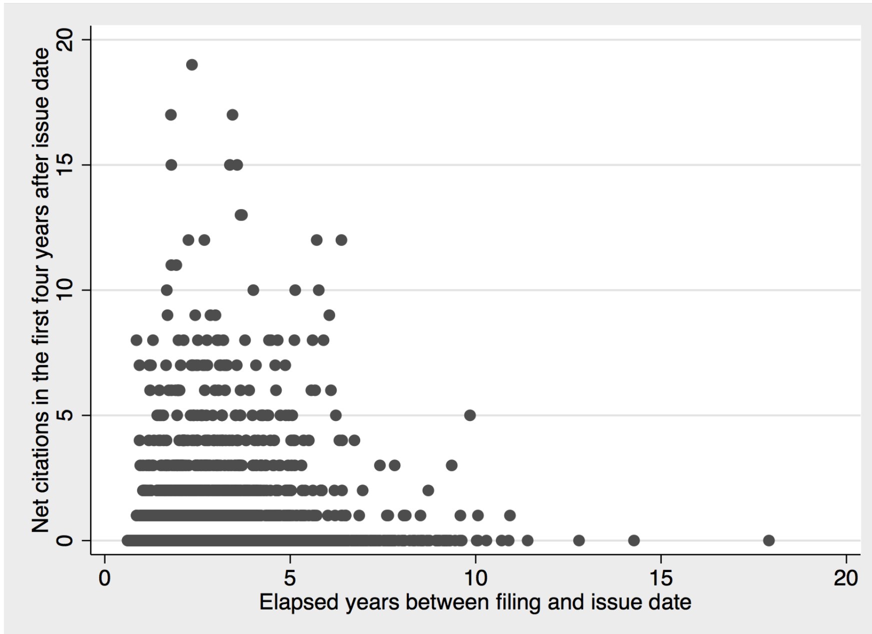


Figure 2.8: Net citations in the first four years by examination time

The GM crops technology shows evidence that if one orders the importance of a patent as the number of net citations in the first four years, more valuable patents are issued more rapidly.

One important feature of universities patents must be their originality. One piece of information that may be useful to distinguish whether there is a difference in the degree of basicness between universities and private firms patents is the number of references cited. In Section Data, I mentioned that each patent should legally provide all the prior patents used to achieve the new invention/innovation, called 'References Cited'.

Early patents in the technology cycle should cite less "References cited" since there are not much prior knowledge available. As we move through the cycle, one may expect that the number of ’References Cited’ increases, both for private firms and for universities.

Assuming universities are in fact involved in ”more basic research”, inventors should be, consistently, using less of the patent stock and more original ideas that may come from scientific journals or peer research.

In Figures 2.9 and 2.10, I show the number of ’References Cited’ for universities and private firms by Application Date, in that order. We observe that at the very beginning of the technology cycle, indeed both types of assignees use very few ’References Cited’ if any.

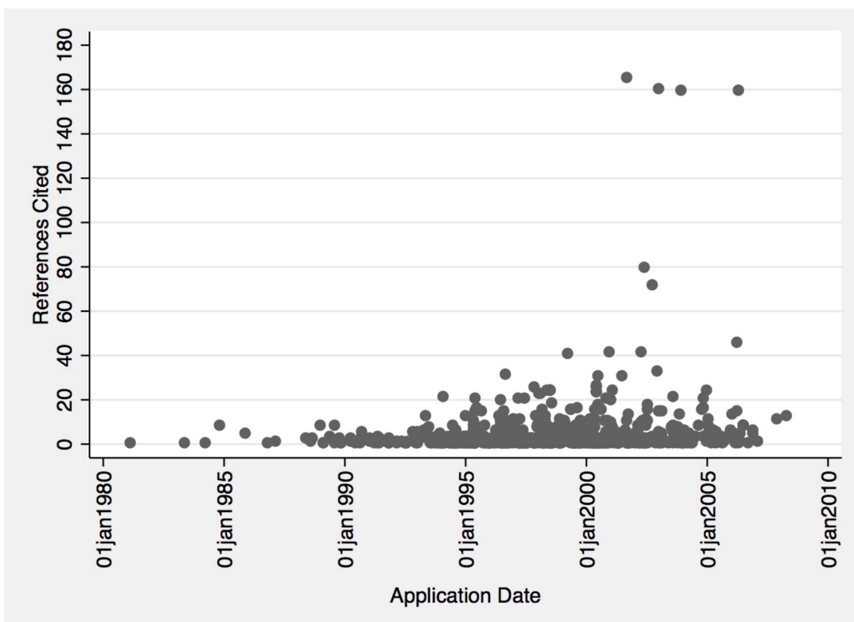


Figure 2.9: References cited by application date: Universities

As the cycle continues, the number of ”References Cited” increases more for private firms than for universities. By 1995, private firms were already using more prior patents than universities (Figure 2.10), the majority of universities patents cite less than 20 patents (Figure 2.9).

It is necessary to note that up to 1995, the pattern for Universities and Private Firms seems symmetrical, after that date the pattern distances from each other.

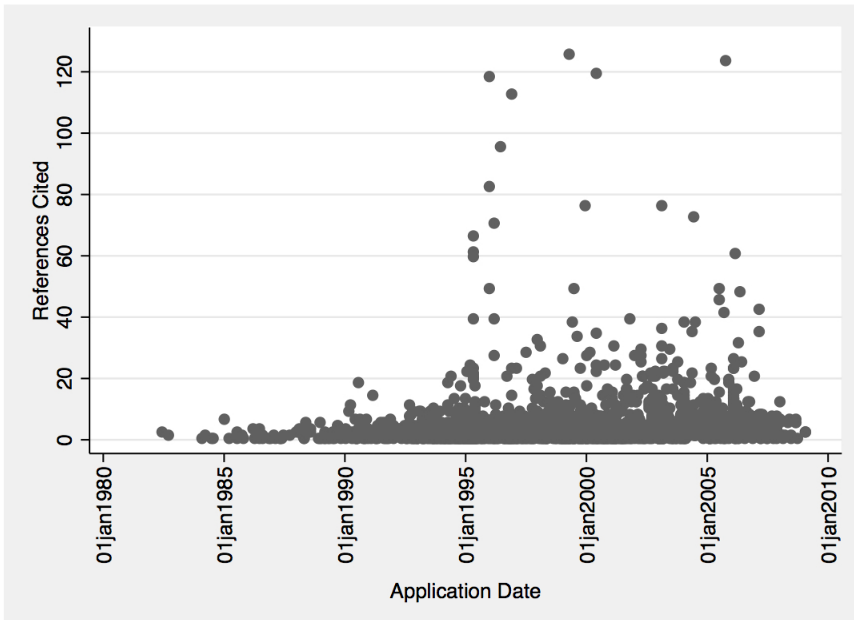


Figure 2.10: References cited by application date: Private Firms

One additional question about the degree of basicness is that if one patent is more basic than another, it should mean that it has a much broader range of applications. If the number of ”References Cited” is a proxy to the degree of basicness, then we would expect that the less ”References Cited”, the more the Net Citations. Moreover, we should expect this relationship to be more pronounce for universities than for private firms.

In Figures 2.11 and 2.12, I show the number of ”Net Citations in the First Four

Years After the Issue Date" by "References Cited", in that order.

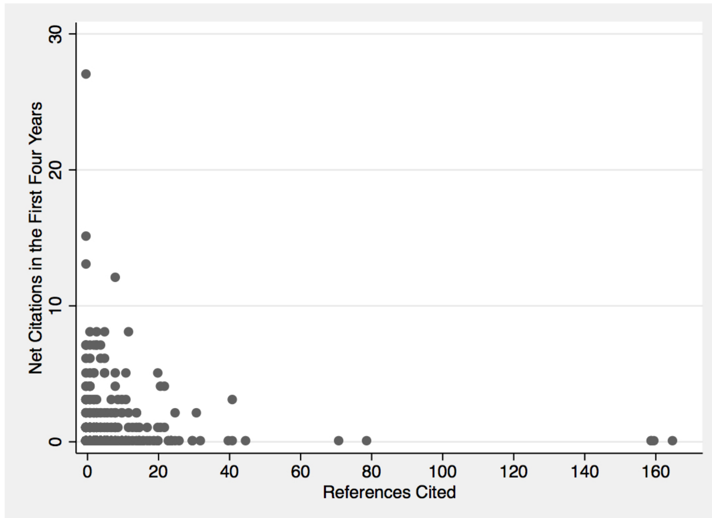


Figure 2.11: Net citations in the first four years by references cited: Universities

In Figure 2.11, we observe a more pronounced negative relationship. However, in both cases we observe that more productive patents, more widely cited, are those with less "References Cited".

This finding supports the inclusion of "References Cited" as a variable of control in the estimation since there is evidence that it has a relationship with the dependent variable.

Linking this observation with what I discussed in Chapter 1, basic research should indeed make use of less prior knowledge since it consists on novel ideas that open new technology areas and that could potentially be used by many areas as well.

Thus, this simple exploration is in itself an interesting support of the use of patents as a proxy of innovation.

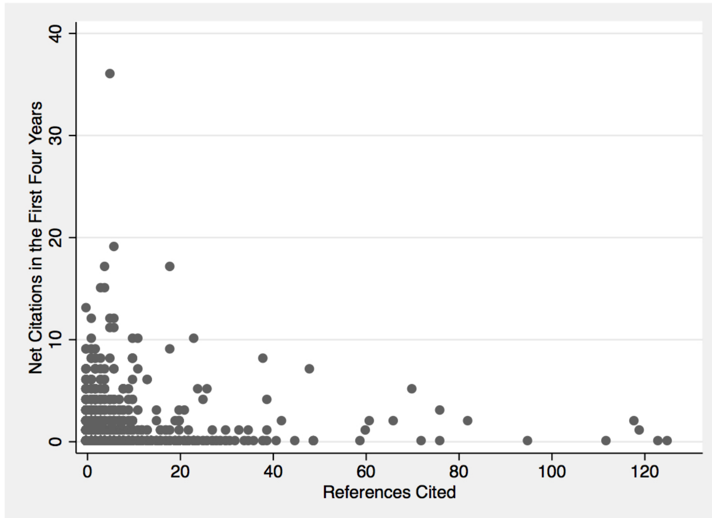


Figure 2.12: Net citations in the first four years by references cited: Private firms

2.6 Results

The aim of this paper is to compare the externalities, measured as future net citations, of universities patents versus the ones of private firms. Thus, in the following results I choose private firms as the category of reference. If universities are generating basic research with a much wider use, we would expect to find positive and significant net effect for universities patents.

As discussed in the previous Section, the position of a patent in the technology cycle (Distance) is important for future citations as well as that the number of references cited.

In Figures 2.13 and 2.14, the net citations in the first four years after the issue date are not homogeneous along the technology cycle. Thus, it is important to consider the effect of the variable ”Distance” and whether this is different for universities and private firms.

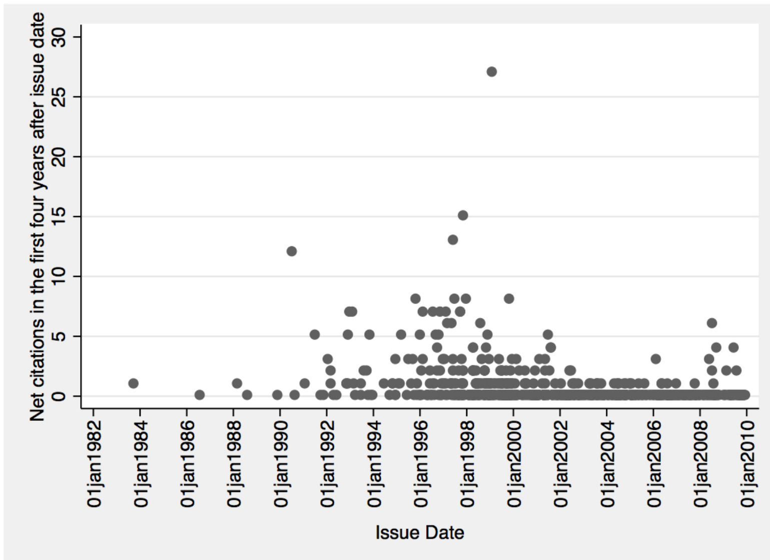


Figure 2.13: Net citations in the first four years according to the technological cycle: Universities

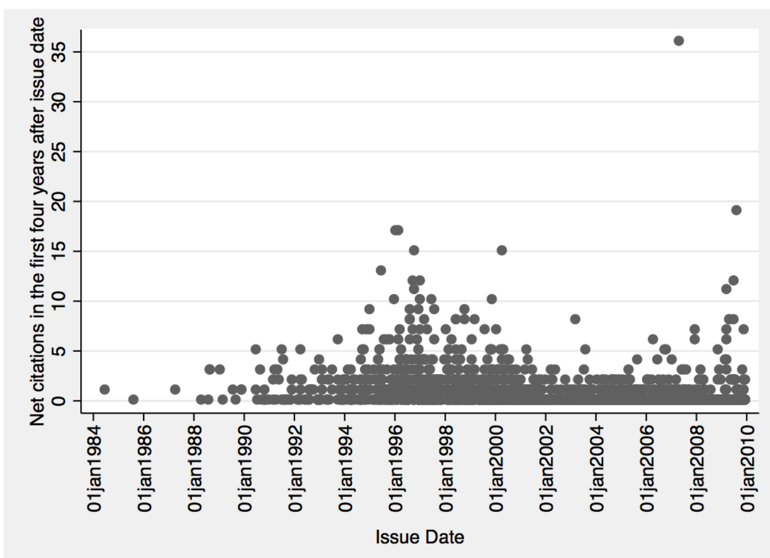


Figure 2.14: Net citations in the first four years according to the technological cycle: Private firms

The number of ”References Cited” could be used as a proxy of how basic/original a patent is. In the previous section, I discussed that on average, universities are using less prior patents for their new inventions compared to the private firms.

In the estimations of this chapter, I introduce ”References Cited=Number of total prior patents used/10” as an explanatory variable. As discussed before, we should expect more important innovations to use less prior patents since they represent new knowledge into the scientific field (Figures 2.9 and 2.10).

Also, in all the following estimations, I include the type of assignee with dummy variables for each type of assignee (”University”, ”Government” and ”Individual”), along with their interaction terms with the variable ”Distance”, to control for the possible effect of the technology cycle for each type compared to the private firms patents.

In Table 2.6, I present the results of the estimations using Negative Binomial (NB), Zero-Inflated Negative Binomial (ZINB) and Pseudo-Poisson Maximum Likelihood (PPML). In these estimations, I do include dummies for ”Examiners”, ”Agents” or ”Countries”, along with the dummies for the type of ”Assignee” and their corresponding interaction terms with ”Distance”, along with the variable ”Reference Cited” and its dependent squared term.

Although, NB, ZINB and PPML deal with discrete dependent variables, the interpretation of their corresponding coefficients should not be considered directly. The importance of comparing these three models is to ensure robustness of the results.

There are two parts to consider in the ZINB estimation: i) the variable(s) that affects the existence of a zero, and ii) the explanatory variables that affect the dependant variable once the observation is not zero. In the present case, the existence of a zero is indicated as *Inflate*, and as discussed before, ”Distance” is the best candidate to affect the existence of a zero net forward citation. The explanatory variables that influence the dependent variable are the same used in the estimations of NB and PPML.

It is also worth mentioning that the interpretation of PPML coefficient is analogous to the OLS analysis consistent in the presence of heteroskedasticity and zero values of the dependent variable (Santos Silva and Tenreyro, 2006).

In these estimations (Table 2.6), I do not include ”Reference Cited” as explanatory variable. We observe that as expected, ”Distance” has a negative effect with the number of net citations in the first four years. Thus, newer patents are less likely to receive more net forward citations than prior patents. Controlling for ”Distance”, the coefficient of ”University” is positive and significant using NB and ZINB while its interaction term is negative and significant.

The effect of ”University” is positive and significant in some specifications: when controlling for Agents/Attorneys (Columns (1) and (2)), but decreasing in ”Distance”. This result is similar to the one of the Columns (7) and (8) when I introduce Countries as explanatory variable.

Thus, at the beginning of the technology cycle, universities do generate more net citations in the first four years than private firms, but this positive effect vanishes as we move farther from the beginning. However, this result only holds assuming that all agents would be the same for all patents, all patents where filed by the same attorney or agent, and when all the patents belong to the same country.

Table 2.6: Results including dummies of Examiners, Agents and Countries

Dependent variable: net citations first four years after issue date

	(1) NB	(2) ZINB	(3) PPML	(4) NB	(5) ZINB	(6) PPML	(7) NB	(8) ZINB	(9) PPML
Distance	-0.108***	-0.010	-0.106***	-0.122***	-0.030*	-0.114***	-0.130***	-0.023*	-0.125***
	(0.013)	(0.014)	(0.018)	(0.014)	(0.015)	(0.019)	(0.010)	(0.011)	(0.012)
University	1.137**	1.081**	0.634	0.622	0.738*	0.494	0.858*	0.823*	0.358
	(0.422)	(0.381)	(0.384)	(0.400)	(0.366)	(0.381)	(0.419)	(0.373)	(0.350)
Government	1.432	1.235	1.467	0.216	0.120	0.435	0.178	-0.189	0.103
	(1.064)	(1.018)	(0.965)	(0.885)	(0.835)	(0.895)	(0.969)	(0.870)	(0.729)
Individual	-0.568	-0.624	-0.972	-0.829	-1.067	-0.899	-0.879	-0.928	-1.200**
	(0.805)	(0.708)	(0.546)	(0.793)	(0.725)	(0.504)	(0.837)	(0.714)	(0.451)
University*Distance	-0.077**	-0.077**	-0.048	-0.042	-0.049*	-0.033	-0.057*	-0.059**	-0.024
	(0.024)	(0.024)	(0.025)	(0.023)	(0.023)	(0.024)	(0.024)	(0.023)	(0.021)
Government*Distance	-0.128*	-0.124*	-0.132*	-0.057	-0.052	-0.072	-0.038	-0.022	-0.038
	(0.058)	(0.059)	(0.056)	(0.048)	(0.049)	(0.053)	(0.052)	(0.051)	(0.044)
Individual*Distance	0.028	0.026	0.048	0.054	0.068	0.052	0.055	0.054	0.070*
	(0.045)	(0.043)	(0.034)	(0.044)	(0.045)	(0.034)	(0.046)	(0.043)	(0.029)
Agents	Yes	Yes	Yes						
Examiners				Yes	Yes	Yes			
Countries							Yes	Yes	Yes
Constant	1.536***	0.478*	1.489***	1.656***	0.605*	1.422***	1.682***	0.500	1.603***
	(0.235)	(0.223)	(0.234)	(0.281)	(0.262)	(0.287)	(0.350)	(0.344)	(0.320)
Ln(alpha)	0.975***	0.190		1.044***	0.297**		1.103***	0.306**	
	(0.061)	(0.110)		(0.059)	(0.107)		(0.059)	(0.100)	
Inflate									
Distance		0.278***			0.283***			0.294***	
		(0.021)			(0.022)			(0.020)	
Constant		-5.410***			-5.530***			-5.649***	
		(0.469)			(0.499)			(0.445)	
Observations	3428	3428	3380	3428	3428	3428	3428	3428	3412

Standard errors in parentheses

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

It is worth mentioning that, since the ZINB estimations are adjusted by the excess of zeros in the distribution of the dependant variable, the coefficients are not directly comparable with the NB (without adjustment).

For instance, controlling only for Agents(Table 2.6, Column (2)), once a patent has crossed the threshold of zero net forward citations (using ZINB), the fact that a patent belongs to a "University" increases the chance to receive a further citation in $\exp(1.081) = 2.95$ while holding all the other variables constant. This result holds in the other specifications of the ZINB (Columns (5) and (8)) to a lesser extent, but still positive and significant.

However, the positive effect of "University" decreases as "Distance" increases. When $University = 1$, a patent that belongs to a University will have, on average, more forward net citations, but the effect decreases as we move along the technology cycle. Every year that passes from the beginning of the period, the forward net citations for a "University" patent will decrease by a factor of $\exp(-0.077) = 0.93$.

It is worth mentioning that in all specification of ZINB, the "University" has a positive and significant effect, but decreasing as "Distance" increases.

In Table 2.7, I do not control for "Agents", "Examiners" or "Countries" (Table 2.7) and "References Cited". In Columns (4), (5) and (6) of Table 2.7, the variable that indicates the number of "References Cited" is included and in Columns (7), (8) and (9), I add its squared term. Controlling for "Distance" and "References Cited" the coefficient for "University" patents and its interaction term with "Distance" are as before.

The above suggests that at the beginning of the technology cycle patents whose assignee is a "University" generate more net citations, but as "Distance" increases this effect decreases.

Table 2.7: Results with dummies of Assignees

Dependent variable: net citations on the first four years after issue date

	(1) NB	(2) ZINB	(3) PPML	(4) NB	(5) ZINB	(6) PPML	(7) NB	(8) ZINB	(9) PPML
Distance	-0.131***	-0.026*	-0.128***	-0.139***	-0.036***	-0.133***	-0.148***	-0.043***	-0.141***
	(0.009)	(0.011)	(0.012)	(0.009)	(0.011)	(0.012)	(0.010)	(0.011)	(0.012)
University	0.911*	0.872*	0.356	0.991*	0.886*	0.402	0.933*	0.890*	0.342
	(0.408)	(0.363)	(0.349)	(0.410)	(0.366)	(0.347)	(0.409)	(0.366)	(0.344)
Government	0.049	-0.073	0.170	-0.026	-0.168	0.123	-0.110	-0.234	0.030
	(0.906)	(0.822)	(0.776)	(0.904)	(0.823)	(0.766)	(0.904)	(0.823)	(0.741)
Individual	-0.906	-0.863	-1.090*	-0.896	-0.876	-1.107*	-0.872	-0.851	-1.117*
	(0.817)	(0.700)	(0.434)	(0.814)	(0.702)	(0.434)	(0.811)	(0.701)	(0.434)
University*Distance	-0.060*	-0.061**	-0.024	-0.064**	-0.061**	-0.028	-0.060*	-0.061**	-0.023
	(0.023)	(0.023)	(0.021)	(0.024)	(0.023)	(0.021)	(0.024)	(0.023)	(0.021)
Government*Distance	-0.053	-0.049	-0.060	-0.045	-0.040	-0.055	-0.037	-0.033	-0.047
	(0.049)	(0.048)	(0.046)	(0.049)	(0.048)	(0.045)	(0.049)	(0.048)	(0.044)
Individual*Distance	0.049	0.042	0.059*	0.052	0.047	0.062*	0.053	0.047	0.066*
	(0.045)	(0.042)	(0.029)	(0.045)	(0.042)	(0.029)	(0.044)	(0.042)	(0.029)
References Cited				0.214***	0.211***	0.130***	0.555***	0.489***	0.499***
				(0.052)	(0.060)	(0.024)	(0.091)	(0.094)	(0.091)
References Cited^2							-0.047***	-0.045***	-0.045***
							(0.011)	(0.011)	(0.012)
Constant	1.897***	0.732***	1.849***	1.927***	0.788***	1.867***	1.959***	0.804***	1.879***
	(0.172)	(0.166)	(0.182)	(0.172)	(0.167)	(0.183)	(0.171)	(0.167)	(0.181)
Ln(alpha)	1.138***	0.349***		1.120***	0.365***		1.096***	0.351***	
	(0.058)	(0.100)		(0.059)	(0.098)		(0.059)	(0.099)	
Inflate									
Distance		0.290***			0.292***			0.292***	
		(0.020)			(0.020)			(0.021)	
Constant		-5.552***			-5.655***			-5.668***	
		(0.441)			(0.454)			(0.457)	
Observations	3428	3428	3428	3428	3428	3428	3428	3428	3428

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

As presented in Figures 2.11 and 2.12, the relationship between number of ”References Cited” and the dependant variable is not linear. It has a concave relationship, where very few ”References cited” increase the net forward citations of the first four years and decreases once a threshold is crossed. For this reason, the coefficient of ”References Cited” is positive and significant and its squared term is negative and significant.

Controlling only for type of Assignee(Table 2.7, Column (2)), once a patent has crossed the threshold of zero net forward citations, using ZINB, the fact that a patent belongs to a ”University” increases the chance to receive a further citation in $\exp(0.872) = 2.39$ while holding all the other variables constant, which is of similar magnitude of the corresponding coefficients with other explanatory dummies. This result holds in the other specifications of the ZINB (Columns (5) and (8)) in the first years, still positive and significant.

In Table 2.8, I consider dummy variables of examiners, agents and countries together, in contrast to Table 2.7, where they were included one by one. The results do not change significantly, and the same basic result survives, university patents do generate more net forward citations in the first four years compared to the private firms only at the beginning of the cycle, but this effect decreases as we move farther from the start of it.

It is worth noting that controlling for ”Agents” along with Examiners and Countries the effect of Universities is positive and significant. This result may indicate that the access to different attorneys that file patent applications could have a different consequence in the later importance of the patent. One possible interpretation is that if universities had the same attorneys as private firms, their patents would be more cited in the next four years after issue than the ones of private firms.

Controlling only for ”Examiners” and ”Countries”, the effect of ”University” is not significant. Thus, if a patent would be assessed by the same examiner and belong to the same country, it would not be different in its net forward citations whether if belongs to a university or a private firm.

Table 2.8: Results including dummies of Examiners, Agents and Countries

Dependent variable: net citations first four years after issue date

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML
Distance	-0.103***	-0.018	-0.095***	-0.106***	-0.006	-0.103***	-0.120***	-0.025	-0.111***	-0.103***	-0.016	-0.093***
	(0.016)	(0.017)	(0.023)	(0.013)	(0.014)	(0.018)	(0.014)	(0.015)	(0.019)	(0.016)	(0.017)	(0.023)
University	0.920*	1.015**	0.741	0.979*	0.966*	0.508	0.513	0.657	0.431	0.726	0.869*	0.533
	(0.419)	(0.386)	(0.416)	(0.430)	(0.389)	(0.382)	(0.413)	(0.376)	(0.378)	(0.428)	(0.394)	(0.415)
Government	1.585	1.315	1.700	2.472*	2.104	1.968*	0.199	-0.143	0.282	2.428*	1.937	2.089*
	(1.046)	(1.030)	(1.084)	(1.188)	(1.156)	(0.943)	(0.946)	(0.880)	(0.832)	(1.176)	(1.171)	(1.002)
Individual	-0.592	-0.920	-0.838	-0.547	-0.666	-1.045	-0.905	-1.280	-0.914	-0.642	-1.116	-0.835
	(0.792)	(0.747)	(0.553)	(0.821)	(0.725)	(0.575)	(0.804)	(0.738)	(0.507)	(0.803)	(0.763)	(0.572)
University*Distance	-0.065**	-0.072**	-0.055*	-0.072**	-0.074**	-0.044	-0.038	-0.047*	-0.031	-0.059*	-0.069**	-0.048
	(0.024)	(0.025)	(0.028)	(0.025)	(0.024)	(0.025)	(0.023)	(0.023)	(0.024)	(0.025)	(0.025)	(0.028)
Government*Distance	-0.131*	-0.120*	-0.143*	-0.151*	-0.141*	-0.135*	-0.035	-0.014	-0.047	-0.143*	-0.122	-0.141*
	(0.057)	(0.060)	(0.064)	(0.063)	(0.065)	(0.055)	(0.051)	(0.052)	(0.051)	(0.063)	(0.066)	(0.061)
Individual*Distance	0.039	0.058	0.047	0.034	0.038	0.054	0.064	0.087	0.057	0.047	0.078	0.047
	(0.044)	(0.046)	(0.036)	(0.045)	(0.044)	(0.036)	(0.045)	(0.046)	(0.034)	(0.045)	(0.047)	(0.037)
Agents	Yes	Yes	Yes	Yes	Yes	Yes				Yes	Yes	Yes
Examiners	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes
Countries				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.226***	0.301	1.065**	1.301***	0.161	1.182**	1.693***	0.589*	1.441***	1.345***	0.367	1.151***
	(0.316)	(0.292)	(0.329)	(0.384)	(0.377)	(0.371)	(0.290)	(0.267)	(0.282)	(0.320)	(0.295)	(0.321)
Ln(alpha)	0.889***	0.141		0.924***	0.141		1.012***	0.249*		0.844***	0.094	
	(0.062)	(0.116)		(0.061)	(0.111)		(0.060)	(0.107)		(0.063)	(0.117)	
Inflate												
Distance		0.279***			0.283***			0.287***			0.284***	
		(0.023)			(0.021)			(0.022)			(0.024)	
Constant		-5.538***			-5.540***			-5.618***			-5.687***	
		(0.536)			(0.482)			(0.501)			(0.556)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412	3428	3428	3364

Standard errors in parentheses

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

In 2001, the USPTO changed the rule of patent application disclosure, where patent applications would be published within eighteen months after the effective filing date, allowing inventors the possibility of ”royalties from others who make, use, sell, or import the invention during the period between the time the patent application is published and the patent is granted”[9].

I introduce the variable ”Year filed $\geq$ 2001” to capture those patents that were filed in or after 2001. Also, I add interaction terms of this variable with each type of assignee (University*Year01, Government*Year01, and Individual*Year01).

In Table 2.9, we observe that patents filed after 2001 that belong to ”Government” have an adverse effect on the net citations in the first four years compared to the private firms, assuming that all patents were granted in or after 2001 and are located in the same part of the technology cycle.

The variable ”Distance” remains as in the previous specifications of this chapter, coefficient negative and significant in all the estimations (NB, ZINB and PPML).

This result survives when we introduce dummies of ”Agents”, ”Examiners” and ”Countries” (Tables 2.10 and 2.11).

The fact that only ”Government” patents were affected by the change in legislation of 2001 is an important result of this chapter, and this could be explained because Government innovations that lead to a granted patent are perhaps much more specific in their use than the corresponding patents of other assignees. Moreover, by 2001 the technology field was already mature and dominated by private firms and to a lesser extent by universities.

In *Appendix A*, I provide the results including ”References Cited” as a control, however, the results do not change.

[9]http://www.uspto.gov/about-us/news-updates/uspto-will-begin-publishing-patent-applications

Table 2.9: Results considering the change in 2001

Dependent variable: net citations first four years after issue date

	(1) NB	(2) ZINB	(3) PPML	(4) NB	(5) ZINB	(6) PPML	(7) NB	(8) ZINB	(9) PPML
Year filed≥2001	0.089	0.523**	-0.195	0.147	0.582**	-0.173	0.119	0.539**	-0.208
	(0.156)	(0.178)	(0.167)	(0.156)	(0.178)	(0.167)	(0.156)	(0.177)	(0.168)
Distance	-0.144***	-0.063***	-0.120***	-0.156***	-0.078***	-0.126***	-0.162***	-0.081***	-0.132***
	(0.014)	(0.014)	(0.009)	(0.014)	(0.015)	(0.009)	(0.014)	(0.015)	(0.010)
University	-0.026	0.004	0.008	-0.006	0.021	0.019	-0.007	0.016	0.007
	(0.111)	(0.099)	(0.118)	(0.111)	(0.099)	(0.117)	(0.111)	(0.099)	(0.118)
Government	-0.795***	-0.793***	-0.794***	-0.724**	-0.730**	-0.760***	-0.679**	-0.705**	-0.726***
	(0.237)	(0.222)	(0.218)	(0.238)	(0.222)	(0.217)	(0.238)	(0.222)	(0.216)
Individual	-0.111	-0.201	-0.255	-0.036	-0.126	-0.228	0.012	-0.093	-0.192
	(0.245)	(0.217)	(0.214)	(0.245)	(0.217)	(0.215)	(0.244)	(0.217)	(0.217)
University*Year01	-0.316	-0.425	-0.334	-0.380	-0.450	-0.458	-0.317	-0.440	-0.301
	(0.247)	(0.298)	(0.323)	(0.248)	(0.297)	(0.333)	(0.248)	(0.296)	(0.322)
Government*Year01	-0.401	-0.326	-0.353	-0.376	-0.289	-0.332	-0.318	-0.239	-0.252
	(0.496)	(0.578)	(0.532)	(0.496)	(0.576)	(0.532)	(0.496)	(0.574)	(0.533)
Individual*Year01	0.285	0.222	0.483	0.270	0.211	0.498	0.281	0.216	0.550
	(0.474)	(0.560)	(0.592)	(0.472)	(0.557)	(0.592)	(0.470)	(0.553)	(0.592)
References Cited				0.215***	0.222***	0.133***	0.554***	0.486***	0.497***
				(0.052)	(0.059)	(0.024)	(0.091)	(0.094)	(0.090)
References Cited^2							-0.047***	-0.043***	-0.045***
							(0.011)	(0.011)	(0.012)
Constant	2.091***	1.226***	1.760***	2.175***	1.322***	1.789***	2.175***	1.305***	1.777***
	(0.221)	(0.200)	(0.146)	(0.222)	(0.202)	(0.147)	(0.221)	(0.201)	(0.145)
Ln(alpha)	1.145***	0.371***		1.128***	0.385***		1.103***	0.372***	
	(0.058)	(0.097)		(0.059)	(0.095)		(0.059)	(0.096)	
Inflate									
Distance		0.305***			0.309***			0.308***	
		(0.022)			(0.022)			(0.022)	
Constant		-5.871***			-6.023***			-6.012***	
		(0.482)			(0.498)			(0.500)	
Observations	3428	3428	3428	3428	3428	3428	3428	3428	3428

Standard errors in parentheses

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

Table 2.10: Results considering the change in 2001 and dummies for Examiners, Agents and Countries

Dependent variable: net citations first four years after issue date

	(1) NB	(2) ZINB	(3) PPML	(4) NB	(5) ZINB	(6) PPML	(7) NB	(8) ZINB	(9) PPML
Year filed≥2001	0.384*	0.988***	0.140	0.165	0.556**	0.102	0.022	0.466*	-0.216
	(0.175)	(0.214)	(0.249)	(0.170)	(0.195)	(0.265)	(0.158)	(0.182)	(0.168)
Distance	-0.143***	-0.066***	-0.118***	-0.140***	-0.064***	-0.124***	-0.138***	-0.057***	-0.116***
	(0.015)	(0.015)	(0.012)	(0.017)	(0.017)	(0.015)	(0.014)	(0.014)	(0.010)
University	-0.023	0.001	-0.018	-0.042	0.018	0.030	-0.065	-0.025	-0.001
	(0.125)	(0.113)	(0.122)	(0.114)	(0.102)	(0.115)	(0.117)	(0.105)	(0.123)
Government	-0.627*	-0.658**	-0.645**	-0.671**	-0.649**	-0.665**	-0.443	-0.513*	-0.507*
	(0.250)	(0.239)	(0.236)	(0.239)	(0.224)	(0.221)	(0.274)	(0.260)	(0.214)
Individual	-0.034	-0.151	-0.245	0.012	-0.068	-0.141	0.030	-0.087	-0.201
	(0.242)	(0.217)	(0.237)	(0.245)	(0.218)	(0.219)	(0.256)	(0.226)	(0.223)
University*Year01	-0.603*	-0.840*	-0.604	-0.144	-0.214	-0.329	-0.247	-0.394	-0.311
	(0.263)	(0.329)	(0.375)	(0.252)	(0.306)	(0.336)	(0.250)	(0.301)	(0.322)
Government*Year01	-0.981	-1.037	-0.935	-0.545	-0.402	-0.558	-0.257	-0.129	-0.181
	(0.553)	(0.667)	(0.570)	(0.507)	(0.609)	(0.543)	(0.511)	(0.599)	(0.539)
Individual*Year01	-0.123	-0.364	0.163	0.466	0.782	0.412	0.281	0.276	0.561
	(0.480)	(0.569)	(0.616)	(0.493)	(0.675)	(0.632)	(0.478)	(0.575)	(0.605)
Agents	Yes	Yes	Yes						
Examiners				Yes	Yes	Yes			
Countries							Yes	Yes	Yes
Constant	2.044***	1.214***	1.673***	1.942***	1.091***	1.558***	1.785***	0.936**	1.502***
	(0.253)	(0.227)	(0.185)	(0.302)	(0.271)	(0.231)	(0.377)	(0.363)	(0.294)
Ln(alpha)	0.983***	0.199		1.048***	0.305**		1.110***	0.328***	
	(0.061)	(0.107)		(0.059)	(0.105)		(0.059)	(0.098)	
inflate									
Distance		0.299***			0.293***			0.308***	
		(0.023)			(0.023)			(0.022)	
Constant		-5.832***			-5.752***			-5.948***	
		(0.517)			(0.526)			(0.485)	
Observations	3428	3428	3380	3428	3428	3428	3428	3428	3412

Standard errors in parentheses

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

Table 2.11: Results considering the change in 2001 and dummies for Examiners, Agents and Countries

Dependent variable: net citations first four years after issue date

	(1) NB	(2) ZINB	(3) PPML	(4) NB	(5) ZINB	(6) PPML	(7) NB	(8) ZINB	(9) PPML	(10) NB	(11) ZINB	(12) PPML
Year filed≥2001	0.425*	0.941***	0.435	0.355*	0.973***	0.114	0.095	0.487*	0.047	0.398*	0.916***	0.380
	(0.186)	(0.227)	(0.325)	(0.175)	(0.214)	(0.250)	(0.171)	(0.197)	(0.266)	(0.187)	(0.226)	(0.323)
Distance	-0.140***	-0.070***	-0.122***	-0.139***	-0.061***	-0.114***	-0.133***	-0.054**	-0.117***	-0.139***	-0.066***	-0.117***
	(0.018)	(0.018)	(0.016)	(0.015)	(0.015)	(0.013)	(0.017)	(0.017)	(0.015)	(0.018)	(0.018)	(0.016)
University	-0.072	-0.021	-0.014	-0.110	-0.067	-0.088	-0.112	-0.038	-0.013	-0.192	-0.122	-0.134
	(0.127)	(0.116)	(0.119)	(0.130)	(0.119)	(0.134)	(0.120)	(0.108)	(0.119)	(0.134)	(0.122)	(0.135)
Government	-0.513*	-0.535*	-0.531*	-0.013	-0.110	-0.205	-0.340	-0.350	-0.427*	0.085	0.017	-0.120
	(0.252)	(0.240)	(0.242)	(0.297)	(0.296)	(0.238)	(0.276)	(0.262)	(0.211)	(0.299)	(0.296)	(0.237)
Individual	0.066	-0.024	-0.129	0.092	-0.038	-0.248	0.089	-0.006	-0.081	0.135	0.052	-0.132
	(0.243)	(0.221)	(0.235)	(0.255)	(0.231)	(0.244)	(0.253)	(0.225)	(0.223)	(0.253)	(0.232)	(0.236)
University*Year01	-0.425	-0.564	-0.562	-0.558*	-0.830*	-0.562	-0.073	-0.192	-0.285	-0.386	-0.585	-0.477
	(0.269)	(0.339)	(0.381)	(0.266)	(0.329)	(0.374)	(0.255)	(0.307)	(0.338)	(0.272)	(0.336)	(0.381)
Government*Year01	-1.054	-0.925	-1.047	-1.029	-1.097	-0.940	-0.348	-0.111	-0.348	-1.043	-0.896	-1.004
	(0.559)	(0.710)	(0.582)	(0.573)	(0.706)	(0.569)	(0.525)	(0.633)	(0.560)	(0.580)	(0.758)	(0.586)
Individual*Year01	0.113	0.258	0.189	-0.094	-0.233	0.273	0.499	1.002	0.443	0.163	0.608	0.222
	(0.494)	(0.667)	(0.643)	(0.483)	(0.592)	(0.632)	(0.498)	(0.718)	(0.651)	(0.498)	(0.726)	(0.668)
Agents	Yes	Yes	Yes	Yes	Yes	Yes				Yes	Yes	Yes
Examiners	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes
Countries				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.812***	1.031***	1.418***	1.769***	0.889*	1.411***	1.911***	1.003***	1.542***	1.897***	1.062***	1.455***
	(0.318)	(0.283)	(0.256)	(0.393)	(0.375)	(0.315)	(0.307)	(0.273)	(0.231)	(0.321)	(0.287)	(0.259)
Ln(alpha)	0.894***	0.140		0.932***	0.150		1.017***	0.258*		0.848***	0.093	
	(0.062)	(0.114)		(0.061)	(0.108)		(0.060)	(0.106)		(0.062)	(0.114)	
Inflate												
Distance		0.295***			0.305***			0.297***			0.301***	
		(0.025)			(0.023)			(0.023)			(0.025)	
Constant		-5.850***			-5.983***			-5.825***			-6.015***	
		(0.569)			(0.531)			(0.527)			(0.589)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412	3428	3428	3364

Standard errors in parentheses

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

2.7 Conclusions

There is a broad view that public funding to university research is essential because: i) in the absence of such intervention the private sector would not adequately supply certain types of research vital to the society progress, and ii) basic research is unlikely to provide substantial economic rewards to the inventor (low appropiability)

Moreover, there is a widespread belief that university patents generate proportionally more positive knowledge externalities than private research. However, some authors have shown that this affirmation is not straightforward and that the relation between the dependent and universities has been changing over time.

In this paper, I compare the knowledge externalities generated by a university and private firms patents related to GM crop research. The primary measurement of externalities is the total number of third-party citations produced by a patent (net citations) in the first four years after its issue date.

By considering a well-defined research field I count with advantages over a random sample of all university patents, such as identifying and controlling for the innovation cycle. In this sense, the present analysis is unique not only for the study of differences of patents between universities and private firms, but also is a step forward in the understating of the evolution of a technology cycle using patent information.

Moreover, policymakers around the world are continuously arguing about the best tools to encourage technological change, without losing track of the use of public resources. Specifically, public policy towards university research is mainly tailored to specific areas. As the government controls the allocation of federal funds and can decide whether or not, for instance, biotechnology, or even GM crops, is a field of research it cares to subsidise.

The main result is that patented university research is weakly associated with greater knowledge externalities than private firms patents one only at the beginning of the technology cycle and this importance vanishes as time passes and private firms become engage in the field. The results remain when we control for examiners, agents and countries.

Thus, in line with the model of Aghion et al. (2008), this study suggests that the role of universities is fundamental in early stages of a technology cycle, and that the transition should be done later in the cycle from academia to private sector or to seek shared resources to develop new technologies.

Federal funding is needed at the incubation periods of a technology cycle given that research at universities provides freedom to pursue the most original ideas that are embodied by nature with more uncertainty. If the technology is successful in the first years, it is likely that private firms will become attracted to the area and invest in both basic and applied research, but this will happen when they consider it is economically rewarding or it can give them a strategic position in the market.

One possible implication of these conclusions is that once private firms and academia are equally engaged in a technological area, research agreements between the two may result beneficial for both. For a private, it may be cheaper to get 'basic research' through a university, since academic researches salaries are usually lower than in the private sector and the physical resources are owned and paid by the university. For a university, this agreement is also beneficial because the source of income diversifies and expensive research areas may not be dropped due to lack of money.

Chapter 3

New Product Development

3.1 Introduction

New product development (NPD) is a crucial support for competitive strategy in many markets, especially high technology industries were the need to bring new products to the market rapidly requires firms to move along the NPD process more quickly (Hartley and Zirger, 1996).

The NPD process involves not only managers and designers within the company but also supplier and customer involvement from an early stage of the design. The argument in support of supplier engagement is that a manufacturer can absorb the supplier's knowledge and resources, and in turn reduce the time spent in the design and development (Chiang and Wu, 2016).

Firms under collaboration agreements may fear their partners could appropriate a significant portion of the economic benefits of the NPD outputs (Bhaskaran and Krishnan, 2009). In particular, this becomes a major issue when the rights and obligations of each agent are not clearly stated at the beginning of the project.

It may happen that an agent free-rides its partner's capabilities and knowledge, making this situation worse when one of them legally protects a part of the output without the other's approval. Even though collaboration may provide advantages, it also generates the issue of incentives mismatch among the players that gives rise to the need for monitoring, efficient contract design to reduce the risk of project failure and unanticipated high costs that could even endanger the survival of manufacturers and suppliers.

The goal of this chapter is to provide background that joins Chapter 4 and 5 of this dissertation. In this Chapter 3, I will present a literature review of the role of suppliers in a NPD, examining the degree of involvement, going from mere manufacturer to designer and owner of whole parts, and I will introduce the role of uncertainty in a NPD.

In Chapter 4, the role of suppliers is discussed in the latest major projects of Boeing and of Airbus, emphasising the type of contracts each one signed with their respective suppliers along with the consequences of them. The crucial difference in the relationship each firm decided to pursue with the suppliers has direct consequences in the NPD process of the projects. Boeing faced severe delays on the first deliveries of its latest commercial aircraft when the firm decided to outsource complete parts of the aircraft becoming only the final assembler and being in the need to buy suppliers to ensure the progress of the project[1], while

[1]http://boeing.mediaroom.com/2009-07-30-Boeing-Completes-Acquisition-of-Vought-Operations-in-South-Carolina

Airbus kept all the decision in-house and faced in less extent these issues.

The topic of uncertainty, inherent to any major NPD, is emphasised in the strategic decisions each firm undertakes. In Chapter 5, I present a dynamic duopoly model using real options analysis, where firms face two types of uncertainty (technological and from the market) and strategically decide the optimal time to launch their new product. One main result is that when two firms are of similar size and have access to similar resources, a higher probability of success in the NPD does not mean higher value for the firm since less uncertainty results in earlier investment, and the preemptive behaviour lowers the value of the investment opportunity for both firms.

The structure of this chapter is as follows: in the first section, I provide a general description around the role of suppliers into NPD; in the second section, I describe the role of uncertainty in NPD.

3.2 Role of suppliers

Many authors have investigated the role of early involvement of suppliers in NPD; however, there is still a lack of agreement on what a successful manufacturer-supplier relationship involves in a NPD project (Johnsen, 2009).

Depending on the needs of a firm, the degree of involvement of third-parties will change. It may be the case where the lack of knowledge or lack of capacity for a particular part of a NPD makes it more expensive to produce it within the firm than outsourcing it. The issue becomes to delimit rights and obligations between supplier and the original firm.

The first empirical studies that looked at the involvement of suppliers in NPD were done by Imai et al. and Takeuchi and Nonaka in the 1980s (Johnsen, 2009), in these papers the authors presented the results of seven case studies within five Japanese firms, concluding that the superior performance of these companies was due to their extensive supplier involvement in NPD projects (Johnsen, 2009).

Much of the advantage of Japanese manufacturers over their Western counterparts was associated with the supplier engagement from the very early stages of the NPD process, where it was calculated that around one-third of their advantage was due to this factor (Johnsen, 2009).

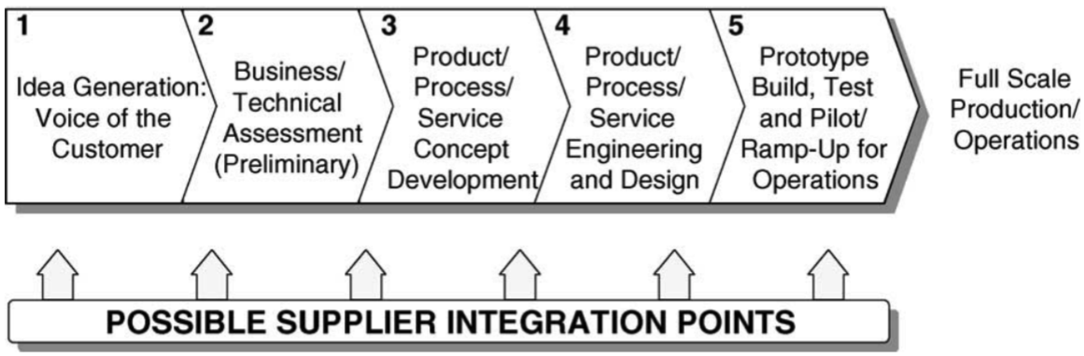
Nevertheless, some authors have recognised that a successful involvement of suppliers depends on the type of product, highlighting the need of customisation of supplier roles in product development (Laseter and Ramdas, 2002).

The weight a supplier plays in the NPD process depends on their capacity of investments in personnel and technology, prototyping facilities, and R&D capabilities (Kamath and Liker, 1994).

Suppliers can have a significant effect on cost, quality, technology, speed and responsiveness of the new product, in turn, effective integration at the right time of the cycle of NPD; thus, the appropriate role for each supplier may help the final manufacturer to achieve improvements to remain competitive (Handfield et al., 2002).

A supplier may get involved in different stages of a NPD, from the idea generation, when the last manufacturer is conceiving the idea considering the need of its clients, passing through the technical stages to finally arrive at the creation and development of the blueprint.

There are at least five different phases in a NPD process where a supplier can be involved (Figure 3.1).



Source: Handfield et al. (2005)

Figure 3.1: NPD development process

Various authors have shown the benefits of early supplier involvement are more significant when the technology uncertainty is high; however, such participation requires appropriate monitoring and joint measurements of targets, especially in the case where suppliers are given important responsibility in the project (Handfield et al., 2005).

Once we have recognised the stages where a supplier may get involved in a NPD, the question becomes in which degree they will be involved. The last manufacturer may retain all the rights and obligations of the outsourced part, and in this case, the supplier will act only as an extension of the manufacturer's capabilities.

It can also occur that the supplier responds to the manufacturer needs with or without the manufacturer's guidance, or major involvement where the supplier is a partner of the manufacturer, retaining the intellectual property of its part and having its technology, knowledge and capacity.

Recently Boeing's 787 case has been the subject of study since it shows an unconventional supply chain within the firm and the aircraft industry aiming to reduce costs and time (Tang & Zimmerman, 2009).

In the 787's project, Boeing changed its role to mere final assembler being the dominant player of the R&D phase of a tiered relationship with system/structural partners sharing costs and revenues. The Tier-1 partners were responsible for the design and outsourcing of their respective parts. In this way, Boeing lost the control of its Tier-2 suppliers, and also of the specifications of the components received from Tier-1 suppliers.

Table 3.1 presents a summary of the four primary roles a supplier can play in a NPD project, depending on their capabilities and on the type of responsibility they agree with their customer (final manufacturer). We can distinguish four major types of suppliers (Partner, Mature, Child and Contractual).

A supplier(s) involvement in a NPD presents several challenges for manufacturers and suppliers as well. Among the barriers, we can mention the unwillingness to share information and the difficulty to protect the intellectual property (Handfield et al., 2002).

	Partner	Mature	Child	Contractual
Design responsibility	Supplier	Supplier	Joint	Customer
Product complexity	Entire subsystem	Complex assembly	Simple assembly	Simple parts
Specifications provided	Concept	Critical specifications	Detailed specifications	Complete design
Supplier's influence on specifications	Collaborate	Negotiate	Present capabilities	None
Stage of supplier's involvement	Pre-concept	Concept	Post-concept	Prototyping
Component-testing responsibility	Complete	Major	Moderate	Minor
Supplier's technological capabilities	Autonomous	High	Medium	Low

Source: Kamath and Liker (1994)

Table 3.1: Supplier's role in NPD

3.3 Uncertainty in NPD

Uncertainties in technology and the market conditions are the primary sources of unpredictability in NPD projects (Wang and Yang, 2012).

Contract terms and conditions become more detailed and more explicit the greater the technical uncertainty (Adler et al., 2016). Not only the successful completion of the R&D process remains a major issue for projects that have high sunk costs, but also conditions on the market such as demand uncertainty and the competition they face.

Uncertainty can be decomposed into volatility and ambiguity (Carson et al., 2006):

- Volatility: refers to the rate and unpredictability of change in an environment over time, which create uncertainty about future conditions.
- Ambiguity: refers to inherent uncertainty in perceptions of the current environmental state irrespective of its change over time.

In many cases, manufacturers are reluctant to invest in spare capacity, since it could expose the firm to significant financial risk due to a high capacity cost linked to demand uncertainty, but by not doing so, they can face severe capacity shortages that could result in the undermining of its position in the market (Erkoc and Wu, 2005). Thus, investment in capacity by the supplier benefits the manufacturer when demand is uncertain as they are better positioned to respond to shocks (Gurnani et al., 2011).

Two main approaches can be used to motivate suppliers to invest in extra capacity (Carson et al., 2006): option contracts with guaranteed supply and firm order contracts.

- Option contract (with guaranteed supply) refers to the contract where the manufacturer (buyer) purchases an option to buy up any quantity, up to a pre-agreed limit, to the supplier. In this type of contract, the supplier faces both demand and supply, while the manufacturer minimises or avoids supply risk.

- Firm order contract refers to a conventional contractual agreement, with a well specified ex-ante quantity. In this type of contract, the buyer faces demand and supply risk since it is unlikely the supplier has spare capacity.

A pre-agreed quantity ensures that the needs of the buyer will be covered up to a certain limit, but this entails two risks for the buyer: if the demand decreases the buyer is obliged to buy the complete pre-ordered amount, if the demand increases there is no guarantee the supplier will be able to cover the excess of demand.

In the option contract, the buyer has more flexibility, while the supplier is the responsible for keeping the capacity to meet the buyer's demand. Even if the option contract, may sound as beneficial only for the purchaser, it may represent an opportunity for the supplier to expand its business, serving other buyers.

Technical and market uncertainty increases the complication of any NPD, even without the involvement of suppliers. In this sense, as conditions are changed, and new information arrives, managers face new choices to adjust the project to a better outcome (Jiang et al., 2013).

The real options analysis applies financial options theory to investment decisions under uncertainty, since it gives the right but not the obligation to get the present value of the expected cash flows by making an investment when the conditions are optimal (Wang and Yang, 2012). In Chapter 5, I will present in detail the aspects of real options analysis that consider the decision-making process of a firm that is engaged in an uncertain NPD process, faces competition and reacts to the changing market conditions.

A high degree of technology uncertainty is a characteristic of many NPD projects and can yield to a low average success rate for market launch, in this case, real options analysis is a suitable approach to improve R&D decisions as the project progresses and market conditions change (Wang and Yang, 2012).

Net Present Value analysis has been the standard tool to decide whether a project should be undertaken or not when the net worth of future profits exceeds the initial investment, the project is said to be rewarding. However, it does not recognise the changing conditions of the market, and once the decision is taken, there is no flexibility to stop or expand the project.

The use of real options has become a popular tool to deal with NPD since it provides flexibility to adapt projects as new conditions emerge, and can be tailored to incremental or radical innovations (Jiang et al., 2013).

Manufacturer-supplier relationships entail several aspects, not only to identify the phase where the supplier will be involved in the NPD process, but also the degree of rights and responsibility each will have. Suppliers are chosen to their capabilities and the extent in which they can adapt to the buyer's needs.

Suppliers can also benefit by expanding their knowledge and capacity. One early example is the one of Eaton Corporation who in 1986 entered an agreement with Ford to take the complete design and manufacture of an entire system. By that time, Eaton produced more than 90 percent of Ford's valves and lifters worldwide; this transition Eaton made from part-supplier to Ford's partner allowed them to improve their R&D capabilities and expanded their customer base to reach other firms (Kamath and Liker, 1994). In 2013, for three consecutive years, Eaton Corp. was among Thomson Reuters 2013 Top 100 Global Innovator, holding 10,510 patents in total and getting 874 patents only in 2012 [2].

The complexity increases when the uncertainty of the market is considered, the decision-making process is not as simple to compare predetermined future profits of the project with the cost of the project, because new information arrives every day and the demand conditions change continuously.

[2] http://www.eaton.com/Eaton/OurCompany/NewsEvents/NewsReleases/PCT_918223

Chapter 4

Using patents to assess different models of innovation: evidence from Boeing vs. Airbus

4.1 Introduction

New Product Development (NPD) involves several phases where a final manufacturer decides not only its internal R&D organisation but also the relationship with the suppliers and their respective degree of involvement in the project. As discussed in the previous chapter, the role of a supplier may range from a contractual one where simple parts are sold to the final manufacturer, to a significant partner in charge of an entire subsystem.

In the previous chapter, I discussed several aspects of the manufacturer-supplier relationship, where the mismatch of incentives creates the need for contractual and relational agreements to carry out a NPD efficiently. The optimal choice of the role of each supplier is vital not only for the completion of the product on time but also to ensure the financial stability of all parties.

One major approach in the management literature that has gained popularity if the so-called 'Open innovation', where the internal innovation system of a firm is complemented by the external knowledge that facilitates the access to new and complex ideas that could result in new technologies (Chesbrough, 2003).

Uncertainty about the outcome of a NPD and high costs of R&D phase require firms to join physical and human capital resources and to enter into cost-sharing and revenue-sharing contracts; moreover, some industries require high investments for R&D and commercialisation, and coordination about the final product characteristics due to the large stock of knowledge required (Bhaskaran and Krishnan, 2009).

Early involvement of suppliers provides advantages to the last manufacturers, but it may also mean unexpected high costs, slowing down of the NPD process, and it may provide very limited added value (Laseter and Ramdas, 2002).

The importance of this issue has been recently highlighted in the latest major aircraft project of Boeing and of Airbus, where each company decided to pursue different paths in their relationship with their corresponding suppliers in the NPD process.

On the one hand, Boeing's 787 project was based on an "open innovation" model, where the firm was conceived as the final assembler while outsourcing all the major components. On the other hand, Airbus' A380 project was done in a "closed innovation" model, where the firm was the designer, manufacturer and assembler of the aircraft.

In the present paper, I offer a detailed case study of each firm's models of innovation by using a unique patent database. This exercise is unique on its kind since by following the career of each inventor, I can make inference over each firm's innovation attitudes. In particular, I explore interesting features of Boeing's interaction path with other firms by examining the inventors' patent history.

The purpose of the present paper is to provide empirical evidence of the different innovation attitudes of Boeing and Airbus by tracking the careers of the inventors that have been present in at least one patent owned by any of these firms. By doing this exploration, I am able to show that Boeing's inventors have been present not only in the innovations of the same firm but also in the innovations of other firms, while been employees of Boeing, and that some other inventors have patents that are assigned to Boeing while they have never been employees of the company. I do not find this behaviour with the inventors involved in the patents of Airbus.

To my best knowledge, this is the first-time patents are used to provide evidence of a firm's innovation path. The main contribution of this chapter is that by looking in detail at each of these practices, I can analytically identify their R&D approaches by using patent information.

I also use information publicly released by Boeing and Airbus to make considerations about the history of the firms and the management of their latest major

NPD projects. The patent information comes from the USPTO and corresponds to patents issued only in the U.S.

Since manufacturer-supplier agreements are confidential, I am only able to explore the NPD process with the information publicly disclosed by each firm or by the government, and by the information, I get from the patent database.

Moreover, the detailed organisational structure is confidential along with the information of the military/space branch of each company. It is worth noting that this approach does not require the disclosure of all the information and may also be used in the opposite direction were by using patent information I can infer a significant part of the firm's innovation path.

The present case study serves as the motivation for the next chapter of this dissertation, where I consider that a NPD could potentially fail under a duopoly framework, and this failure may be due to the manufacturer-supplier agreements as discussed in this chapter. However, in the next chapter, I do not consider the possible circumstances that can affect the successful introduction of a new product into the market.

One major aim of this chapter is to analyse the case of a duopoly where each competitor has different approaches to a NPD major project, which has consequences in the delivery of the final product and the success of the R&D phase.

The present chapter is structured as follows: in Section 1, I present a description of the commercial aircraft industry; Section 2 provides the most important aspects of the models of innovation; in Section 3, I describe the methodology; in Section 4, I describe the database; Section 5, I use patent information to illustrate each model of innovation; Section 6 shows the relationship of each firm with their suppliers; and finally, I present the conclusions.

4.2 Commercial aircraft industry

To analyse the innovation attitude of a firm it is important to understand first where the organisational behaviour comes from. To do this, it is essential not only to comprehend the evolution and characteristics of the industry as a whole but also the history of each firm.

In this section, I examine the Commercial Aircraft (CA) industry and its current state briefly. Moreover, I analyse the records of Boeing Company and Airbus Group to place their current innovation models as a result of their evolution.

The CA industry has attracted academic consideration due to the unusual market structure, in which economies of scale are more than proportional relative to market demand (Irwin and Pavcnik, 2004). Also, unlike other technology-intensive industries, such as semiconductors, the product cycles are quite long (Baldwin and Krugman, 1988).

Baldwin and Krugman (1988) highlight that once a new aircraft model enters the market, the average cost falls significantly as the production increases, mainly because: i) the R&D expenditure can be spread, and ii) the production costs decrease with the learning curve.

Furthermore, the CA industry has been dominated for the last decades by two firms: Airbus Group (Airbus) and The Boeing Co. (Boeing). Both firms have proven quite different not only in the perceptions about the future of the passenger jets' size but also on the innovation path they have chosen. These management decisions have enduring consequences not only for the customers but also for the CA manufacturers:

1. Process from the design of the product to delivery may take well over a decade
2. The cost of each commercial aircraft is high within a range of 70 to 400 million USD, depending on the model [1] [2].
3. The customers of the CA -airlines- keep each aircraft for several years and once they choose one they are tied to the original manufacturer for the lifetime of the product mainly through the purchase of spare parts.

Even if the passengers are the final consumers, the real consumers for the aircraft manufacturers are the airlines. In this sense, the existence of different air routes creates a demand for aircraft with particular characteristics depending on the routes they serve (Baldwin and Krugman, 1988).

Airlines face short-run tactical and operational decisions, where the first type is focused on fleet planning (fleet commonality, purchasing price and service route structure), and the operational one is mainly focused on fleet assignment on a daily basis; in the long run, the airlines' strategy is affected by competitors, gov-

[1] http://www.boeing.com/company/about-bca/#/prices

[2] http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/new-airbus-aircraft-list-prices-for-2015/

ernment regulation, airport policies, and aircraft manufacturers (Hansen and Wei, 2007).

Hansen and Wei (2007) mention that Boeing has foreseen that in order to cover the growing demand, airlines will offer more frequencies as a primary form of non-price competition, and thus, they will need smaller and more efficient planes, while Airbus forecasts that airlines will use larger aircraft to meet increasing demand to tackle the lack of airport capacity.

It is well documented that Boeing and Airbus have pursued different marketing strategies and technical developments that have significantly influenced the emergence of different technological adoptions for commercial aeroplanes. Boeing has wagered to ensure continuity between its new models and older ones -a strategy of ”accommodation”- while Airbus has established fleet commonality (Ibnes, 2009).

Fleet commonality refers to one type of technology throughout all the equipment and allows the airline to buy multiple parts from a single seller, and to train all the staff in only one technology (Ibnes, 2009). For instance, Airbus announced the reduced pilot training program where ”a pilot flying Airbus; smallest aircraft, the A318, can be qualified to fly the A380 in 13 working days. It offers operators significant cost savings since training times can be halved compared to standard type rating courses [3]”.

Boeing continuity principle emphasises the use of the current knowledge of the aircraft crew, mainly the pilot, where the main idea is that new aircraft would

[3] http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/reduced-pilot-training-now-approved-for-the-a380/

behave as close as possible to the older one (Ibnes, 2009). In other words, Boeing tried to improve what already existed, while Airbus bet for a new technology path.

Airbus staked its future on new technologies to ensure a dominant position in the commercial aircraft market, and Boeing kept unchanged its airframe technologies and instead bet for improvements in material technologies (Lawrence and Thornton, 2005).

4.2.1 Boeing Company

The Boeing Company (Boeing) was founded by William Edward Boeing on July 15th, 1916, as Pacific Aero Products Company in Seattle and became the Boeing Airplane Company a year later [4]. Initially, the firm success was driven by their military production, but in the 1950s Boeing achieved great success in the CA with the introduction of the first jet airliner, the 707 (Kienstra, 2012).

The product expansion that Boeing successfully pursued along with its dual relationship of a civil and defence oriented product was crucial to Boeing's commercial success (Lawrence and Thornton, 2005). In 1991, a Congressional Office of Technology Assessment reported "The single greatest means by which U.S. government policy has affected the competitiveness of the commercial aircraft industry is in the procurement of military aircraft and funding of the related R&D. Of several ways in which the military side of the industry has advanced the commercial side, technology synergies are in the top rank of importance[5]".

[4] http://www.boeing.com/resources/boeingdotcom/history/pdf/Boeing_Chronology.pdf
[5] http://www.publications.parliament.uk/pa/cm200607/cmselect/cmtrdind/427/427we16.htm

After the Airline Deregulation Act was introduced in 1978 in the United States, the aviation industry in the country changed radically, and competition between airlines became an important factor, forcing also aircraft manufactures to compete intensely for costumers (Kienstra, 2012).

Due to the increasing pressure to gain and retain customers, Boeing merged with McDonnell Douglas Corporation (MDC) on August 1st, 1997 [6]. With this acquisition, Boeing became the last remaining major producer of commercial aircraft in the United States (Kienstra, 2012).

Before the merge, both Boeing and MDC were fully integrated aerospace firms, active in all aerospace sectors (commercial, defence and space)[7]

Under the Merger Agreement, there was a requirement that one-third of the new Boeing Board would be formed by former McDonnell Douglas directors[8].

In 2014, Boeing reported a net income of 5.4 billion dollars and 3 billion dollars of R&D expenses [9].

In 2014, 66 percent of the total revenues of the group corresponded to the commercial aircraft branch, and 34 percent to the military and space branch [10].

In 2016, Boeing aeroplanes represent about half of the world's fleet, with more than 10,000 jetliners in service [11].

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[6] http://www.boeing.com/resources/boeingdotcom/history/pdf/Boeing_Chronology.pdf

[7] http://ec.europa.eu/competition/mergers/cases/decisions/m877_19970730_600_en.pdf

[8] http://www.sec.gov/Archives/edgar/data/12927/0000950157-97-000394.txt

[9] http://investors.boeing.com/investors/investor-news/press-release-details/2016/Boeing-Reports-Fourth-Quarter-Results-and-Provides-2016-Guidance/default.aspx

[10] http://investors.boeing.com/investors/investor-news/press-release-details/2016/Boeing-Reports-Fourth-Quarter-Results-and-Provides-2016-Guidance/default.aspx

[11] http://www.boeing.com/resources/boeingdotcom/company/general_info/pdf/boeing_overview.pdf

4.2.2 Airbus Group

In response to the American dominance in the CA industry, on December 18th, 1970, Airbus was officially created, formed by France's Aerospatiale (a merger of SEREB, Sud Aviation and Nord Aviation), and Deutsche Aerospace (Messerschmittwerke, Hamburger Flugzeugbau, VFW GmbH and Siebelwerke ATG), and one year later, a third partner was added: Spain's Construcciones Aeronauticas SA (CASA)[12]. In 1979, the British BAE Systems acquired 20 percent of the shares [13].

In 1998, Aerospatiale was merged with CASA and became the European Aeronautic Defence and Space Company (EADS) [14]. In this way, EADS owned 80 percent of Airbus, while BAE Systems held the remaining 20 percent.

In 2006, EADS bought out the remaining twenty per cent from BAE Systems of the United Kingdom and was incorporated as a single joint stock company, Airbus Group [15].

The new unified firm grew rapidly and began to gain market share to Boeing in the CA industry. From 1995 to 2014, Airbus increased its share market from 18 to 49.5 percent [16].

Due to the success of Airbus, the consortium began to expand its line of business. In 1999, Airbus Military was set up with the first project to produce an Airbus military transport aircraft in consultation with some European governments

[12]http://www.airbus.com/company/history/
[13]Ibid.
[14]Ibid.
[15]Ibid.
[16]Market & Commercial Overview, January 2015, Airbus

[17].

In 2014, Airbus Group reported a net income of 2.3 billion euros and 3.4 billion euros of self-financed R&D expenses [18].

In 2014, sixty percent of the total revenues of the group corresponded to the CA branch, 21 percent of the military and space, and 10 percent of helicopters [19].

4.3 Models of innovation

In this section, I examine two major approaches in the innovation literature: in-house and open innovation. Boeing and Airbus have had a different innovation attitude since each comes from a distinct organisational history. On the one hand, Airbus was conceived as a collaboration among European countries to offset the American control of the CA industry, while Boeing has been for a long time one of the jewels of America's private firms with substantial government support.

The present case of study is focused on Boeing 787 and Airbus A380. Even if these two jets are not directly comparable because they represent a very different passenger capacity and technology, they are a clear manifestation of each firm's innovation philosophy. The focus of this paper is not to compare the performance of Jets or the market share for comparable commercial aircraft, but to present an analysis, through patent information, of a major NPD project and var-

[17] http://www.airbus.com/newsevents/news-events-single/detail/establishment-of-airbus-military-company-sas/

[18] http://www.airbusgroup.com/int/en/investors-shareholders/Publications/Annual-Report-2014.html

[19] http://www.airbusgroup.com/int/en/investors-shareholders/Publications/Annual-Report-2014.html

ious manufacturer-supplier agreements.

There are two main models of innovation: in-house or closed and open. Each of these models requires a difference governance method to align the incentives of the agents involved.

Firm specific factors		Environmental factors	
Innovation strategy	**Firm resources**	**Appropiability regime**	**Market dynamics**
Internal R&D	Financial constraints	Effectiveness of formal IP protection	Technological change
Acquisition of knowledge	Knowledge gaps	Effectiveness of strategic IP protection	Uncertain demand
			Competitive threats

Source: based on Drechsler and Natter (2012)

Figure 4.1: Degree of openness in innovation

The degree of openness in innovation varies from closed to a high level of openness. According to (Drechsler and Natter, 2012), four main factors affect a firm's decision of openness (Figure 4.1): innovation strategy, firm's resources, appropriability regime and market dynamics.

In the previous chapter, I analysed the governance in NPD projects where the mismatch of incentives and resources between manufacturer and supplier can cause delays and unforeseen costs for one or both parties. Depending on the degree openness a firm decides to pursue, the communication channels and property rights management may differ.

According to Felin and Zenger (2014), in the closed innovation model, there two main governance forms (authority-based hierarchy and consensus-based hierarchy) aimed only at organised the project within the firm since all the intellectual property of the NPD will remain with the focal firm; in the open model, there are four main governance forms where the intellectual property is either owned by one party and shared to the others or split among the participants (Figure 4.2).

	Firm/closed		Open innovation			
	Authority-based hierarchy	Consensus-based hierarchy	Markets/Contracts	Partnerships/ alliances/CVC	Contests/tournaments/ platforms	Users/communities
Communication channels	Vertical, socially embedded within firm	Horizontal, socially embedded within firm	Limited, selective invitations	Bilateral, socially embedded	Horizontal, broadcast, IT supported	Horizontal, socially embedded outside the firm
Property rights	Possessed by focal firm	Possessed by focal firm	Externally owned and exchanged	Negotiated	Varied (dispersed or focal firm)	None

Source: Felin and Zenger, 2014

Figure 4.2: Comparative analysis of governance forms

4.3.1 Open innovation: the case of Boeing

In January 28th, 2005, Boeing gave the 7E7 Dreamliner its official model designation number of 787, and it was early established that the project would be focused on keeping down the development and manufacturing costs [20].

To increase the share of revenue from each jet sold, Boeing's Board introduced a strategy where suppliers would become partners and finance and produce whole sections of the 787. Initially, the target was that Boeing would make 30 percent of all the components of each aircraft and buy 70 per cent[21].

Hart-Smith (2001) presented a now well-known paper introducing the case of Boeing's open model of innovation. In the document, Hart-Smith describes the potential problems of outsourcing in a firm such as Boeing, arguing that the major hurdles to overcome are:

[20]http://www.businessweek.com/articles/2013-01-24/boeings-787-dreamliner-and-the-decline-of-innovation

[21]http://www.businessweek.com/articles/2013-01-24/boeings-787-dreamliner-and-the-decline-of-innovation

- Prime manufacturers cannot afford to have expensive facilities that are underutilised, even if it represents savings for future derivative work.

- There are documented cases where outsourcing was directly accountable for the total re-manufacture of the parts prior installation on the final product, either because the specification changed during the NPD process or due to the lack of knowledge and/or technology of the suppliers, increasing the costs for both the final manufacturer and its supplier significantly.

According to Boeing Chief Technology Officer, Jim Jamieson, each year the firm invests about 4 percent of its total revenue in R&D that along with the contracts in R&D provides a substantial R&D budget for the firm[22].

Boeing distributes its R&D budget among[23]:

1. Business units: each unit focuses on the immediate needs for product and process development and improvements;

2. Phantom Works: a centrally managed advanced R&D unit which focuses on providing systems and technologies that will benefit products across all the business units (short and long term). It focuses on technologies that do not have an immediate connection to a product and are further out from production or implementation.

3. Enterprise initiatives: each one concentrates on common processes and systems which are intended to help business units and general functions of the

[22] http://www.boeing.com/news/frontiers/archive/2005/july/cover.html
[23] Ibid.

company.

To allocate the R&D resources, Boeing uses a technology prioritisation process to determine what will be worked on. First, Commercial Airplanes and Integrated Defence Systems leaders assess what technology needs they have and share this information with Phantom Works [24].

The above means that Business units usually take the lead on the short-term innovation projects while Phantom Works provides support through its nearer-term work; however, Phantom Works is a business unit aimed to take risks in developing and testing new technologies, with the goal of discovering potential issues before the business units apply the new technology [25].

Hart-Smith (2001) highlighted that in the 1970s Phantom Works (part of Douglas Aircraft Company) first adopted an implicit open innovation model when the directives realised that its under-utilised facilities could serve outside customers for the kind of work that only aerospace workers were able to provide; by doing this, the gap between revenues and salaries of its workers was narrowed because the firm would add innovative work to retain skilled workers, even if that meant diversifying into non-traditional technology areas.

After the merging with McDonnell Douglas in 1997, Phantom Works -which was the R&D heart of McDonnell Douglas- became the general technology generator of Boeing to improve manufacturing processes around the group[26].

The term of "Open Innovation" was formally introduced in the literature by

[24]Ibid.
[25]Ibid.
[26]http://www.economist.com/node/343468

Henry Chesbrough in 2003 and its main feature is that "enterprises can and should use external ideas as well as internal ideas, and internal and external paths to market, to discover and realize innovative opportunities "(Chesbrough et al., 2008).

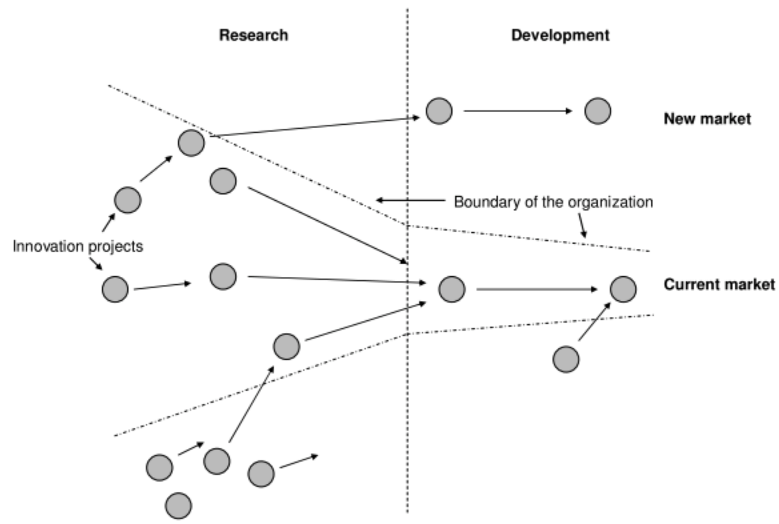
Dr. Atkins, Vice-President of Product Application Technology with the McDonnell Douglas Aerospace Company and Vice-President of Technology and Define Process for Boeing Corporation at Phantom Works, provides a good description of how this philosophy would work on the inventors' intention "*that took away the fear that if they produced something really good, they would have to leave the Phantom Works. They would leave for a little while and then they would come backwe had the assurance that the individual wouldn't lose their job within the research area by transferring the technology and going with it for a while until it got put well into place*"[27].

In the open model, firms manage their Intellectual Property (IP) in a different way, taking care that these innovations have legal protection. These innovations are usually patented to avoid being blocked or held up by other firms and to prevent their rivals from using them. Thus, in the open model, firms not only need access to outside IP to accelerate their research, but also, they own an IP portfolio that may be profitable and as alternative source of income since they may license out to external partners who can use the technology in exchange for paying royalty fees (Chesbrough, 2006).

Chesbrough et al. (2008) highlight that to adopt the open model does not mean that in-house R&D has to become obsolete, it remains essential as the main source to develop new products and is indispensable to exploit the absorptive capacity

[27]http://iweb.tntech.edu/ll/atkins.htm

of the firm and apply new external knowledge; ideas are still generated inside the firm, but may go out to external markets through third-party channels that are outside the current businesses of the firm (Figure 4.3).



Source: Chesbrough et al., 2008

Figure 4.3: R&D in open innovation model

Boeing, like any other large enterprise, does not patent all its inventions. Innovations that are observable on products and services or the ones that can be easily duplicated are the main candidates for protection. However, Boeing often decides not to patent many military-specific innovations or innovations that can actually be protected as trade secrets[28].

Peter Hoffman, Boeing's Vice President of Intellectual Property Management, provides the company's approach to IP management "*Boeing's portfolio of IP assets our trademarks, copyrighted material, patents and trade secrets is a corporate asset[...]currently*

[28]http://www.wipo.int/wipo_magazine/en/2014/01/article_0004.html

our licensing activities, which are substantial and expanding, are primarily focused on the companies in our supply chain and the partners with whom we produce aircraft [...] we are very good at packaging and delivering our technology in this way and this is one of the key discriminators for us in the market [...] Staying at the cutting edge of technology is very expensive. At Boeing, we try to mitigate these costs by striking up business relationships with companies and researchers trying to solve the same problems we face. We co-invest in this research and share the results, which makes it more affordable for both parties"[29].

4.3.2 Closed innovation: the case of Airbus

The traditional R&D model is the "Closed Innovation" model, where firms rely on the investment made in in-house R&D, which is meant to lead to breakthrough discoveries, which will allow later to produce new products, to have higher revenue margins and then to reinvest in a domestic innovation (Chesbrough, 2003).

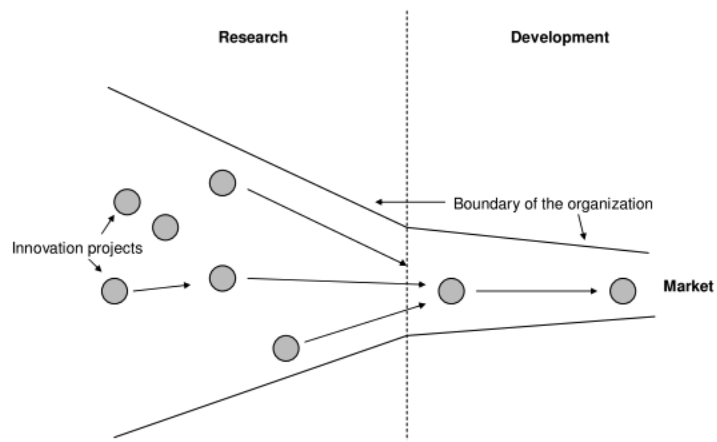
On December 18, 2000, Airbus presented its newest model, the A380. This aircraft was the world's first double-decker passenger aeroplane and the largest passenger aircraft ever conceived (carrying around 555 passengers). In this way, Airbus aimed at the major long-haul routes [30].

In the closed innovation philosophy, usually, ideas that are not well aligned with the needs of the firm can remain on the shelf for a long time, waiting for internal development which can lead inventors to leave the firm and develop their ideas on their own; moreover, in this model enterprises should introduce innovations by themselves; while in the open model there are many potential ways to

[29] Ibid.
[30] http://www.airbus.com/newsevents/news-events-single/detail/a380-launch/?type=310

exploit the knowledge (Chesbrough et al. 2008).

This model of innovation considers an in-house research process where the innovations are managed and fully developed within the firm (Figure 4.4) until the products are delivered to the market (Chesbrough et al., 2008).



Source: Chesbrough et al., 2008

Figure 4.4: R&D in closed innovation model

Firms, where the close model prevails, are dependent mainly on patents to protect their innovations and new technologies. However, due to labour mobility, enterprises are facing problems with keeping their knowledge secret (Chesbrough et al., 2008).

Airbus has followed for a long time a closed model and only until recently the Board has been moving towards an open model. Airbus has focused mainly on in-house development in close cooperation with a certified supply base, where the preferred innovation activities are the ones that support the company's corporate strategy (Bader and Enkel, 2012).

Due to the difficulties to maintain the knowledge internally and to exploit efficiently new technologies, Airbus has announced a path towards a more open innovation model in the next few years. In 2007, Airbus established a project to allow for new initiatives that could end in the development of new businesses. Otto Gies, EADS Vice President of R&D Strategy and New Business, describes this new approach as *"in such in-house venture capital initiatives, a systematic process assists the employees with the development of novel business models and to stronger capitalize the company's internal knowledge base"*[31].

4.4 Methodology

In the present chapter, I use a novel approach to finding evidence of the different models of innovation Boeing and Airbus have pursued. I gather an original database of inventors who have been registered as inventors in at least one issued patent whose Assignee[32].

The primary source of information is the database of patents of the United States Patent and Trademark Office (USPTO).

The methodology to create the database is as follows:

1. Obtain all the patents in the USPTO whose Assignee is either Boeing or Airbus, during 2000 and 2009.

[31] http://performance.ey.com/wp-content/plugins/download-monitor/download.php?id=225

[32] According to the USPTO, an assignment of a patent, or patent application is the *transfer to another of a party's entire ownership interest or a percentage of that party's ownership interest in the patent or application. For an assignment to take place, the transfer to another must include the entirety of the bundle of rights that is associated with the ownership interest, i.e., all of the bundle of rights that are inherent in the right, title and interest in the patent or patent application*

2. Extract a list of all the inventors involved in each patent of the list (i).

3. From list (ii), per inventor, obtain from the USPTO database all the patents in which he/she appears registered as inventor, in the period January 1976-January 2014.

4. From list (iii), per inventor, order his/her patents chronologically according to the patent application date.

It is worth noting that with this patent database, I am not able to identify the magnitude of the contribution of open innovation to the total innovation of Boeing. In Chapter 1, discussed the fact that not all innovations are patented and patentable, and one may probably argue that many of the real advances in the research within a firm are kept as secrets instead of being filed for patent protection immediately.

It is also important to mention that the re-codification of the name of the Inventors, between the step (ii) and (iii), was done carefully. The challenge was to homogenise all the different names that correspond to only one person. For example, if the original information extracted from the USPTO database recorded patents to Joe E. Smith, J.E. Smith, J. Ernest Smith, and Joe Ernest Smith one had to look for each of the variations to discern which patents corresponded indeed to the person in question and record all of them under one name. The same with other variations such as Dave and David, Bill and William.

Another important task when making the list of inventors was to check one by one whether the same name did not correspond to two different people. In this sense, I looked for the information of each inventor online to check whether they have been mentioned as employees of the corresponding firm. When I was not able to differentiate effectively, I decided to drop the name of the inventor. However, this was not a major incident that could alter the representativeness of the database significantly.

A relevant consideration was to homogenise the name of the Assignees. For instance, Boeing Co., The Boeing Company, The Boeing Co. Boeing, where all recorded as Boeing. The above results convenient in a later stage of the analysis when one is interested in analysing whether a person appears in patents registered to only one Assignee or more than one.

4.5 Data description

The database includes information about the patent that is displayed on the USPTO website. In contrast to Chapter 2, where I am interested in identifying whether there is a difference in a patent's forward citations between two types of assignees (universities and private firms). The goal is to use the information a patent provides for forming links between two agents through the interaction of inventors.

When two or more inventors are listed, it is not straightforward to separate the contribution of each one in the final invention. The USPTO considers this issue as follows [33]: '*Inventors may apply for a patent jointly even though (1) they did not physically work together or at the same time, (2) each did not make the same type or amount of contribution, or (3) each did not make a contribution to the subject matter of*

[33] http://www.uspto.gov/web/offices/pac/mpep/s2137.html

every claim of the patent'. Due to this ambiguity, I am not able to identify, whether a link between two firms is due to formal collaboration or because the inventors relate to each other outside the firm.

Variable	**Description**
1. Number of patent	Unique number assigned to applications that have issued as patents
2. Original assignee	Name of the individual or entity to whom ownership of the patent was assigned at the time of issue
3. Inventor(s)	Name of the individual(s) who conceived the invention
4. Application date	Date when a complete application was received by the USPTO
5. Publication date	Date the patent was officially issued by the USPTO
6. Examiner	Name of the primary examiner responsible for examining the patent application
7. Agent/Attorney	Name of the legal representative of the patent applicant
8. Referenced cited	Number of patents that correspond to prior-art
9. Referenced by	Number of patents that have made use of an existing patent, either by the same Assignee of by a third party.

Table 4.1: Variables of database

It is important to note that in this database, the majority of the patents are published with one single inventor. However, 68 percent of the patents is published with a single-inventor, 19 percent corresponds to a two-inventor patent, and only 7 percent to a three-inventor patent (Table 4.2).

Number of inventors	Number of patents	% of total patents
1	4010	68
2	1116	18.9
3	463	7.4
4	169	2.9
5	80	1.4
6	47	0.8
7	9	0.2
8	15	0.3
9	4	0.1
10	3	0.1
11	3	0.1
12	7	0.1
13	1	0

Table 4.2: Number of inventors per patent

The novelty of the original approach I use in this chapter is that I can track the patent-career of the inventors. To do so, one should be able to identify whether they have been involved in Boeing or Airbus or more firms, because Boeing and Airbus have suffered merges, and acquisitions, I decided to gather the subsequent assignees into:

- Boeing: HRL Laboratories, McDonell Douglas, Hughes Aircraft, and Rockwell International.
- Airbus: Aerospatiale Mantra Airbus, Deutsche Aerospace Airbus, EADS Airbus, Aerospatiale Societe Nationale Industrielle, Societe Nationale Industrielle et Aerospatiale, and Messerschmitt Boelkow Blohm.

In this sense, if one inventor appears originally with patents of McDonell Douglas and Boeing, he was categorised as 1 in ”Dummy Boeing/Airbus”.

I recorded a categorical variable ”Dummy Boeing/Airbus” that takes the value:

Value	Description
1	All the patents of the inventor are assigned to Boeing (Only Boeing).
2	All the patents of the inventor are assigned to Airbus (Only Airbus).
3	At least one patent of the inventor is assigned to Boeing, but he/she also appears in at least on patent whose assignee is other than Boeing (Mixed Boeing).
4	At least one patent of the inventor is assigned to Airbus, but he/she also appears in at least on patent whose assignee is other than Airbus (Mixed Airbus).
5	At least one patent of the inventor is assigned to Airbus and at least one patent is assigned to Boeing (Boeing & Airbus)

Table 4.3: Dummy Boeing/Airbus values

There are 1263 different inventors in this database, from them 68 per cent appear only in patents registered to Boeing, while 8 percent appear only in patents registered to Airbus(Table 4.4). Also, the inventors of 'Mixed Boeing' category represent 21 percent of all the inventors, while the 'Mixed Airbus' inventors are 1.5 percent of all.

Only one inventor appears to work for Boeing and Airbus (Sarh Branko), involved in 41 different patents: five for Airbus, 31 for Boeing, one for Rhor Industries and four as an Individual. Thus, there are no links between Airbus and Boeing within this database.

With the current information, I am not able to distinguish whether this division between the inventors of Boeing and Airbus is due to employee contract clauses or because there is no voluntary mobility among the workers.

Dummy Boeing/Airbus	Number of inventors	% of total
Total	1263	
1: Only Boeing	860	68.1
2: Only Airbus	104	8.2
3: Mixed Boeing		
3.1: Simultaneous patenting	145	11.5
3.2: Switching of employer	101	8.0
3.3: Never with Boeing	27	2.1
4: Mixed Airbus	19	1.5
5: Boeing & Airbus	1	0.1

Table 4.4: Type of inventor

Moreover, almost all the firms in which inventors that have changed from or to Airbus are based in Europe. [34]

There are 452 different firms, academic institutions, government agencies or private enterprises that appear in the database. Only by focusing in the inventors ”Mixed Boeing”, there are 414 different firms apart from Boeing. Firms involved with the inventors ”Mixed Airbus” are only 38 including Airbus.

Among the firms of the database, 14 of them are within the Top 100 Arms-Producing and Military Services Companies in the world [35]. Boeing and Airbus are ranked second and 7th, respectively. These results are evidence that both firms

[34] Agilent Technologies (US), Aixtron, BAE Systems, Bouygues, Brennstoffinstitut Freiberg, Calor, Degussa Huls, Deutsches Zentrum fuer Luft und Raumfah, Dornier, Duennebier Maschinenfabrik, Enthone, Fresenius, Fresenius Kabi Deutschland, Forschungszentrum Informationstechnik, Infineon Technologies, Kid Systeme, Leopold Kostal, Liebherr Aerospace Lindenberg, Mannesmann, Max Planck Society, Messerschmitt-Blkow-Blohm, Messier-Bugatti-Dowty, Moeller, Philips Electronics (US), Procter and Gamble (US), Robert Bosch, Rowenta Werke, Rubbermaid, SAP AG, Siemens, Smith Corona/Acer (US), Stmicroelectronics, Thyssen, Virtual Forge (NL), Volkswagen, von Ardenne, and Winkler Duennebier.

[35] http://www.sipri.org/research/armaments/production/Top100

do not only compete for the commercial aircraft market, but also on the military market.

Boeing/Airbus	Number of patents that have cited each patent							
	Mean	Std. Dev.	Percentiles					Max
			10th	25th	Median	75th perc	90th perc	
Total	10	16	0	0	5	15	26	270
1: Only Boeing	10	15	0	0	5	15	26	172
2: Only Airbus	7	10	0	0	2	11	18	84
3: Mixed Boeing								
3.1: Simultanous patenting	9	14	0	0	3	13	24	121
3.2: Switching of employer	11	17	0	0	6	15	26	262
3.3: Never with Boeing	13	19	0	0	7	17	32	270
4: Mixed Airbus	9	18	0	0	2	12	25	108
5: Boeing & Airbus	11	13	0	0	6	16	27	49

Table 4.5: Descriptive statistics: forward total citations (referenced by)

In Table 4.5, I present some descriptive statistics of the variable "Referenced by". Patents of inventors who have only registered inventions to Boeing have on average 11 further total citations, while the patents of the inventors "Only Airbus" have on average seven further citations. This same difference can be seen in the patents of the "Mixed Boeing" category with an average of 11 further citations, while on average the patents of the inventors "Mixed Airbus" received nine further citations.

Also, patents of inventors that have at least one patent for Boeing (type 1 and 3) have a median and a maximum number of citations higher than their Airbus counterparts (type 2 and 4) (Table 4.5). However, I am not able to distinguish whether these forward citations are self-citations, where the assignees are internalising their inventions, or third parties are using them.

4.6 Using patents to monitor models of innovation

In Chapter 1, I described how patents represent one good proxy to measure innovation. Moreover, I also explained how patents entailed hidden information about the innovative path that led to them. In this chapter, I make use of the abundant information, explicit and implicit, a patent holds to draw links between inventors.

I am particularly interested in the information that the category ”Mixed Boeing” sheds about the behaviour of Boeing. As discussed in this chapter, Boeing has been recently characterised for its open innovation model, where the knowledge comes and goes through different mechanisms.

With the unique database, I built for the purpose if this chapter, I can recognise whether an inventor has applied for a patent in one or more *Assignee(s)* (legal owner(s) of a patent). I use this information to link the inventors' careers and each firm's model of innovation

4.6.1 Patent-careers and the relationship with the model of innovation

By analysing the behaviour of the ”Mixed Boeing” inventors, evidence emerges of the open innovation model that Phantom Works (Boeing) has followed. Within this group of inventors there are three sub-groups:

(a) Inventors that had indeed moved from one job to another, and have patented in each of these jobs, including when they were employees of Boeing.

(b) Inventors that have never been employees of Boeing, but appear as inventors of patents registered to Boeing.

(c) Inventors that have been employees of Boeing, while patenting with other firms or individually.

The mere existence of groups (b) and (c) represents evidence that Boeing has used an open innovation model, where they have either used external knowledge or let their employees to patent somewhere else while being employees at Boeing.

It is relevant to state that the inventors ”Mixed Airbus” only appear with a patent registered to another firm other than Airbus, when they have in fact moved from Airbus or if they have never been Airbus' employees, not while being still in Airbus. In this group, there are no sub-groups, unlike the case of Boeing, which matches with a Closed Innovation Model.

4.6.2 Bringing external knowledge

It is relevant to explore case *b) Inventors that have never been employees of Boeing, but appear as inventors of patents registered to Boeing*, since this group is characteristic of the R&D management of Boeing only. Natural questions arise from this subgroup of inventors, for example, i) where did these inventors come from? and ii) have there been any structural changes of the choice Boeing did when bringing external knowledge?

In this subsection, I present the interaction between Boeing and the source of the external knowledge/innovation, first by observing the whole period (Figure

4.5) and then by breaking it into waves to account for any structural change in the choice of these sources.

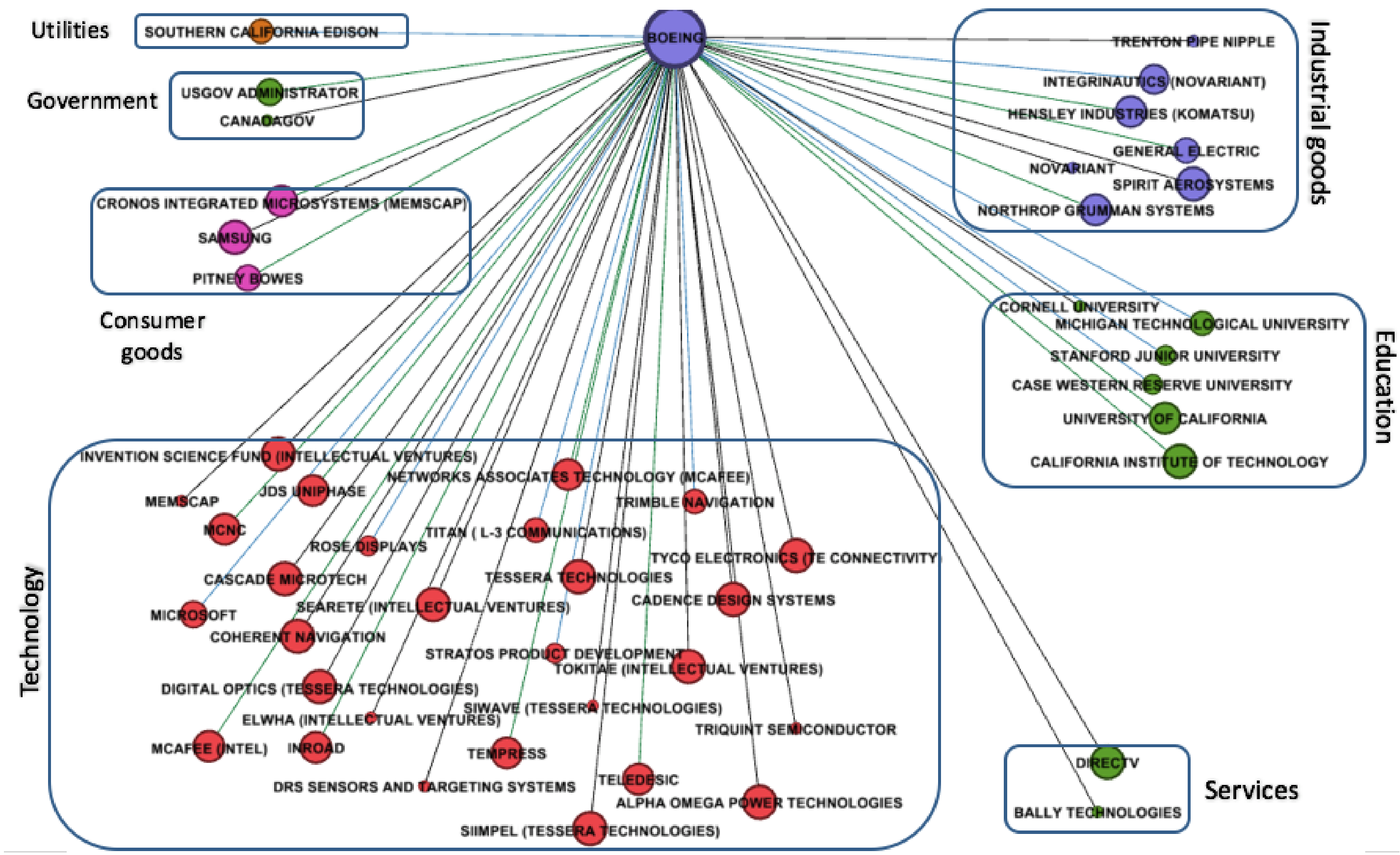


Figure 4.5: Boeing's external sources of innovation: 1971-2013

There is one remarkable result that come from the analysis, we identify the sources of the external knowledge that Boeing has either financed or bought. Figure 4.5 shows all the firms for the whole period 1971-2013.

As one may expect, the majority of the external knowledge comes from firms of Technology and Industrial Goods Sectors. However, there is a good proportion that represents Universities. It is natural that a firm such as Boeing has used technology made on research centres of Universities, either by paying the license to use the invention or by funding a project with a specific technological target.

Between 1986 and 1990, Boeing has only relationship four other entities, where one of them is the U.S. government (Figure 4.6), while in 1991 to 1994 the relations increased both in number and variety, increasing mainly the interaction with universities and technology firms (Figure 4.7).

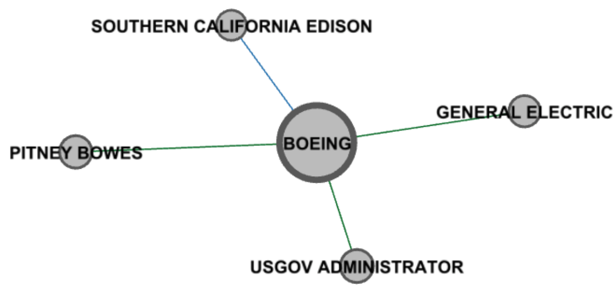


Figure 4.6: Boeing's external sources of innovation: 1986-1990

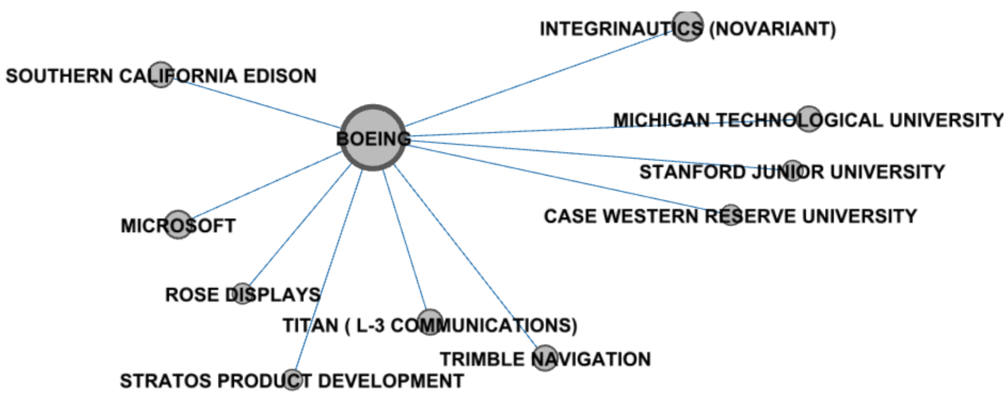


Figure 4.7: Boeing's external sources of innovation: 1991-1995

Breaking the whole period into sub-periods, it results evident that after the merge of McDonell Douglas and Boeing in 1997, the numbers of relationships with external sources increased (Figure 4.8).

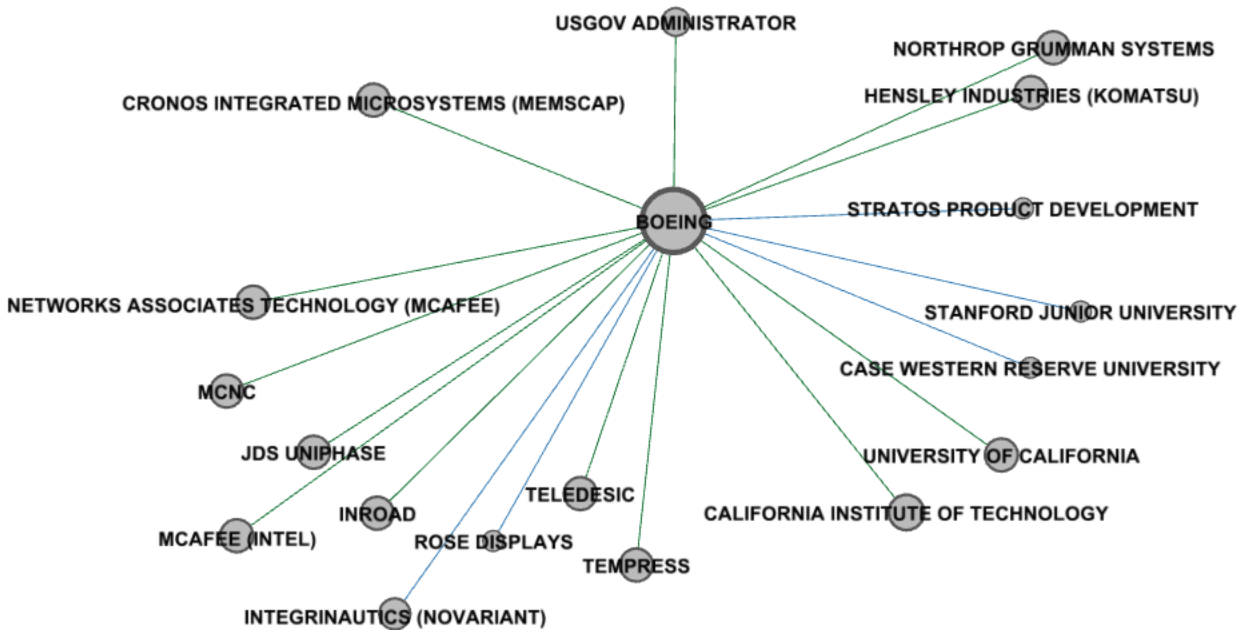


Figure 4.8: Boeing's external sources of innovation: 1996-2000

If it is well known that at least part of the former board of McDonell Douglas became key players in the decisions of Boeing, one may expect that after some years and once Boeing have absorbed all the patents, the increase of external sources will continue to diversify, and this is the pattern that emerges when we observe the external sources of innovation for the period 2006-1010 (Figure 4.9).

I have exemplified with this analysis that by focusing on the patent information it is possible to construct a patent-career of all the individuals involved in Boeing's invention (employees or not) to extrapolate the R&D behaviour of the entire firm, even if the information about partnerships, payment of royalties or sponsorship is not/partially disclosed.

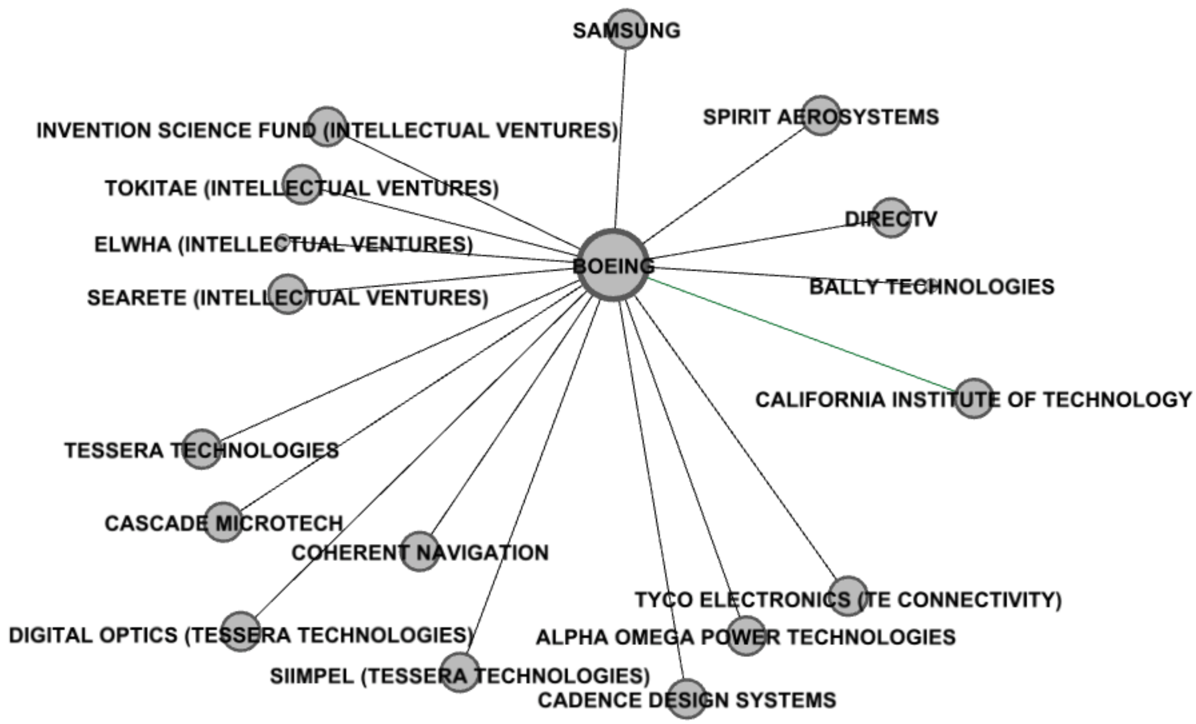


Figure 4.9: Boeing's external sources of innovation: 2006-2010

4.6.3 Simultaneous innovation with other agents

Boeing's open model of innovation is mainly managed by its central R&D unit, Phantom Works. In this sense, it is through Phantom Works that different strategies to build Boeing's IP portfolio have been applied. Among the most important ones are:

1. Let their engineers develop their ideas outside of Boeing. Some of these start-ups have counted with Boeing's financial sponsorship, and in other cases, they have been individual entrepreneurship.

   - Gordon Alward and Robert DiChiara founded GEO2 Technologies in

2004, a clean-energy start-up privately financed. DiChiara has been an employee of Boeing since 1989 uninterruptedly [36]. The dataset shows that individual innovations made by Boeing's employees are not assigned to Boeing.

- Nitinol Technologies (later NDC Technologies) was founded in 1991 and owns several patents over Nitinol material. Since 1996 Boeing's engineers have been working along with NDC on the research to use the material on aircraft [37]. The dataset of this paper gives evidence that, even if Boeing has been financing part of the research, it has kept some of the patents while others have been assigned to NDC.

2. Some outside firms or the government of the USA have commissioned Boeing with particular innovations. Boeing uses its workforce to perform such tasks.

- US Government has been the main financial supporter of Boeing, since the creations of the firm. Boeing relies heavily on the R&D subsidies it receives from the Government. For instance, government funds were provided for specific research into composite technology that apart from having a military and space use, it has also been implemented on the 787 airframe [38]. The dataset shows that in these cases the patents that result from the research is assigned to Boeing's customer.

[36] According to its Linkedin information.
[37] http://www.boeing.com/news/frontiers/archive/2006/march/i_tt.html
[38] http://trade.ec.europa.eu/doclib/docs/2010/september/tradoc_146503.pdf

3. Boeing has established partnerships with other firms (government, universities or research centres) to develop a new technology and both firms share engineers to carry out the project.

    - United Technologies Corp formed Pratt & Whitney Rocketdyne in 2005, by the acquisition of Rocketdyne Propulsion & Power, fully owned by Boeing Company, and Pratt & Whitney's space propulsion business [39]. The dataset shows that Boeing worked with Pratt & Whitney before the merging and continued doing so after United Technologies acquired it. Also, the dataset shows that the link between Rocketdyne's employees remained after United Technologies bought the firm from Boeing.

This database provides empirical evidence of the organisational change in the way Boeing interacted with other firms after it adopted the Open Innovation when it replaced its main R&D unit for Phantom Works.

As discussed in a previous section of this chapter, when Boeing acquired McDonnell Douglas the R&D unit was replaced by Phantom Works who was already using the open innovation model. Thus, we observe a breakthrough in the simultaneous inventions once this change happened.

We find a substantial increase not only in the number of entities with which Boeing was interacting but also in the variety of technologies it was approaching. Before the acquisition of McDonell Douglas, the number of Boeing's interactions with other firms was small (Figures 4.10 and Figure 4.11).

[39] http://www.pw.utc.com/Where_Weve_Been

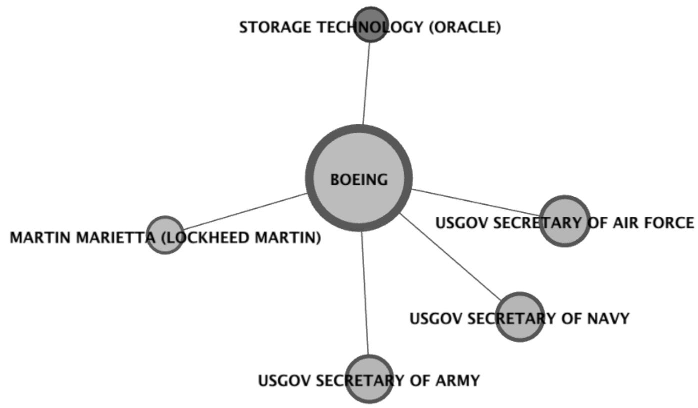


Figure 4.10: Boeing's simultaneous inventors: 1971-1985

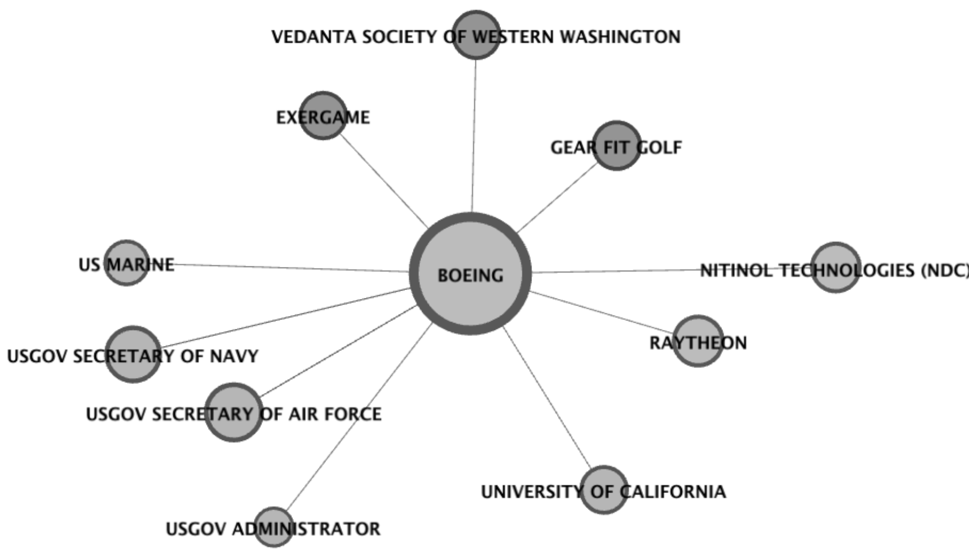


Figure 4.11: Boeing's simultaneous inventors: 1986-1995

In the first four years after the acquisition, the number of interactions increased, mainly because of the addition of McDonell Douglas' patents to Boeing's patent portfolio and also because Boeing began explicitly to use open innovation themselves (Figures 4.12 and 4.13).

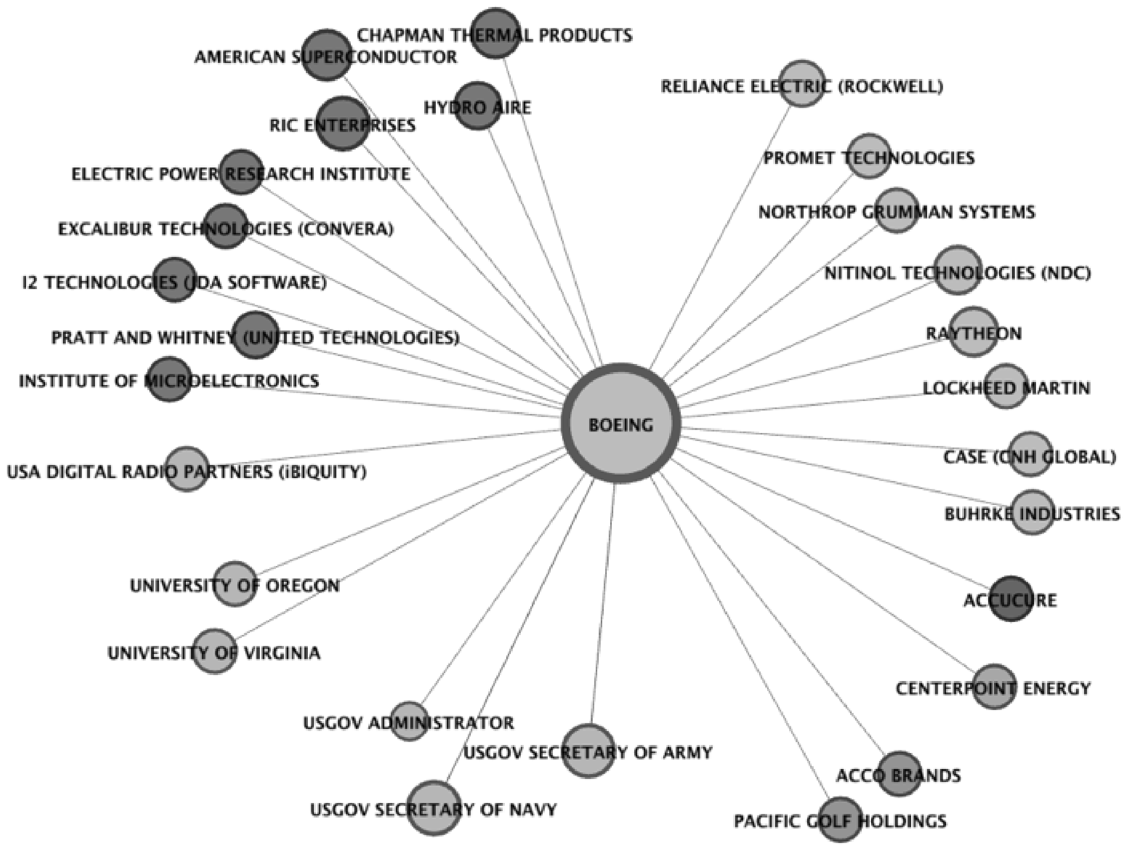


Figure 4.12: Boeing's simultaneous inventors: 1996-2000

Some of the firms that appear with the inventors that have simultaneously patented with Boeing are small, but highly specialised ones, such as Breeze Torca or GEO2 Technologies.

It is interesting to note that in the simultaneous innovation, some of the firms that appear in Figure 4.13 are ownership of Boeing's employees as I discuss in this Chapter. As of the involvement with the government this is mainly through the Secretary of Navy and Secretary of Army which is consistent with Boeing's history of heavy government support.

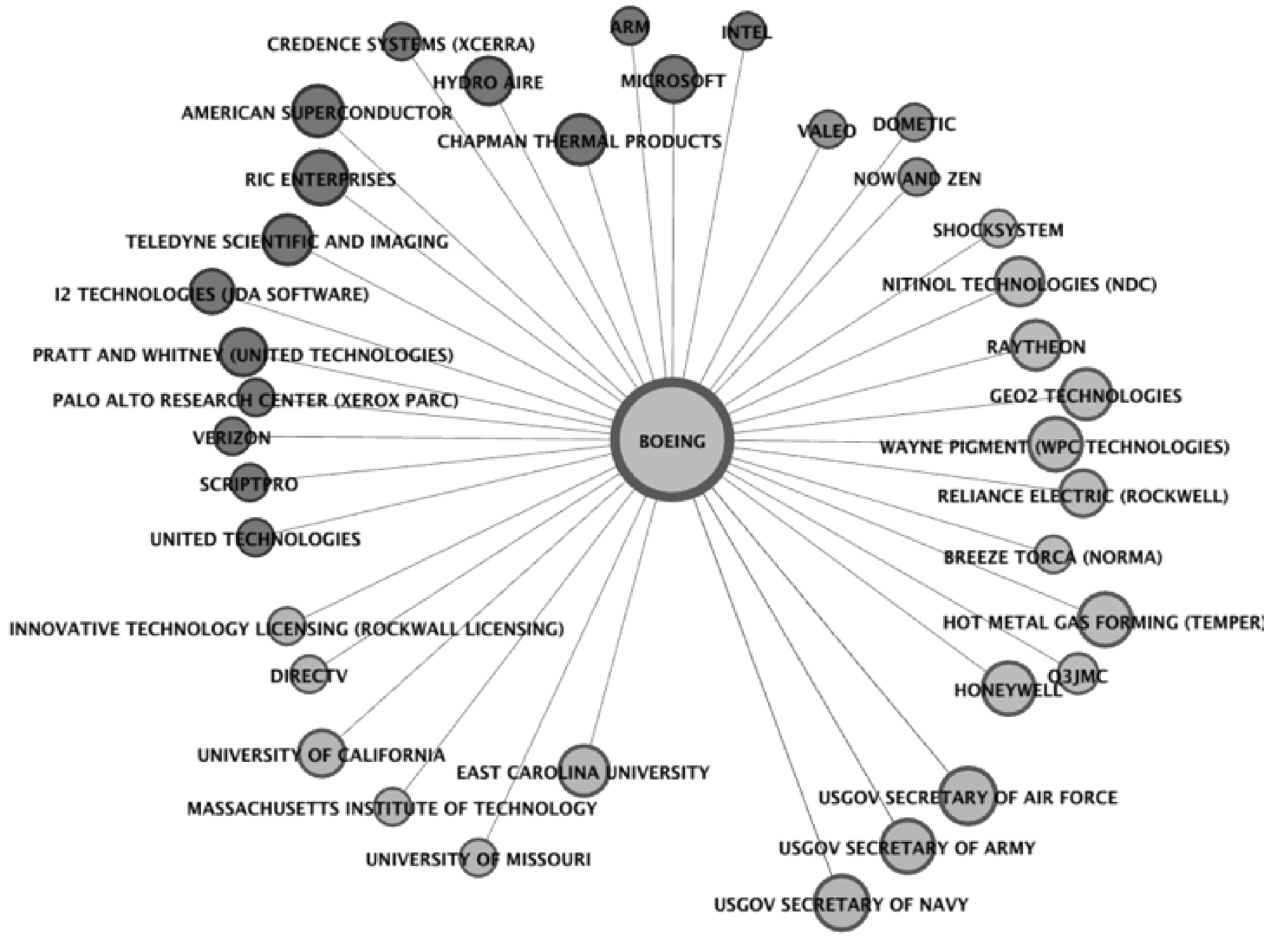


Figure 4.13: Boeing's simultaneous inventors: 2001-2005

4.7 Relationship with suppliers and implications

In the previous chapter, I analysed the different supplier's relationships a NPD involves where the range spans from a small supplier that only delivers specific parts and does not entail any R&D on its own to a partner that owns and designs entire sections of the project.

In this section, I describe the supplier contracts that Boeing and Airbus pursued to their latest major NPD projects. Moreover, I discussed the main differences and their corresponding implications in the outcome of the projects.

4.7.1 Boeing 787

Boeing introduced new ”risk sharing” contracts with its Tier-1 suppliers, those who interact directly with them. In fact, Boeing outsourced 70 per cent of the development and production of the 787 project, to shorten the development time and keep the cost down (Tang & Zimmerman, 2009).

Under the 787 program, Boeing remained mainly a ”System Assembler”. According to information of Boeing, for the first time, they outsourced the complete design and production of:

- Nose-and-cockpit section was outsourced to Spirit (USA)
- Forward fuselage was outsourced to Kawasaki (Japan)
- Centre fuselage was outsourced to Alenia (Italy)
- After fuselage was outsourced to Vought (USA)
- Wings mainly outsourced to Fuji, Kawasaki and Mitsubishi all of them from Japan and to KAL-ASD (Italy)

Tang & Zimmerman (2009) describe the main differences of the new contracts were Tier-1 suppliers were for the first time responsible of:

- Making the necessary upfront costs for the project.
- Designing and producing entire sections of the plane.
- Choosing their Tier-2 and Tier-3 suppliers.

Apart from the differences mentioned above, Tier-1 suppliers entered an agreement with Boeing, and they agreed to receive payment until the first aircraft was delivered with a pre-negotiated price per unit, receiving a profit proportional to Boeing's total profit (Shenhar & Zhao, 2016).

The main incentive for entering into such agreements was that Tier-1 suppliers were allowed to keep the IP of their part of the project, that ensured them that they would not be replaced in later stages and that since they were the owners of the technology they could commercialise or sell the technology on their own (Tang & Zimmerman, 2009).

Under the new scheme proposed by Boeing there was not only the need for coordination between them and its Tier-1 suppliers, but also to ensure that Tier-1 suppliers have the technological capability, production capacity, and financial stability to keep the project on track.

Due to the constant delays of the projects and the kind of contracts, Boeing and its Tier-1 suppliers have faced severe financial hurdles. Some of the most notable examples of the 787 project problems have been:

1. Mitsubishi, Kawasaki and Fuji are among companies awaiting a payoff from their investments in the plants and workforce it takes to make parts for the 787, that represents not only a challenge for the survival of these firms but a

potential crisis point for both Boeing and the Japan's aerospace programs[40]". It is estimated that Japanese government has subsided directly or indirectly the 787 program up to 7 billion USD; in fact, according to Airbus, the 787 project has been the most heavily subsidised civil aircraft in history [41].

2. In June 2009 Boeing acquired Vought Aircraft Industries' interest in Global Aeronautica, a joint venture form in 2005 by Alenia and Vought for the 787 program. Given this transaction, Global Aeronautica became a 50-50 joint venture between Boeing and Alenia North America, a subsidiary of Italy's Alenia Aeronautica. Vought continued to produce the aft fuselage for the 787 at its facility adjacent to Global Aeronautica in North Charleston [42].

3. In July 2009, Boeing finalised the acquisition of the business and operations conducted by Vought Aircraft Industries at its South Carolina facility. The newly acquired facility was called Boeing Charleston and became solely managed by the 787 program[43].

4. In December 2009 Boeing purchased Alenia's portion of Global Aeronautica, dissolving the joint enterprise and creating Boeing Charleston (now Boeing South Carolina), a full Boeing site [44]. It is believed that Vought and Alenia initially invested around 560 USD million in the creation of two separate

[40]http://www.bloomberg.com/news/2013-01-30/boeing-s-grounded-787-dreamliner-means-risk-for-japan-suppliers.html
[41]http://www.economist.com/node/14214813
[42]http://boeing.mediaroom.com/index.php?s=20295&item=107
[43]http://boeing.mediaroom.com/index.php?s=20295&item=775
[44]http://boeing.mediaroom.com/index.php?s=20295&item=1007

Charleston plants, both on the same 380-acre site next to Charleston International Airport [45].

5. In February 2014, Boeing and Alenia Aermacchi finalised the restructuring of the contract for the 787 program. The agreement establishes a new performance-based business arrangement aimed to improve operational performance [46]

Apart from the problems mentioned above, Boeing was in need to send hundreds of its employees to the sites of different suppliers around the world to work out several technical issues that led to the delay in the 787s delivery[47]. Finally, Boeing redesigned the complete aircraft assembly process[48].

All Nippon Airways (ANA) was the first customer for the Dreamliner 787, with the first of 50 aircraft to be delivered in 2008. However, after a series of delays on September 26th, 2011 the first jet was delivered to ANA, more than three years behind schedule. According to Boeing information, at the end of March 2014, Boeing had only delivered 12.8 percent of the total net orders[49] (Figure 4.14). According to Boeing information, at the end of March 2014, Boeing had only delivered 12.8 percent of the total net orders.

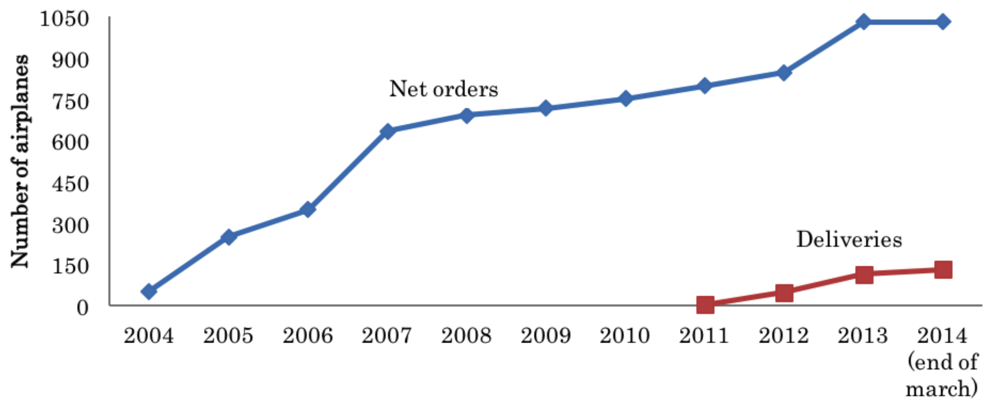
[45] http://www.crda.org/news/local_news/north_charleston_selected_for_7e7_fuselage_assembly-402

[46] http://www.aleniaaermacchi.it/en-US/Media/News/Pages/Boeing-and-Alenia-Aermacchi-have-finalized-a-restructured-contract-for-the-787-Program.aspx

[47] http://www.reuters.com/article/us-boeing-idUSN3129818220070131

[48] http://www.forbes.com/sites/stevedenning/2013/01/21/what-went-wrong-at-boeing/

[49] http://boeing.mediaroom.com/index.php?s=20295&item=1939



Source: The Boeing Company

Figure 4.14: Boeing 787: Net Orders and Deliveries

Boeing's open model of innovation implied that:

- Boeing organised its 787 program as a "principal-agent" problem were comprehensive monitoring was not implemented, and thus, the well-known issues of this relationship arose. In fact, by examining the database on can identify that from the major Tier-1 suppliers, under the new scheme of Boeing for the 787, only Spirit Aerosystems seemed to have a patent relationship with Boeing during the period of development of the 787. The Japanese firms (Kawasaki, Fuji and Mitsubishi), Vought or Alenia, do not appear at all in the database in any period.

- From the database, we can affirm that Boeing has only pursued its relationships with the other main military-oriented firms and the American government continuously.

- New Tier-1 suppliers were inexperienced in designing from scratch complete sections and, in some cases, were unfamiliar with new technology. For instance, it has been accepted that Vought hired low-wage trained-on-the-job workers that had no previous aerospace experience and did not have and engineering department when selected as supplier[50].

- Because Boeing thought that they could not afford underutilised facilities and wanted to retain skilled employees, they allowed the mobility of its workforce. The analysis of the database of this paper clearly supports this point.

- Contracts with Tier-1 suppliers were renegotiated.

- Boeing suffered from a hold-up problem as a result of the post-contractual moral hazard problem that arises from asymmetric information. Once Tier-1 suppliers agreed to invest in the upfront non-recurring costs, they renegotiated the contract for their advantage.

- Since Boeing is heavily subsidised and financially backed up by the government of the United States, and by the government of Japan in the case of 787 program, the firm enjoyed much lower borrowing costs than the majority of its Tier-1 suppliers, serving as a lender for them.

- The significant and constant delays in the 787 program have deteriorated Boeing's position in the market, giving room for a bigger share to its com-

[50] http://seattletimes.com/html/boeingaerospace/2008471651_boeing050.html

petitor, Airbus. In fact, during the 787's crisis, the A330 production reached record numbers, with deliveries of over 100 planes annually [51].

- Coordination problems were suppliers' individual costs were minimised, but the overall cost of the 787 program was not minimised.
- The cost cutting through outsourcing resulted in an increase in indirect costs for Boeing. Since they decided to decrease the fixed assets and to reduce the time of development, Boeing incurred in extra costs such as sending engineers to Tier-1 suppliers to fix the design and production problems, buying Tier-1 suppliers, to be highly tied to a foreign government (Japan).

4.7.2 Airbus A380

In January 2013, Airbus implemented a new manufacturing organisation system that allows Airbus plants to be fully responsible for delivering aircraft components to the final assembly[52]. This change is not moving in the same direction as the Boeing outsourcing system, it is only intended to empower individual plants that are fully owned by Airbus. In summary, and according to Airbus information, the way Airbus manages its supply chain is:

- Engineering, procurement and quality are now under the leadership of the individual plant head, but still aligned and motivated by the consortium.

[51] http://www.forbes.com/sites/richardaboulafia/2013/05/24/787-delays-continue-to-boost-airbus/

[52] http://www.airbus.com/company/aircraft-manufacture/how-is-an-aircraft-built/production/

- Tier-1, Tier-2 and Tier-3 suppliers are under the responsibility of individual Airbus plants. This point is in particular different from Boeing organisation, since Boeing only deals with Tier-1 suppliers.

Due to the consortium structure of Airbus and the history of it, there are some commitments to the governments of Germany, Spain, France and the UK to maintain the major plants in each of these countries. This structure can be observed when one compares the outsourcing system of the A380 aircraft with Boeing's 787 (Table 4.6).

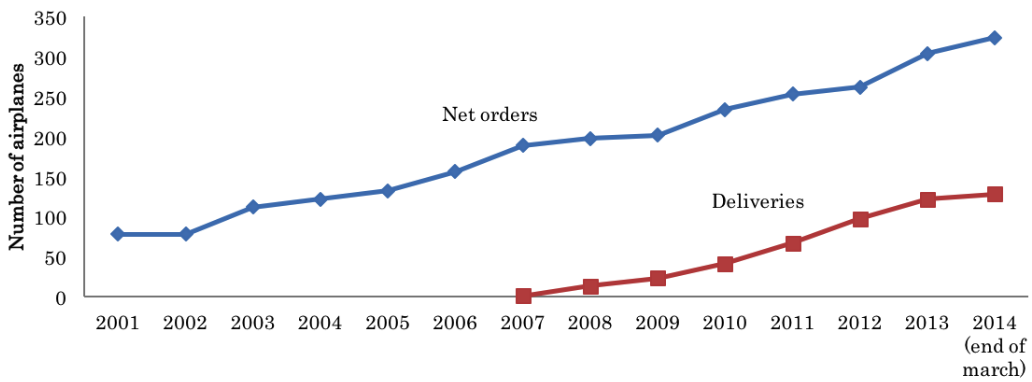
Section	Dreamliner 787	Airbus A380
Forward fuselage	Kawasaki (Nagoya, Japan) Spirit Aerosystems (Kansas, USA)	Airbus (Saint Nazaire, France)
Centre fuselage	Alenia (Grottaglie, Italy)	Airbus (Saint Nazaire, France)
Rear fuselage	Vought (South Carolina, USA)	Airbus (Hamburg, Germany)
Wings	Fuji (Nagoya, Japan) Mitsubishi (Nagoya, Japan) Kawasaki (Nagoya, Japan) KAL-ASD (Seoul, Korea) Boeing (Melbourne, Australia)	Airbus (Broughton, UK)

Source: Boeing and Airbus

Table 4.6: Major components: comparison of suppliers

Airbus also faced several delays in the delivery of the A380. According to Airbus press statements, the first delay was announced in June 2005 and was expected to be of six months. On 13 June 2006, Airbus announced a second delay for an additional six to seven months. Finally, on 3 October 2006, Airbus announced a third delay, stating that the first delivery was to be made in October 2007.

The first orders of the A380 were received in 2001, and the first delivery was made in 2007. At the end of March 2014, Airbus had delivered 39.5 per cent of its net orders (Figure 4.15).



Source: EADS Airbus

Figure 4.15: Airbus A380: Net Orders and Deliveries

On February 28th, 2007, Airbus announced Power8 restructuring plan to the Airbus European Works Council to tackle the challenge of the U.S. dollar weakness, increased competitive pressure, the financial burden related to the A380 delays as well as the need to meet its other future investment requirements[53].

It is worth noting that, unlike Boeing, once Airbus started the first delivery of the A380, the firm has uninterruptedly delivered aircraft, not without a very significant increase in the total development cost of the project, from 15 billion

[53]http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/power8-prepares-way-for-new-airbus/

USD originally to around 25 billion USD[54].

4.8 Conclusions

Factors within and outside a firm affect the decision of the degree of openness in innovation, inside factors (firm's resources and innovation strategy) and external factors (appropriability regime and market dynamics) determine the manufacturer-supplier relationships and the governance of these.

In this chapter, I consider the commercial aircraft industry, a duopoly (Boeing and Airbus), that serves as a solid case to present two different degrees of openness in innovation.

I present a case study of the different models of innovation within the civil commercial aircraft industry. On the one hand, The Boeing Company has pursued an Open Innovation model, where the firm outsourced not only the manufacturing of some major components of its latest jet, Dreamliner 787, but also the R&D of each of them becoming only the final assembler. On the other hand, Airbus Group has aligned itself with a Close Innovation model with an in-house R&D philosophy.

Using a unique patent database, I can reconstruct both the inventors patent careers and the firms' innovation paths. In this way, I extrapolate each firm's behaviour through the analysis of the inventors' links with other enterprises. I find evidence that Boeing has pursued an Open Innovation model, where Boeing

[54] http://www.nytimes.com/2014/08/10/business/oversize-expectations-for-the-airbus-a380.html

has to acquire external innovations or the firm has let their employees to patent somewhere else while being employees at Boeing. Using the same technique, we do not observe this behaviour with Airbus' inventors.

One of the main contributions of this chapter is the use patent information to examine the innovation path of a firm. This original methodology is valuable since by doing this, I can draw a picture of a firm's R&D behaviour without any formal corporate information, licensing information or disclosed collaboration agreements.

Even though the construction of the database is time-consuming and requires careful attention, patents are powerful to examine a firm's history and any structural changes that may have happened within it. This approach sheds light on a firm's innovation profile only when the firm actively uses patents or in the case where the inventors patent their innovations, regardless of the firm's patenting profile.

It is worth noting that although the decisions of Boeing and Airbus on the type of innovation they signed with their corresponding suppliers did affect their earliest deliveries, the uncertainty on demand played a role in the more recent decisions.

This chapter should serve as the motivation for the next chapter, where I consider that a NPD could potentially fail under a duopoly framework. One purpose of this chapter is to analyse the case of a duopoly where each competitor has different approaches to a NPD major project that have consequences in the delivery of the final product.

Moreover, the use of patents to track inventors history and to link these to an entire private firm's innovation path is unique in the literature. To my best knowledge, this is the first-time patents are used to serve this purpose and represents an original case study of the innovation economics literature.

Chapter 5

New Product Development and Uncertainty of Technological Success

5.1 Introduction

Any manager or policymaker that faces an investment decision is well aware that most projects are partially or completely irreversible, there is uncertainty on the future market conditions, and postponement of the investment may give higher benefits than undertaking the project once and for all.

The method of Net Present Value (NPV) does consider a project to be irreversible and does not consider a delay chance or a dynamic environment where the market conditions are changing continuously. In this sense, the use of real options as a tool to decide the optimal timing of investment has gain great popularity, since it considers the features mentioned above.

In this chapter, the role of uncertainty in a NPD project is introduced when two competitors, of the same size, are deciding the optimal timing of investment. This uncertainty was empirically discussed in the previous chapter where I analysed the latest major NPD projects of Boeing and Airbus. In that industry, both parties are of the same size, competing to introduce a new product, and facing high uncertainty in the R&D process and the market conditions.

The contribution of this chapter is to provide a more general framework to pre-emption games under duopoly using real options analysis. The introduction of uncertainty in the NPD stage, as introduced in this chapter, supports the well-known results in the existing literature (e.g. Weeds (2002), Boyer et al. (2012)). However, there are many real-life examples where the final product is not ready, even after it was publicly announced, making this framework relevant.

Real options analysis links financial options and game theory, where even if these options are not traded on a formal market, they still hold the features of the financial ones (Chevalier-Roignant and Trigeorgis, 2011). For instance, one may think of expansion projects, option to expand the current capacity of a plant or when to abandon a machine. Moreover, real options are particularly useful when the projects have significant sunk costs, such as the oil, aircraft or electricity industries.

Boyer et al. (2012) introduced a dynamic duopoly investment game using real options modelling. The authors find that early stages of R&D are characterised by intense competition even though only one firm may be active at that stage; despite this, both firms are only willing to enter into the game if they could potentially receive equal payoff notwithstanding the fact that they invest at different market stages.

When considering a duopoly framework, one needs to analyse the features of a particular industry. For instance, Mason and Weeds (2010) find that industries where there are incompatible technologies a first-mover advantage is likely to prevail, mainly due to the enduring benefits of being the first firm with a new product into the market.

The duopoly setting of investments is relevant since it is present in industries such as the one of the commercial aircraft where Boeing and Airbus share the market in almost equal proportion.

Weeds (2002) presents a duopoly model of real options where their technological success of the project is probabilistic. The author finds that the cooperative equilibrium represents the most favourable outcome for both firms; however, it is dominated by the non-cooperative equilibrium. When firms act separately, the preemptive actions prevails, where one firm invests too early in the game in the hope of higher profits derived from the new product, but this advantage is rapidly diminished when other firms join with its new product.

In the present paper, I introduce a model with uncertainty in the development stage in a dynamic duopoly setting where both firms are already active in the market, assuming that both firms face the same uncertain outcome in the R&D phase. I model a duopoly industry where the leader and the follower roles are endogenously assigned since both firms are of the same size and have access to the same resources and capital. Such setting is present in different industries, for instance, Boeing vs. Airbus, Samsung vs. Apple, etc.

The current work does provide original results relevant and useful to managers in the decision-making process that face the situation discussed in the model.

Moreover, the results of this Chapter are not comparable to any other of the existing literature, since the elements I introduce are not present in any other work. Thus, the findings should be analysed in its context.

The paper is structured as follows: in the first Section, I introduce the assumptions and the dynamics of the model; in the next Section, I derive the expected payoff for each case of the model; in the third Section, I analyse the case of the sequential investment equilibrium; in the fourth Section, I introduce the analysis of the simultaneous optimal investment; in the fifth Section, I present the conditions for equilibria and the value of the firm; finally, I present the conclusions.

5.2 The model

This section develops a reduced-form model where the exists uncertainty in the outcome of the R&D stage of each firm.

Two risk neutral agents labelled i $\in \{1, 2\}$ each can invest in a project. If the R&D is successful, the firms will have a new product ready to be launched into the market. Both firms are already operating in the market, receiving equal profits. There is a cost $I > 0$ to launch the new product that may be thought as an initial cost, symmetric for both agents. Investment is irreversible and can be, potentially, delayed forever.

The timing of launching the new product is the primary concern of this analysis. The introduction of the new product by the two agents may occur sequentially and could potentially increase its current profits -each firm launches the new product at distinctly different times, leaving the rival firm with fewer profits from its old product- or simultaneously -both firms launch at the same time and share the profits.

5.2.1 Industry characteristics

The framework of Dixit and Pindyck (1994) and Pawlina and Kort (2006) are used in this paper, with the difference that I consider identical investment cost for both firms and both firms are already operating in the market.

Profit uncertainty comes through a stochastic shock, common to the industry, that follows a Geometric Brownian motion (GBM):

$$d\theta_t = \mu\theta_t dt + \sigma\theta_t dW_t \tag{5.1}$$

where μ and σ are positive constants and $\{W_t\}_{t\geqslant 0}$ is a standard Brownian motion. The parameter μ can be considered as the industry growth rate, while σ can be interpreted as the industry volatility.

The framework of Dixit and Pindyck (1994) discusses that, in the long run, the trend is the primary driver of the GBM, while in the short term, the volatility parameter is the one that dominates the process. Moreover, the expected value of θ_t is given by:

$$\mathcal{E}[\theta_t] = \theta_0 e^{\mu \mathrm{t}} \tag{5.2}$$

The variance is given by:

$$\mathcal{V}[\theta_t] = \theta_0^2 e^{2\mu t}(e^{\sigma^2 t} - 1) \tag{5.3}$$

The expected present discounted value of θ_t is:

$$\mathcal{E}_0 \left(\int_0^\infty e^{-\mathrm{rt}} \theta_t \, dt \right) = \int_0^\infty \theta_0 e^{t(-(r-\mu))} \, dt = \frac{\theta_0}{r-\mu} = \frac{\theta_0}{\delta} \tag{5.4}$$

Where the riskless interest rate equals r. The drift parameter, α, must be strictly less than the risk-free interest rate, or otherwise, the option to invest will never be exercised (Dixit and Pindyck, 1994).

A multiplicative shock is convenient to analyse the effect of the stochastic feature of the profits on the firm's investment decision because the firm knows that if θ rises it will make the investment attractive for itself but also for the other firm as well and vice versa if the value of θ decreases. Therefore, greater uncertainty in θ also deteriorates the value of the investment compared to never investing since the required level profits to make the worth investment increases as well (Dixit and Pindyck, 1994).

Compared to an industry specific shock, the asymmetric effect in the profit of each firm means asymmetric profits as well, and in turn, greater uncertainty for a firm does not necessarily mean that the value of the project decreases since the firm can offset this loss by waiting to invest (Dixit and Pindyck, 1994).

The dividend yield is $\delta = r - \mu$, where $\delta > 0$. The instantaneous profit of the firm i, with $i \in 1, 2$, can be expressed as:

$$\pi_{N_i N_j}(\theta) = \theta D_{N_i N_j} \tag{5.5}$$

where θ represents the value of θ_t at time t, and for $k \in i, j$:

$$N_k = \begin{cases} 1 & \text{if firm } k \text{ has not launched new product} \\ 2 & \text{if firm } k \text{ has launched new product} \end{cases}$$

$D_{N_i N_j}$ represents the deterministic contribution to the profit function, $D_{N_i N_j} > 0$. For each case, we have the following:

- D_{11} means that both firms have not launched the new product, and both firms are currently receiving $\pi_{00}(\theta) = \theta D_{11}$;
- D_{21} means that firm i launched new product, becoming the "leader" because the firm j has not launched yet. The leader is currently receiving monopoly profits $\pi_{21}(\theta) = \theta D_{21}$;
- D_{12} means that firm i is the "follower" because only the other firm j has invested launched the new product. The follower is receiving $\pi_{12}(\theta) = \theta D_{12}$; and
- D_{22} means that both firms have the new product in the market invested in the market, and both firms are receiving duopoly profits $\pi_{22}(\theta) = \theta D_{22}$.

Assumption 1. $D_{12} < D_{11} < D_{22} < D_{21}$.

Assumption 1 is identical to the one presented in Pawlina and Kort (2006) and ensures that the deterministic instant profit of the firm that invests first (D_{21}) is exceeded by the current profit (D_{11}).

On the other hand, it also ensures that the firm faces cannibalisation in the case it comes second ($D_{12} < D_{11}$). Profits, when both firms have the same new product in the market, are less than when only one has the new product but are still larger than current profits ($D_{11} < D_{22} < D_{21}$)

I assume that the first realisation of the process underlying both firms profits, θ_0, is small enough so that an immediate investment is never optimal.

The probability of successful of the R&D phase and, consequently, the possibility of a new product ready to be launched, will be denoted as $p \in (0, 1]$ equal for both firms. In consequence, $(1 - p)$ will represent the probability of failure. One critical assumption whenever the firm decides to invest, the new product is ready to be launched.

I consider that the new product replaces completely the old product for the firm that introduces it, but that action does not mean that the profits for the firm that has not launched the new product are driven to zero.

5.2.2 Dynamics of the game

I describe first, the case of the sequential investment, where one firm (leader) decides to invest strictly before the other (follower).

5.2.2.a Leader's game

In Figure 5.1, I present the leader's game that consists of two parts: before and after the follower invests.

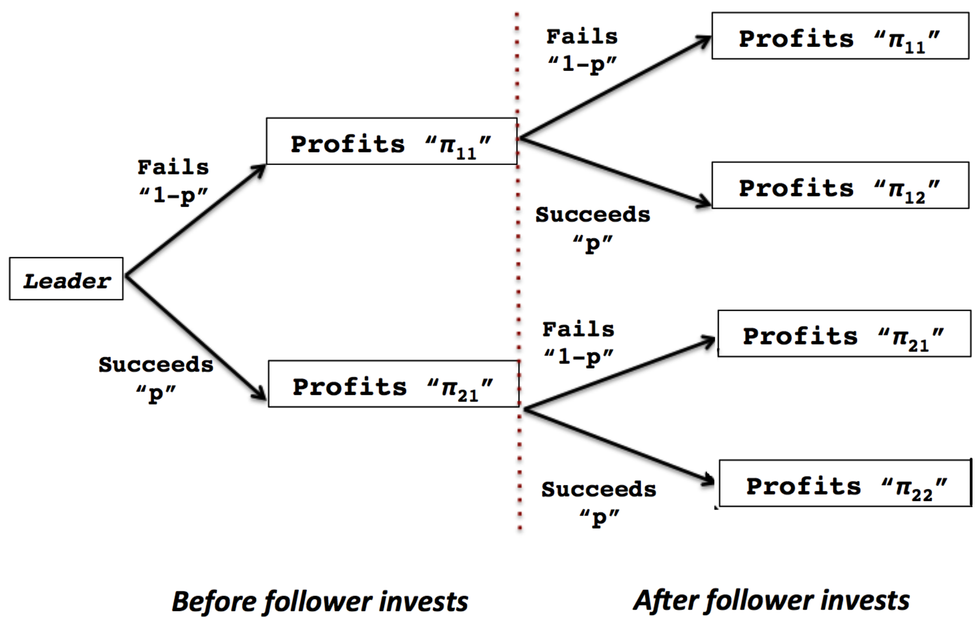


Figure 5.1: Leader's game

Before the follower has invested, the leader:

- with probability $1 - p$ receives profits from the old product π_{11}, and
- with probability p receives monopoly profits from the new product π_{21}

After the follower has invested, the leader:

- with probability $(1 - p)^2$ receives profits π_{11}, and
- with probability $p * (1 - p)$ receives profits π_{12}, and

- with probability $p * (1 - p)$ receives profits π_{21}, and
- with probability p^2 receives profits π_{22}.

5.2.2.b Follower's game

In Figure 5.2, I present the game of the follower, where as in the leader's game, there are two stages: before and after the follower invests.

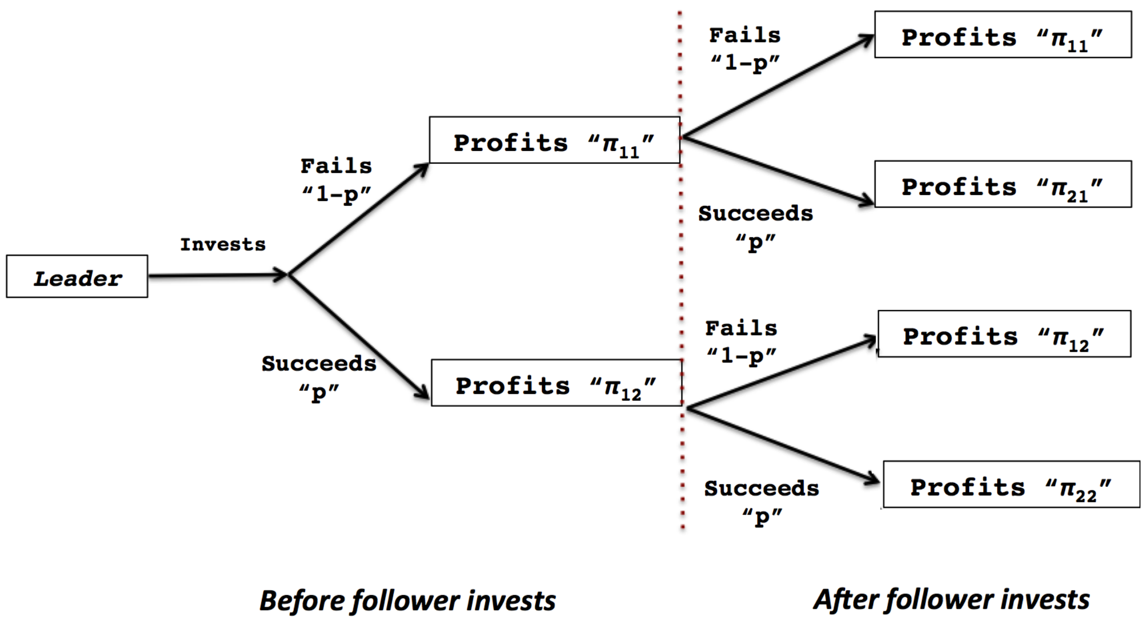


Figure 5.2: Follower's game

After the leader has invested and before the follower invests, the follower:

- with probability $1 - p$ receives profits from the old product π_{11}, and
- with probability p receives profits π_{12}

After both firms have invested, the follower:

- with probability $(1-p)^2$ receives profits π_{11}, and
- with probability $p*(1-p)$ receives profits π_{21}, and
- with probability $p*(1-p)$ receives profits π_{12}, and
- with probability p^2 receives profits π_{22}.

Once the leader has taken the decision to invest, the follower knows the outcome of the R&D of its competitor and would decide when to spend as if there were no other firm present in the market.

5.2.2.c Simultaneous game

In Figure 5.3, I present the game in the case where both firms invest at the same time. It is important to recall that although both firms may decide to invest simultaneously, they do it not cooperatively, making their decision only based on their value functions.

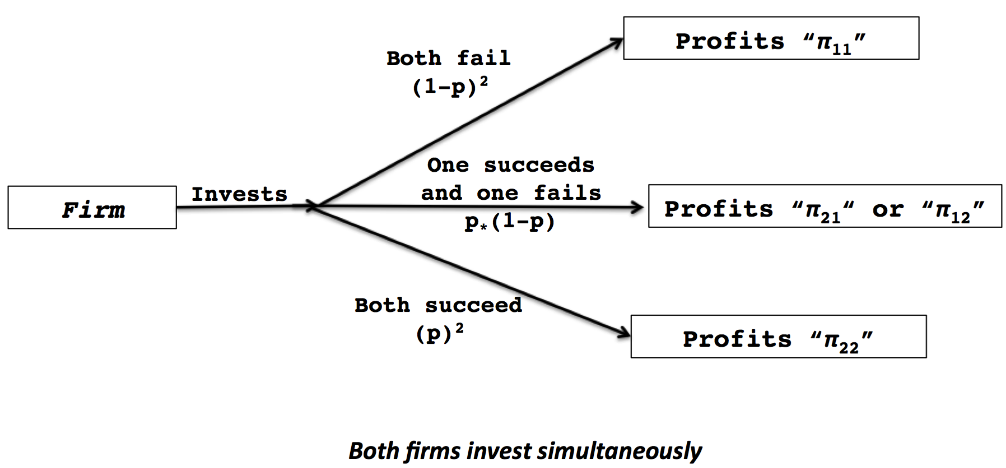


Figure 5.3: Simultaneous game

In the simultaneous situation, each firm is currently receiving π_{11}. Both firms invest at the same time, but not cooperatively. Thus, the possible outcomes will be the same for both firms, given that they face the same probability of success p.

There are four outcomes in this situation: i) both firms succeed, both firms fail or one firm fails and the other one succeeds, and vice versa

5.3 Expected payoff

To decide whether the investment is worth taking or not, each firm needs to consider all the possible cases for the game. As discussed in the previous section, there are two main situations in this model: sequential and simultaneous investment. For the first one, there are two cases for the follower and two cases for the leader depending on its outcome of the R&D stage, but also on the other's outcome. For the simultaneous investment, there is only one symmetric expect payoff for both firms.

In this section, I first present the payoff functions of the follower depending on the R&D outcome of the leader. Immediately, I introduce the payoff functions of the leader which depend only on its R&D outcome. Finally, I show how the simultaneous payoff function is calculated when both firms decide to invest at the same time, not cooperatively.

From the previous section, in the sequential investment, there are two parts to consider: before and after the investment. I represent the expected payoff before the investment invests as $V(\theta)$ for each corresponding situation, while the situation when the follower has already invested as $NPV(\theta)$ since it represents the situation where the investment has already happened.

Before introducing each payoff function, I present a diagram showing the situations that lead to the final functions.

I derive the expected payoff functions in Appendix B.

5.3.1 Follower's cases

5.3.1.a Follower (Case 1): leader was unsuccessful in R&D with probability $1-p$

The follower is currently receiving old profits π_{11} since the leader has been unsuccessful in the research phase and it does not have the new product.

With probability p the follower is successful and receives monopoly profits π_{21}, and with probability $1-p$ the follower is unsuccessful in R&D and receives current profits, π_{21}:

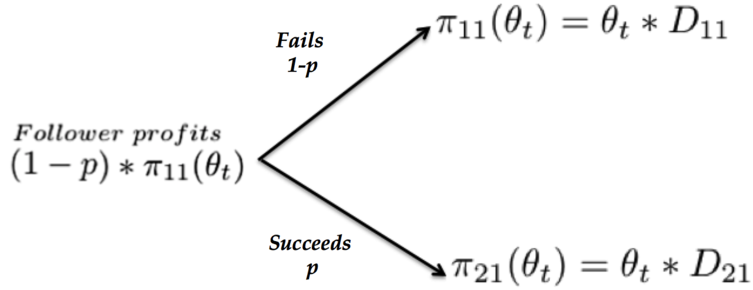


Figure 5.4: Follower's payoff: Case 1

Before the follower invests, the firm has current profits:

$$V_{F1}(\theta) = \mathcal{E}_t \left(\int_t^{\infty} \pi_{11}(\theta_s) e^{-r(s-t)}\, ds \right) = \frac{\theta D_{11}}{\delta} \tag{5.6}$$

Where θ represents the state of θ_t at time t.

Plus the option to invest in the development of a new product. I derive the form of the option to in the section of Sequential investment equilibrium (Equation 5.25).

After the follower invests the firm receives the NPV of the project once it has paid the investment cost. The relevant NPV in this case is:

$$NPV_{F1}(\theta) = \frac{\theta}{\delta} \left[pD_{21} + (1-p)\, D_{11} \right] - I \tag{5.7}$$

5.3.1.b Follower (Case 2): leader was successful in R&D with probability p

Follower is currently receiving profits π_{12}. With probability p the follower is successful and receives duopoly profits D_{22} and with probability $1-p$ the follower is unsuccessful in R&D and receives current profits, D_{12}:

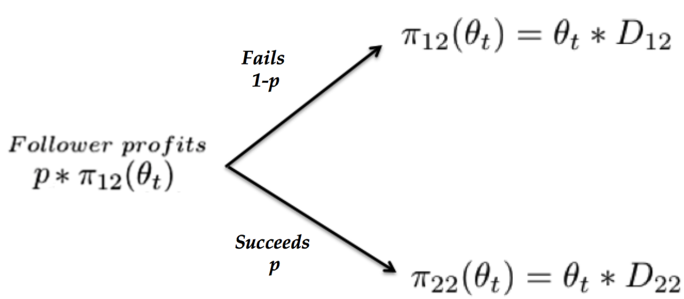


Figure 5.5: Follower's payoff: case 2

Before the follower invests, the firm is receiving:

$$V_{F2}(\theta) = \mathcal{E}_t \left(\int_t^{\infty} \pi_{12}(\theta_s) e^{-r(s-t)} \, ds \right) = \frac{\theta D_{12}}{\delta} \tag{5.8}$$

Plus the option to invest in the development of a new product (Equation 5.25).

After the follower invests the firm receives the NPV of the project once it has paid the investment cost. The relevant NPV in this case is:

$$NPV_{F2}(\theta) = \frac{\theta}{\delta} \left[pD_{22} + (1-p) \, D_{12} \right] - I \tag{5.9}$$

5.3.2 Leader's cases

5.3.2.a Leader (Case 1): firm is unsuccessful in R&D with probability $1-p$

The leader faces two different sources of uncertainty; not only the firm faces the risk of a failed R&D process, but also there exists the possibility that once the firm has invested and has paid the sunk cost, the follower may invest and in consequence may drive its profits down.

In the first case, with probability $1-p$, the leader is unsuccessful. Before the follower invests, the leader receives profits from the old product, π_{11}. After the follower decides to invest: i) with probability $1-p$ the follower will be unsuccessful and in turn, the leader will continue to receive profits π_{11}; and ii) and with probability p the follower is successful and the leader receives profits, π_{12}:

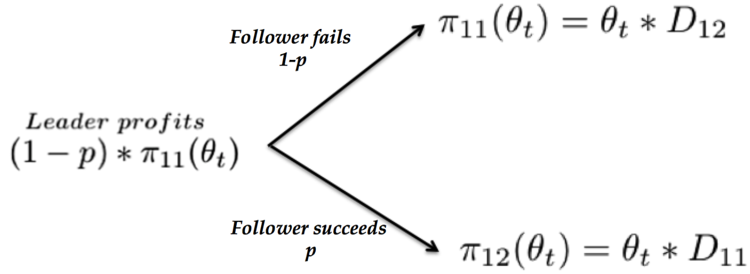


Figure 5.6: Leader's payoff: case 1

Before the follower invests, the profits of the leader are given by:

$$V_{L1}(\theta) = \mathcal{E}_t \left(\int_t^{\infty} \pi_{11}(\theta_s) e^{-r(s-t)}\, ds \right) - I = \frac{\theta D_{11}}{\delta} - I \tag{5.10}$$

After the follower invests, the leader receives the NPV of the project since it does not face any future threat in its profits. The relevant NPV in this case is:

$$NPV_{L1}(\theta) = \frac{\theta}{\delta} \left[pD_{12} + (1-p)\, D_{11} \right] - I \tag{5.11}$$

5.3.2.b Case 2. Leader is successful in R&D with probability p

With probability p, the leader is successful. Before the follower invests, the leader receives monopoly profits from the new product, π_{21}. After the follower decides to invest: i) with probability $1-p$ the follower will be unsuccessful and in turn, the leader will continue to receive monopoly profits π_{21}; and ii) and with probability $p$the follower is successful and the leader receives duopoly profits, π_{22}:

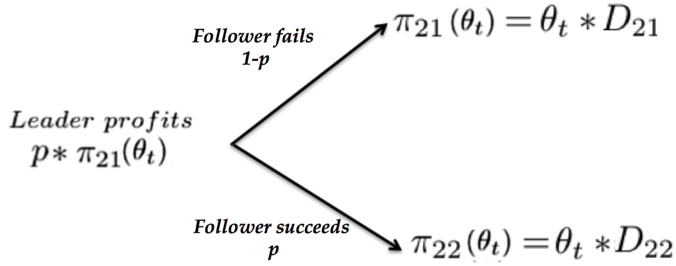


Figure 5.7: Leader's payoff: case 2

To analyse this case, one needs to consider the current profit of the leader, before the leader invests:

$$V_{L2}(\theta) = \mathcal{E}_t \left(\int_t^{\infty} \pi_{21}(\theta_s) e^{-r(s-t)}\, ds \right) - I = \frac{\theta D_{21}}{\delta} - I \tag{5.12}$$

After the follower invests, the leader receives the NPV of the project since it does not face any future threat in its profits. The relevant NPV in this case is:

$$NPV_{L2}(\theta) = \frac{\theta}{\delta} \left[pD_{22} + (1-p)\, D_{21} \right] - I \tag{5.13}$$

5.3.3 Simultaneous case

Before both firms simultaneously invest, each firm receives profits from the old product π_{11}.

After both firms have invested, each firm receives:

- with probability $(1-p)^2$ profits π_{11}, and
- with probability p* $(1-p)$ profits π_{12} or π_{21}, and

- with probability $(p)^2$ profits π_{22}.

where p represents the probability of success for each firm, $p\in [0,1]$, when they invest at the same time, and identical for both firms.

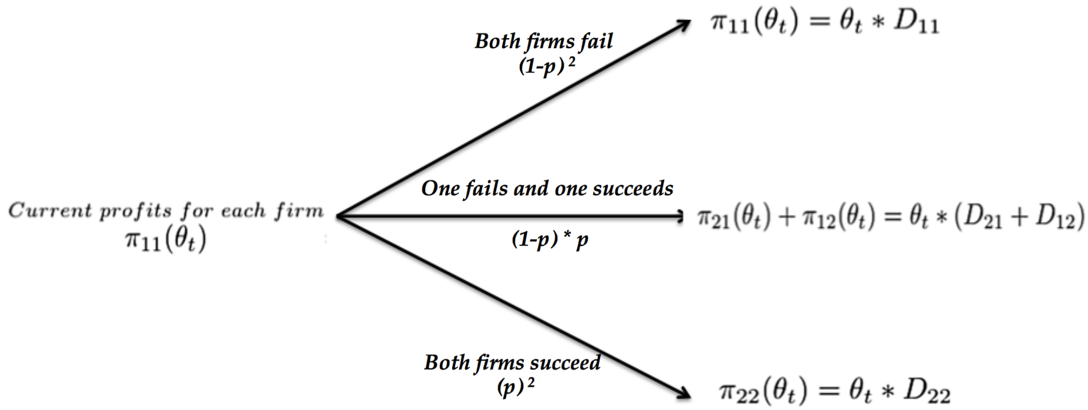


Figure 5.8: Firm's payoff: simultaneous case

Before investment, each firm receives:

$$V_S(\theta) = \mathcal{E}_t\left(\int_t^{\infty} \pi_{11}(\theta_s) * e^{-r(s-t)}\, ds\right) = \frac{\theta D_{11}}{\delta} \tag{5.14}$$

After both firms have invested, they both receive the NPV of the project:

$$NPV_S(\theta) = \frac{\theta}{\delta}\left[pD_{22} + p(1-p)(D_{21} + D_{12}) + (1-p)\, D_{11}\right] - I \tag{5.15}$$

5.4 Sequential investment equilibrium

In this section, I analyse two different types of equilibrium: sequential and simultaneous.

It is important to recall that both firms have the same probability of success, p, which is exogenous.

As stated in Dias and Teixeiras (2003), before any options have been exercised, before the optimal state of θ, and since both firms are active in the market, the value of each firm is the current cash-flow profit in perpetuity:

$$\frac{\pi_{N_iN_j}(\theta)}{\delta} = \frac{\theta D_{N_iN_j}}{\delta}$$

Plus the option to utilise the investment option (as the leader or as the follower) considering the effect of the rival's action (Equation 5.25).

5.4.1 Follower's optimal investment

As presented in Dixit and Pindyck (1994), the solution is done backwards: suppose than one firm has already made the investment in R&D (leader), and it is known if the firm has failed or not, and in turn, whether a new product has entered the market; given the outcome the other firm (follower) will find optimal investment decision.

The follower's value function, in each case of the leader's outcome, has two parts:

- for values of θ_t before the optimal investment trigger point, before the firm has invested, and
- after the firm invests and pays the sunk cost.

Following the reasoning of and McDonald and Siegel (1986) Dixit and Pindyck (1994) and in order to understand the option to invest consider a project with value θ that follows a GBM as presented in (5.16) at a cost $I > 0$:

$$d\theta_t = \mu\theta_t dt + \sigma\theta_t dW_t \tag{5.16}$$

where μ and σ are positive constants and $\{W_t\}_{t\geqslant 0}$ is a standard Brownian motion and $\mathcal{E}(dW) = 0$.

The corresponding investment opportunity is $F(\theta)$ and does not yield any profit until the investment has taken place, representing the value of the option to invest.

$$F(\theta) = \max \mathcal{E}[(\theta_T - I)\exp^{-rT}] \tag{5.17}$$

$F(\theta)$ should be the maximum of the expected value at an unknown time, T, where the investment is made.

To determine the optimal time T to invest a critical value of θ^* is needed.

Consider the region where the investment is not optimal, the relevant Bellman equation is given by:

$$rFdt = \mathcal{E}(dF) \tag{5.18}$$

Where the left side represents the expected value of the investment opportunity over a period dt should be equal to the expected rate of capital appreciation.

Using Ito's Lemma to express dF:

$$dF = F'(\theta)d\theta + \frac{1}{2}F''(\theta)(d\theta)^2 \tag{5.19}$$

Where $F'(\theta) = \frac{dF}{d\theta}$ and $F''(\theta) = \frac{d^2F}{d\theta^2}$.

Substituting 5.16 into 5.19:

$$\mathcal{E}[dF] = \mu\theta F'(\theta)dt + \frac{1}{2}\sigma^2\theta^2 F''(\theta)dt \tag{5.20}$$

Substituting 5.20 into 5.18 and simplifying:

$$\mu\theta F'(\theta)dt + \frac{1}{2}\sigma^2\theta^2 F''(\theta)dt - rF = 0 \tag{5.21}$$

There are three boundary conditions $F(\theta)$ should satisfy:

$$F(0) = 0 \tag{5.22}$$

$$F(\theta^*) = \theta^* - I \tag{5.23}$$

$$F(\theta^*) = 1 \tag{5.24}$$

Equation 5.22 means that when $\theta \approx 0$ it will remain at zero, 5.23 is the *value-matching* condition and 5.24 is the *smooth-pasting* condition where if $F'(V)$ were not continuous and smooth at V^* it would be better to invest at some other point[1].

[1]For further explanation on the meaning of each the boundary conditions see Dixit and Pindyck (1994)

It is worth noting that Equation 5.21 is a second-order differential equation subject to the three boundary conditions (5.22, 5.23 and 5.24). Thus, in order to satisfy Equation 5.22, the solution should take the form:

$$F(\theta) = A\theta^{\beta} \tag{5.25}$$

Where A is a constant to be determined and $\beta > 1$ is a function of $\beta(\mu, \sigma, r)$. Note that 5.25 captures the decrease in profits due to the future entry of the follower, in the case of the leader; or the increase in profits due to an option to invest, in the case of the follower after the leader has already invested.

To know the value of β it is necessary to substitute 5.25 into Equation 5.21; thus, $beta$ should be the positive root of the following quadratic equation:

$$\mu\beta + \frac{1}{2}\sigma^2\beta(\beta - 1) - r = 0 \tag{5.26}$$

$$\beta \equiv \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \tag{5.27}$$

I derive the rest of the value functions, for each case in Appendix C.

5.4.1.a Case 1: Leader is unsuccessful in R&D with probability $1 - p$

As discussed before, the follower acts as monopolist since the firm does not face the threat of future entry of any competitor. However, it does have the opportunity to invest to increase its profits, which is weighted by the probability of success.

I this case, the value function consists of two parts: before and after the follower invests. Recall that before the follower invests, the outcome of the leader is already known and the remaining firm faces either Follower Case(1) or Follower Case (2).

The first part of the value function considers the current profit flow plus the option to invest, while the second part is what the firm gets after the firm invests considering the two possible outcomes of the R&D stage.

$$F_1(\theta) = \begin{cases} \underbrace{\frac{\theta D_{11}}{\delta}}_{\text{Current profit flow}} + \underbrace{B_1 \theta^{\beta}}_{\text{Option to invest}} & \text{if } \theta \leq \theta_{F1} \\ \underbrace{p\left(\frac{\theta D_{21}}{\delta}\right)}_{\text{Profit flow if firm is successful}} + \underbrace{(1-p)\left(\frac{\theta D_{11}}{\delta}\right)}_{\text{Profit flow if firm is unsuccessful}} - \underbrace{I}_{\text{Investment cost}} & \text{if } \theta > \theta_{F1} \end{cases} \tag{5.28}$$

where β is derived as in (5.27):

$$\beta \equiv \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \tag{5.29}$$

As discussed in Dixit and Pindyck (1994), the parameter B_1 and the optimal investment point, θ_{F1}, can be obtained from value-matching and *smooth-pasting* conditions:

$$B_1 = \left[\frac{p\,(D_{21} - D_{11})}{\beta\delta}\right] {\theta_{F1}}^{1-\beta} > 0 \tag{5.30}$$

$$\theta_{F1} = \left(\frac{\beta}{\beta - 1}\right)\left(\frac{\delta I}{p\,(D_{21} - D_{11})}\right) \tag{5.31}$$

The follower's probability of success affects, not only the expected payoff before the firm invests $V_{F1}(\theta)$, but also the expected payoff after the firm has invested $NPV_{F1}(\theta)$.

In the case where there is no uncertainty of success, $p = 1$, the well-known results hold (see Pawlina and Kort (2006) and Mason and Weeds (2010)). The lower the follower's probability of success, the more the optimal investment point is delayed.

In Figure 5.9[2] it can be observed that when the probability of success is equal to one, there is no uncertainty in the R&D outcome, the larger the expected gain of investing, $D_{21} - D_{11}$, the more immediately the investment will take place.

The two parts of the value functions are the black solid curve, which is before the follower invests and the red solid line which is what the firm receives after it invested. The red dotted line is not relevant before the trigger point since the NPV is not received after the firm has invested.

As the first mover advantage vanishes, the optimal trigger moves farther, meaning that it is better for the firm to wait given that the potential gains from the investment are smaller. In Figure 5.9, I present the case when there is no uncertainty in the $R\&D$ outcome assuming to different First Mover Advantage. The top

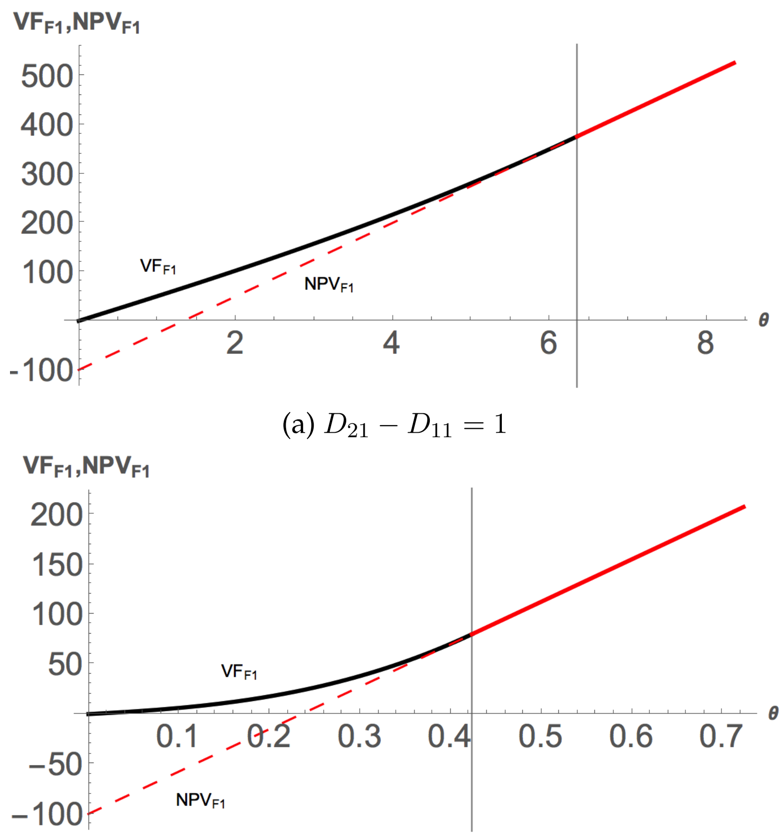
[2] In all the examples of this paper the parameters for the GBM and the risk-free interest rate are as follows:

as follows:	Risk-free interest rate (r)	0.05
	GBM drift (μ)	0.01
	GBM volatility (σ)	0.1
	Adjusted interest rate ($\delta = r - \mu$)	0.04

picture has a FMA of one while the bottom one has a FMA of 15.

Given a probability of success, p, as the FMA increases the trigger point decreases since the investment opportunity becomes more attractive.

In Figure 5.10, I show the case when probability of success is 0.5, where one salient feature is that when $p \rightarrow 0$ and $(D_{21} - D_{11}) \rightarrow 0$, the value of the option to deter the investment is almost zero ($V_{F1} \approx NPV_{F1}$).



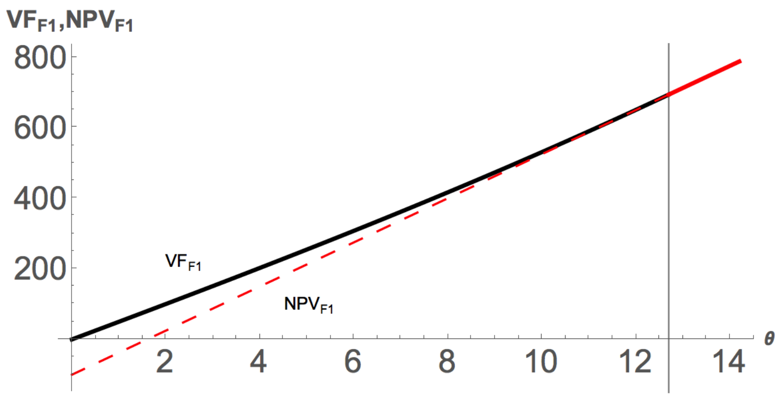
(a) $D_{21} - D_{11} = 1$

(b) $D_{21} - D_{11} = 15$

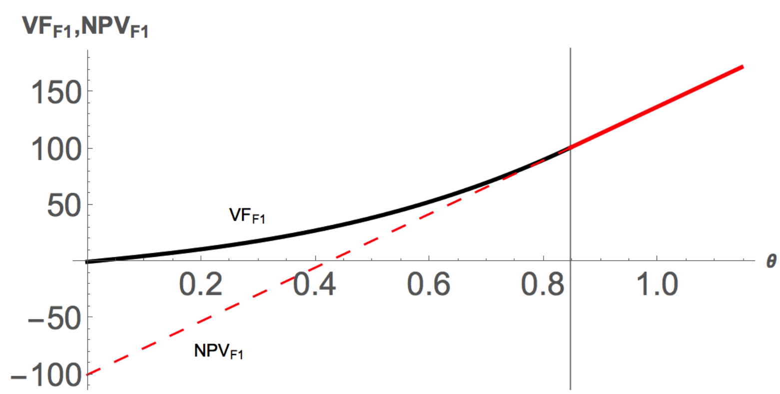
Figure 5.9: Follower's expected payoff (Case 1): "No uncertainty, $p = 1$" $(I = 100, D_{11} = 2)$

Whenever the likelihood of success decreases, the trigger point moves farther since the investment opportunity is less attractive and it would require more waiting to ensure an optimal investment.

It is worth noting that the optimal investment for the follower comes when $VF = NPV$ under the boundary conditions (Equations 5.22, 5.23 and 5.24).



(a) $D_{21} - D_{11} = 1$



(b) $D_{21} - D_{11} = 15$

Figure 5.10: Follower's expected payoff (Case 1): "$p = 0.5$"
$(I = 100, D_{11} = 2)$

The effect of μ, σ and I on the trigger point are not presented in this section although I did analyse them and are consistent with previous findings in the real options literature (e.g. Dixit and Pindyck (1994), Weeds (2002) and Pawlina and

Kort (2006)).

The follower trigger point decreases when:

- μ increases (better trend of the industry)
- σ decreases (less uncertainty in the industry)
- I decreases (lower initial investment cost)

5.4.1.b Case 2: Leader is successful in R&D with probability p

$$F_2(\theta) = \begin{cases} \underbrace{\frac{\theta D_{12}}{\delta}}_{\text{Current profit flow}} + \underbrace{B_2\theta^{\beta}}_{\text{Option to invest}} & \text{if } \theta \leq \theta_{F2} \\ \underbrace{p\left(\frac{\theta D_{22}}{\delta}\right)}_{\text{Profit flow if firm is successful}} + \underbrace{(1-p)\left(\frac{\theta D_{12}}{\delta}\right)}_{\text{Profit flow if firm is unsuccessful}} - \underbrace{I}_{\text{Investment cost}} & \text{if } \theta > \theta_{F2} \end{cases} \quad (5.32)$$

Where β is defined as before.

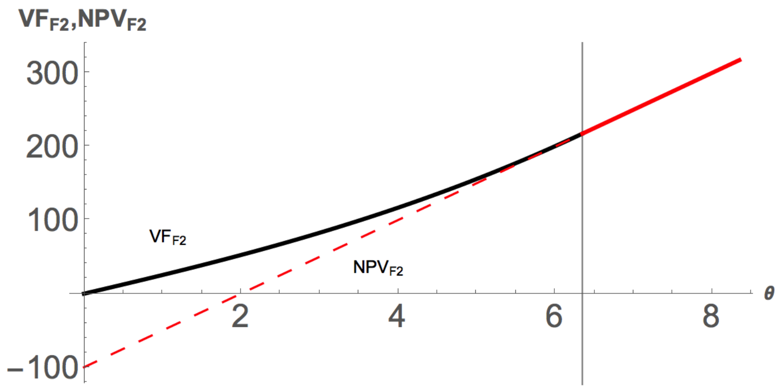
Parameters B_2 and the optimal investment point, θ_{F2} are obtained in the same manner as in the previous case:

$$B_2 = \left[\frac{p\left(D_{22} - D_{12}\right)}{\beta\delta}\right] {\theta_{F2}}^{1-\beta} > 0 \quad (5.33)$$

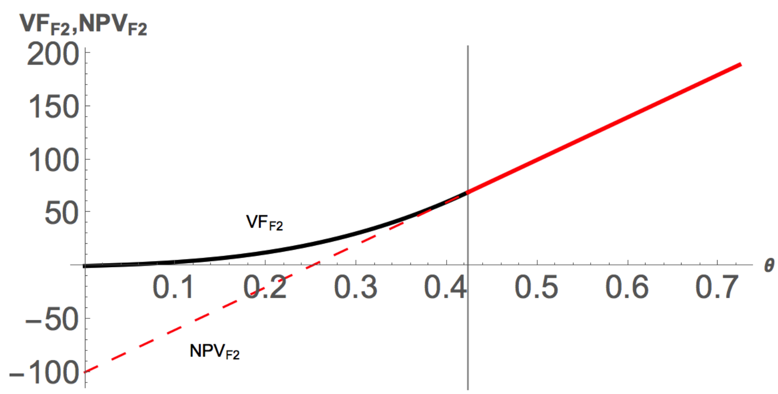
$$\theta_{F2} = \left(\frac{\beta}{\beta - 1}\right)\left(\frac{\delta I}{p\left(D_{22} - D_{12}\right)}\right) \quad (5.34)$$

In this case, the trigger point is mainly driven by the potential gains of a catch-up from the follower ($D_{22} - D_{12}$), but also by the probability of success in the same way as in *Case 1* (Figures 5.11 and 5.12).

However, it is important to note that the follower's expected payoff is always smaller in *Case 2* than in *Case 1*, since in the latter, the follower enjoys the possibility of receiving monopoly profits if successful.



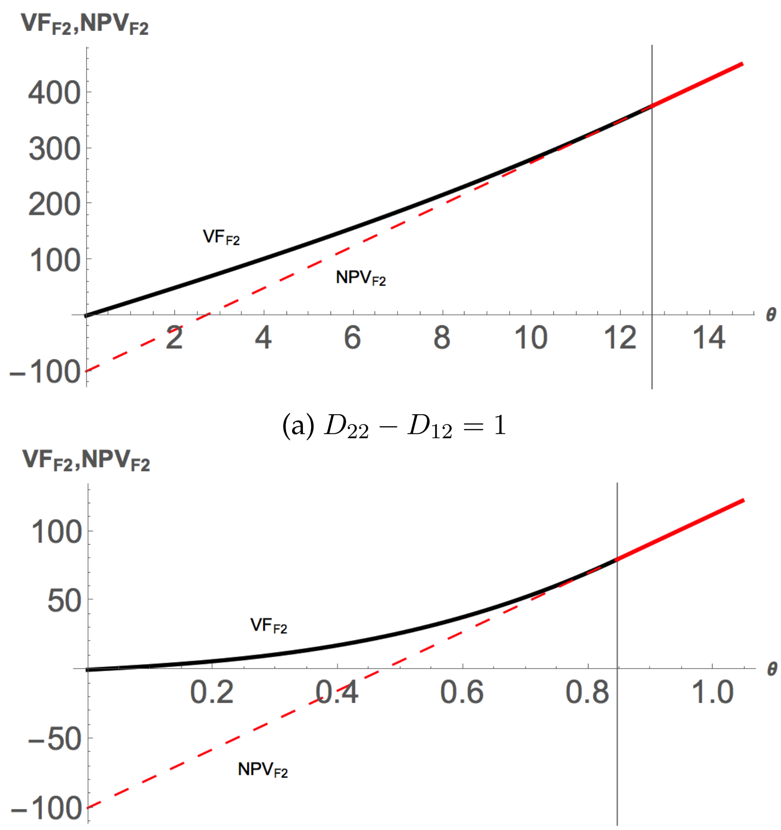
(a) $D_{22} - D_{12} = 1$



(b) $D_{22} - D_{12} = 15$

Figure 5.11: Follower's expected payoff (Case 2): "No uncertainty, $p = 1$" $(I = 100, D_{12} = 1)$

In Case 1 and Case 2 of the Follower, the value function before the firm invests (VF_F) is concave since it contains the current profit flow before investing plus the option to invest which generates value while the firms wait until the trigger point (solid black curve). The red dotted line does not exist until after the trigger point. The solid red line is the second part of the value function after the firm has invested (NPV_F) and paid the investment cost I.



(a) $D_{22} - D_{12} = 1$

(b) $D_{22} - D_{12} = 15$

Figure 5.12: Follower's expected payoff (Case 2): "$p = 0.5$"
$(I = 100, D_{12} = 1)$

The trigger points are obtained using the value functions and the boundary conditions that make the investment optimal for the follower firm.

Assumption 2. $D_{21} - D_{11} > D_{22} - D_{12}$

The above proposition is called "First Mover Advantage" or FMA, and states that the gain in profits for the one that moves first $(D_{21} - D_{11})$ should be larger than the increase in profits for the one that catches up ($D_{22} - D_{12}$). It is important to note that I am only stating that there exists an advantage, but I am not setting this necessarily as an enormous value.

In the analysis of this chapter, I will use different values of FMA to analyse the equilibria.

The next proposition provides the conditions to order the follower's optimal investment point, depending on whether the leader was successful or not.

Lemma 1. *If* $(D_{21} - D_{11}) > (D_{22} - D_{12})$ *then* $\theta_{F1} < \theta_{F2}$.

Proof. The numerator of θ_{F1} and θ_{F2} are equal. The denominator of θ_{F1} is greater than the denominator of θ_{F2} by assumption 2. ■

Note that whenever the leader was unsuccessful, the follower firm will always invest strictly before compared to the case when the leader was successful, regardless of the uncertainty of the market, the probability of success in the R&D stage or the size of the FMA.

5.4.1.c Follower's general problem

Considering both cases the followers faces once the leader has made its decision and the new product is out in the market or not, the follower's value function is obtained by combining Case (1) and Case (2) weighted by the probability of success, and is given by:

$$F(\theta) = \underbrace{(1-p)F_1(\theta)}_{\text{Leader was unsuccessful}} + \underbrace{pF_2(\theta)}_{\text{Leader was successful}} \tag{5.35}$$

Substituting F_1 and F_2 and rearranging the follower's value function is:

$$F(\theta) = \frac{\theta}{\delta}\left[p * D_{12} + (1-p)\, D_{11}\right] + \left(\frac{I\theta^{\beta}}{\beta - 1}\right) * \left(\frac{1-p}{{\theta_{F1}}^{\beta}} + \frac{p}{{\theta_{F2}}^{\beta}}\right) \tag{5.36}$$

It is worth noting that, in contrast to the common framework when $p = 1$, the follower's value function involves both possible leader's outcomes and represents a more general framework that involves many more business possibilities.

This follower's value function, $F(\theta)$, is the relevant one in the pre-investment stage when neither firm has invested. Once the leader invests, the follower will face either $F_1(\theta)$ or $F_2(\theta)$.

5.4.2 Leader's investment decision

The leader will not choose the optimal trigger investment point in the same way as the follower since the firm faces the possibility of a reduction in its profits if the other firm decides to invest. In this manner, the leader will decide when to invest when the expected payoff of leading is equal to the one of following (Fudenberg and Tirole, 1985).

Using Assumption 2, the First Mover Advantage (FMA) is always positive and defined by:

Definition 1. $FMA = D_{21} - D_{11} - (D_{22} - D_{12})$

Note that this FMA assumption makes sense in industries when patents are the result of the R&D stage or when there are huge switching costs for the customer once they decided which product to buy. This latter case is the one that is present in the Commercial Aircraft Industry since airlines decide which type of aircraft to buy based on an entire fleet, as discussed in the previous chapter. Thus, once an airline buys one aircraft, it is extremely costly to change to a different brand due to commonality issues.

5.4.2.a Case 1: Leader is unsuccessful in R&D with probability $1 - p$

As described in the section of the payoff functions, there are two parts of the leader's game: before the follower invests and after the follower invests.

Before the follower invests, the relevant part of the leader's value function is defined as the current profit flow plus the possibility of the reduction of profits due to the future entry of the follower minus the investment cost which has already been paid, strictly before the follower decides to invest at the trigger point θ_{F1}.

After the follower has invested, the leader receives the NPV of the project which is a combination of the two possible profit flows depending on the outcome of the follower after the follower's trigger point weighted by the probability of success p.

Note that the relevant follower's trigger point is $\theta_F 1$ since this is the one the firm chooses once the leader invested and is unsuccessful.

After the leader has invested and was unsuccessful, the value function is:

$$L_1(\theta) = \begin{cases} \underbrace{\frac{\theta D_{11}}{\delta}}_{\text{Current profit flow}} + \underbrace{B_3\theta^{\beta}}_{\text{Decrease in profits when follower invests}} - \underbrace{I}_{\text{Investment cost}} & \text{if } \theta \leq \theta_{F1} \\ \\ \underbrace{p\left(\frac{\theta D_{12}}{\delta}\right)}_{\text{Profit flow if follower is successful}} + \underbrace{(1-p)\left(\frac{\theta D_{11}}{\delta}\right)}_{\text{Profit flow if follower is unsuccessful}} - I & \text{if } \theta > \theta_{F1} \end{cases} \tag{5.37}$$

where β is defined as before, and

$$B_3 = \left(\frac{p\,(D_{12} - D_{11})}{\delta}\right) {\theta_{F1}}^{1-\beta} < 0 \tag{5.38}$$

Parameter B_3 is obtained by imposing the boundary condition (Appendix C). Note that $B_3 < 0$ since $D_{12} < D_{11}$, which represents the reduction of the leader's value function anticipating that the rival would enter the market.

Note that in this case there does not exist one trigger point for the leader since the decision is not optimal, as in the case of the follower.

5.4.2.b Case 2: Leader is successful in R&D with probability p

As described before, when the leader is successful, the value function is divided into two parts: before and after the follower invests.

The value function is divided into two parts: before and after the follower invests, where the relevant follower's trigger point is θ_{F2}.

After the leader has invested and was successful, the value function is:

$$L_2(\theta) = \begin{cases} \underbrace{\frac{\theta D_{21}}{\delta}}_{\text{Current profit flow}} + \underbrace{B_4\theta^{\beta}}_{\text{Decrease in profits when follower invests}} - \underbrace{I}_{\text{Investment cost}} & \text{if } \theta \leq \theta_{F2} \\ \underbrace{p\left(\frac{\theta D_{22}}{\delta}\right)}_{\text{Profit flow if follower is successful}} + \underbrace{(1-p)\left(\frac{\theta D_{21}}{\delta}\right)}_{\text{Profit flow if follower is unsuccessful}} - I & \text{if } \theta > \theta_{F2} \end{cases} \tag{5.39}$$

where β is defined as before, and

$$B_4 = \left(\frac{p\left(D_{22} - D_{21}\right)}{\delta}\right)\theta_{F2}{}^{1-\beta} < 0 \tag{5.40}$$

5.4.2.c Leader's general problem

There are two cases for the leader depending on whether it is successful in launching the new product or not. Thus, the relevant value function is the combination of Case (1) and Case (2) of the leader's problem weighted by the probability of success and is given by:

$$L(\theta) = \underbrace{(1-p)L_1(\theta)}_{\text{Leader is unsuccessful}} + \underbrace{pL_2(\theta)}_{\text{Leader is successful}} \tag{5.41}$$

Substituting $L_1(\theta)$ and $L_2(\theta)$ and rearranging:

$$\begin{aligned} L(\theta) = &\frac{\theta}{\delta}\left[pD_{21} + (1-p)\,D_{11}\right] \\ &- \frac{p\theta^{\beta}}{\delta}\left[(1-p)\left(D_{11} - D_{12}\right)\theta_{F1}{}^{1-\beta} + p\left(D_{21} - D_{22}\right)\theta_{F2}{}^{1-\beta}\right] - I \end{aligned} \tag{5.42}$$

This leader's value function is the relevant one in the pre-investment stage. In this sense, before any firm has invested, each firm will decide to become the leader or the follower by analysing $L(\theta)$ and $F(\theta)$.

If $p = 1$, the problem is simplified to the well know duopoly problem of an existing market (e.g. Pawlina and Kort, 2006).

Figure 5.13 shows the value functions of the follower and the leader at the beginning of the game before any firm invests.

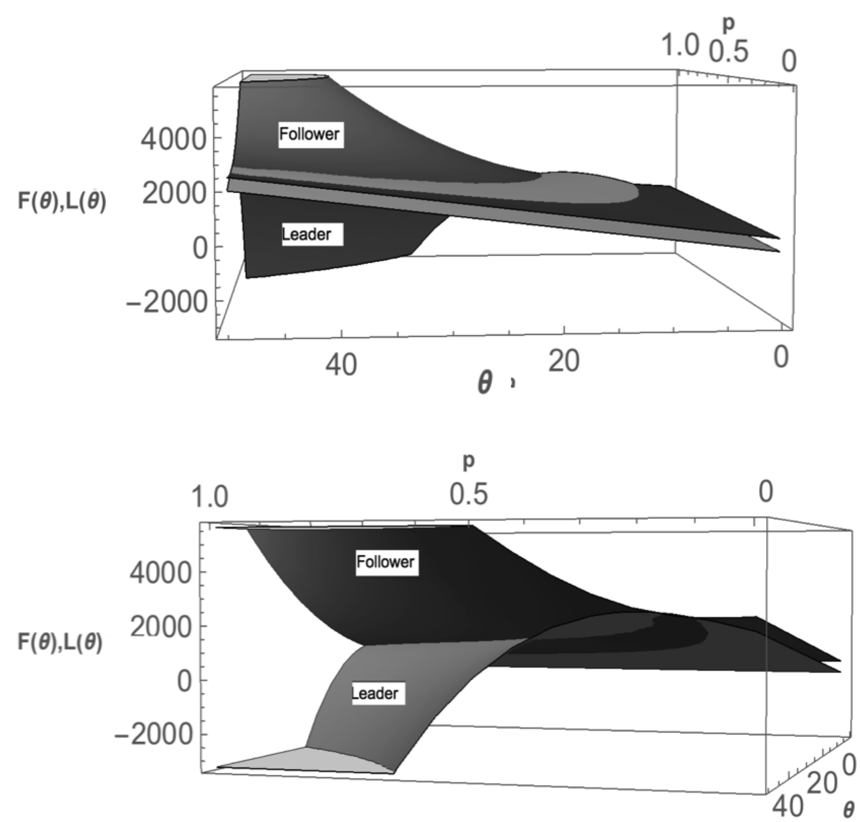


Figure 5.13: Value functions: leader and follower ($I = 500, D_{12} = 1, D_{12} = 2, D_{22} = 3, D_{21} = 6$)

As one should expect, the leader's value function is a concave function since it reflects the possible reduction in the value of the project once the follower decides to enter. In contrast, the follower's value function is a convex function since once the leader has invested the remaining firm acts as it were alone in the market and only takes positive values for all pairs of (θ, p).

It is worth noting that the originality of this Chapter with the introduction of uncertainty in the $R\&D$ stage transform the usual problem into a multidimensional one as presented in Figure 5.13, making the analysis much more complicated.

5.5 Simultaneous optimal investment

Apart from the optimal sequential investment, we need to analyse the situation where both firms invest at the same time, but not cooperatively.

The value function is divided in two parts, before and after both firms invest and is given by:

$$S(\theta) = \begin{cases} \underbrace{\frac{\theta D_{11}}{\delta}}_{\text{Current profit flow}} + \underbrace{B_5 \theta^{\beta}}_{\text{Option to invest}} & \text{if } \theta \leq \theta_S \\ \frac{\theta}{\delta}\left[\underbrace{p^2 D_{22}}_{\text{Both firms are successful}} + \underbrace{p(1-p)(D_{12}+D_{21})}_{\text{One firm is successful and the other is not}} + \underbrace{(1-p)^2 D_{11}}_{\text{Both firms are unsuccessful}}\right] - I & \text{if } \theta > \theta_S \end{cases} \tag{5.43}$$

where B_5 and θ_S are given by (Appendix C):

$$B_5 = \left(\frac{I}{\beta - 1}\right)(\theta_S)^{-}\beta \tag{5.44}$$

$$\theta_S = \frac{\beta\delta I}{p(\beta-1)[pD_{22} + (1-p)(D_{21}+D_{12}) - (2-p)D_{11}]} \tag{5.45}$$

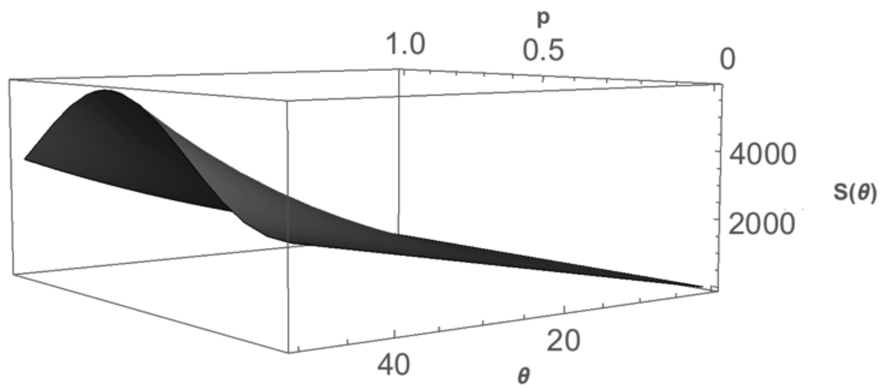


Figure 5.14: Simultaneous' value function $(I = 500, D_{12} = 1, D_{12} = 2, D_{22} = 3, D_{21} = 8)$

The simultaneous value function takes only positive values for all pairs of (θ, p). The more the investment is delayed, regardless of the value of p, the value function increases (Figure 5.14). The latter is consistent with the well-known results when $p = 1$, where the simultaneous value function is a convex one.

Proposition 1. *If* $D_{22} \geq \frac{1}{p}[(2-p)D_{11} - (1-p)(D_{12} + D_{21})]$*, then* $\theta_S \geq 0$.

Proof. Appendix D. ■

Proposition 1 is necessary to ensure that the trigger point is positive and exists.

Lemma 2. $\theta_{F1} < \theta_S$.

Proof. Appendix D. ■

Lemma 2 states that the follower will invest strictly before the simultaneous situation when the leader was unsuccessful (Follower's Case 1). However, the relation between the follower's trigger point when the leader was successful (Follower's Case 2) and the simultaneous trigger point is not straightforward. Thus, the next lemma provides the needed condition to order the trigger points.

Lemma 3. *If* $\frac{D_{11}-D_{12}}{D_{21}-D_{22}} \leq \frac{1-p}{2-p} \Rightarrow \theta_{F2} \leq \theta_S$

Proof. Appendix D.

■

By Lemma 1, the follower's investment will always occur strictly before when the leader is unsuccessful than when the leader is successful, $\theta_{F1} < \theta_{F2}$. The intuition behind this is that since the firm that invested before did not introduce the new product into the market, the remaining firm now has the chance to obtain the higher profits if it launches the new product successfully.

Lemma 2 states that the investment of the follower whenever the leader results unsuccessful will occur always before compared to the case where both firms choose to invest simultaneously. However, if the leader is successful, the time of the follower's investment will be less or equal to the simultaneous investment time only if the Lemma 3 holds. It depends on the distance between the current profits and the potential ones.

As the probability of success the follower's trigger points decrease; however, in the simultaneous case, the effect of p on θ_S could go either way. In the next proposition, the conditions for each case are clarified.

Proposition 2.

(a) If $2D_{11} \leq \ D_{12} + D_{21} \Rightarrow$ *if* p *increases so does* θ_S $(\frac{\partial \theta_S}{\partial p} > 0)$.

(b) If $2D_{11} > D_{12} + D_{21} \Rightarrow$ *if* p *increases,* θ_S *decreases* $(\frac{\partial \theta_S}{\partial p} < 0)$.

Proof. Appendix D. ■

Proposition 2 states that if the average of the two potential profits, one where a firm is successful or not where is not, is at least twice the current profits, then as the probability of success increases so does the optimal investment time.

When $p = 1$, the simultaneous trigger is reduced to the one of Pawlina and Kort (2006).

5.6 Solving the game

The follower's optimal investment point is obtained by considering a single-agent problem since the rival's firm has already invested and do not have the possibility of doing it again. However, the leader's optimal investment trigger cannot be obtained in a similar fashion, because it faces the possibility of the rival's future entry.

The leader's investment trigger comes from the rent equalisation principle (Fudenberg and Tirole, 1985):

$$\theta_L := \inf\{t \geqslant 0 | F(\theta) = L(\theta)\} \tag{5.46}$$

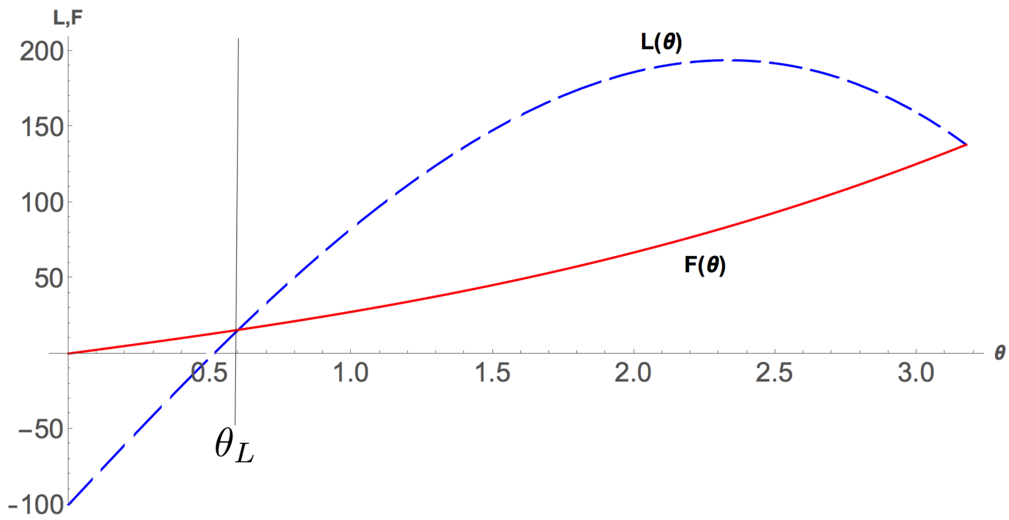
Figure 5.15 shows the leader's value function. The optimal trigger point moves closer to the valuation time when:

- probability of success approaches one, and/or
- larger the first mover advantage

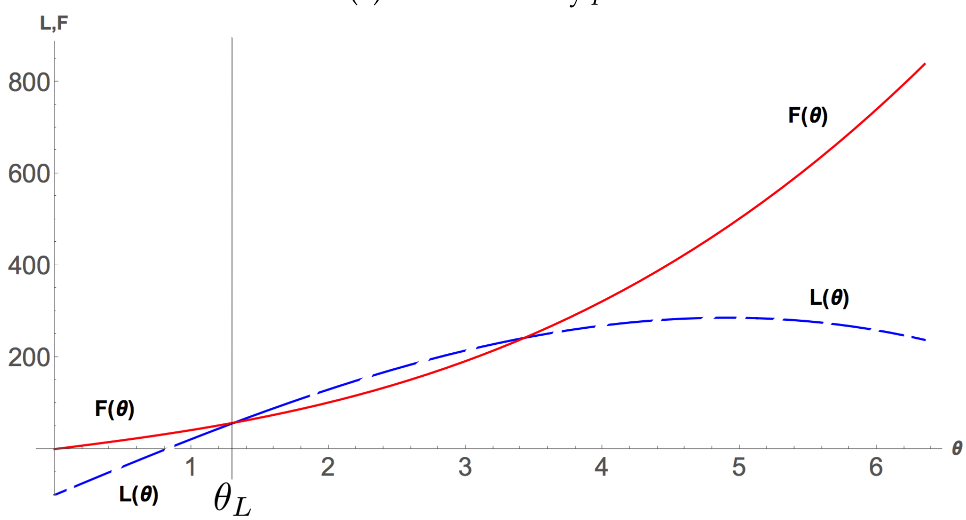
The leader's value function $F(\theta)$ is the one that combines both cases for the follower weighted by the probability of success (Function 5.36), while the leader's value function is the one of its corresponding general problem as well (Function 5.42). As shown in Figure 5.13, the follower's value function, before investment, is convex; the leader's value function, before the follower invests, is concave

It is worth noting that the leader's value function is always concave because it shows the reduction in the profit when the follower introduces its product in the market. On the contrary, the follower's value function is convex, because this firm does not face the threat of future entrance of a competitor (Figure 5.15).

In Figure 5.15, I present two cases of the value functions in the pre-investment stage depending on the value of the probability of success. On the top, there is no uncertainty on the R&D stage ($p = 1$), while at the bottom $p = 0.5$. As expected, the leader's trigger point increases when the probability of success decreases since it is better for the firm to wait to receive a better return on its investment.



(a) No uncertainty $p = 1$



(b) $p = 0.5$

Figure 5.15: Value functions in the pre-investment stage: leader and follower $(I = 100, D_{12} = 1, D_{11} = 2, D_{22} = 3, D_{21} = 8)$

Figure 5.16 shows the expected value of the leader's trigger, $p * \theta_L$, against the probability of technological success, p. When $p = 1$, the expected leader's trigger is equal to the leader's trigger defined in (5.46).

It is worth noting that θ_L is undefined when $p = 0$. As $p \to 1$, the expected value decreases bounded by θ_L. Also, the larger the FMA is, the expected value will be smaller for each value of p.

Focusing on the expected value of the leader's trigger rather than in the leader's trigger point, it is possible to assess the impact that p has on the leader's decision, since it isolates the dominant action of the probability of technological success on the investment decision (impact of p on θ_L).

As expected, less uncertainty accelerates the investment, for any FMA.

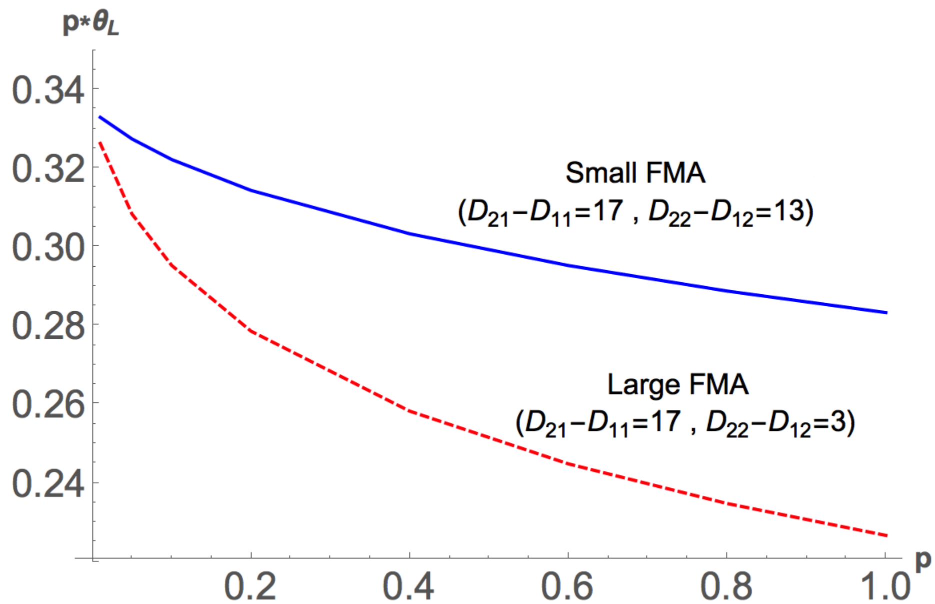


Figure 5.16: Leader's expected trigger
$(I = 100, D_{11} = 2, D_{12} = 1)$

In Figure 5.17, the expected simultaneous trigger ($p * \theta_S$) is shown in the same fashion as in Figure 5.16 for the leader. In this case, the expected trigger when acting simultaneously increases as $p \to 1$. This result means that more uncertainty accelerates the simultaneous investment, which is contrasting to the leader's expected trigger point, $p * \theta_L$, where more uncertainty slows down the investment.

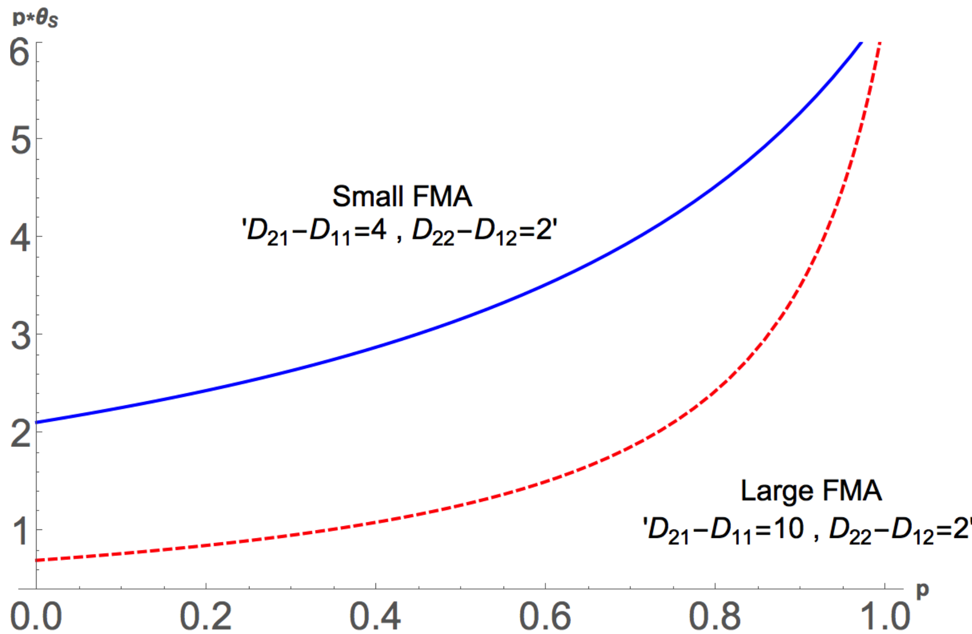


Figure 5.17: Simultaneous' expected trigger
$(I = 100, D_{11} = 2, D_{12} = 1)$

The following Propositions are the formalisation of what I discuss above.

Proposition 3. *The expected simultaneous' trigger point, $p * \theta_S$, increases with the probability of technological success.*

Proof. Appendix D. ∎

Proposition 4. *The expected follower's investment points, $p\theta_{F1}$ and $p\theta_{F2}$, are invariant to the probability of technological success, p.*

Proof. Appendix D. ∎

5.6.1 Conditions for equilibria

The existence of the simultaneous equilibrium depends on the relationship between $S(\theta)$ and $L(\theta)$.

In Figure 5.18 it can be observed that as the probability of success decreases, the leader's value function flattens. It is important to obtain a threshold of p where the leader's value function is always below the one of the simultaneous case for the interval of θ below θ_S.

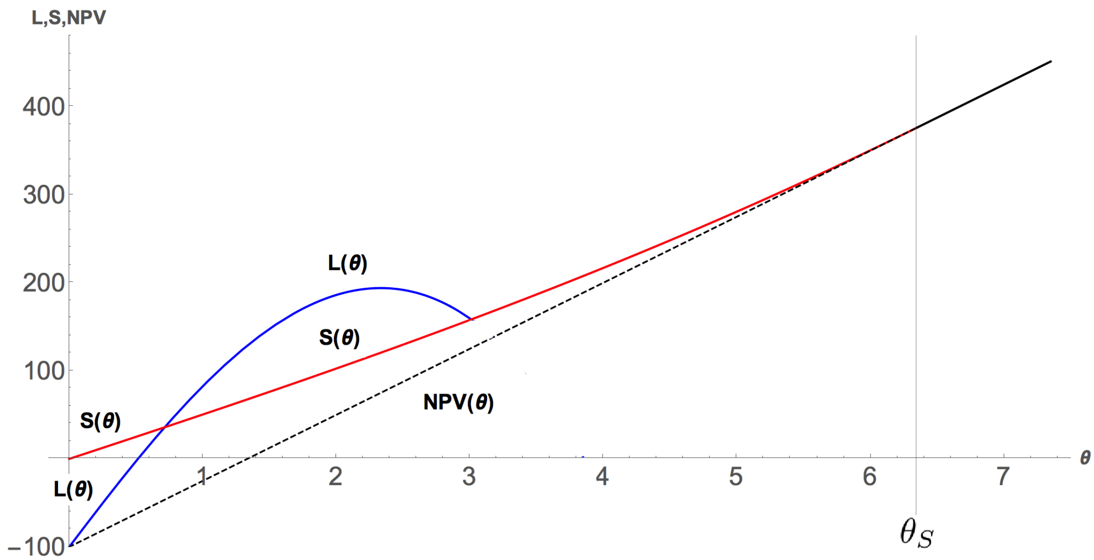
To analyse whether the simultaneous equilibrium is relevant, we will look at the difference between the leader's value function and the simultaneous' value function, for $\theta < \theta_S$. Let $\phi(\theta, p)$ be this difference:

$$\begin{aligned}\phi(\theta) &= L(\theta) - S(\theta)\\ &= \frac{p\theta}{\delta}\left[(D_{21}-D_{11}) - (1-p)(D_{11}-D_{12}) * \left(\frac{\theta}{\theta_{F1}}\right)^{\beta-1} - p(D_{21}-D_{22})\left(\frac{\theta}{\theta_{F2}}\right)^{\beta-1}\right]\\ &\qquad - I\left[1+\frac{1}{\beta-1}\left(\frac{\theta}{\theta_S}\right)^{\beta}\right] \qquad (5.47)\end{aligned}$$

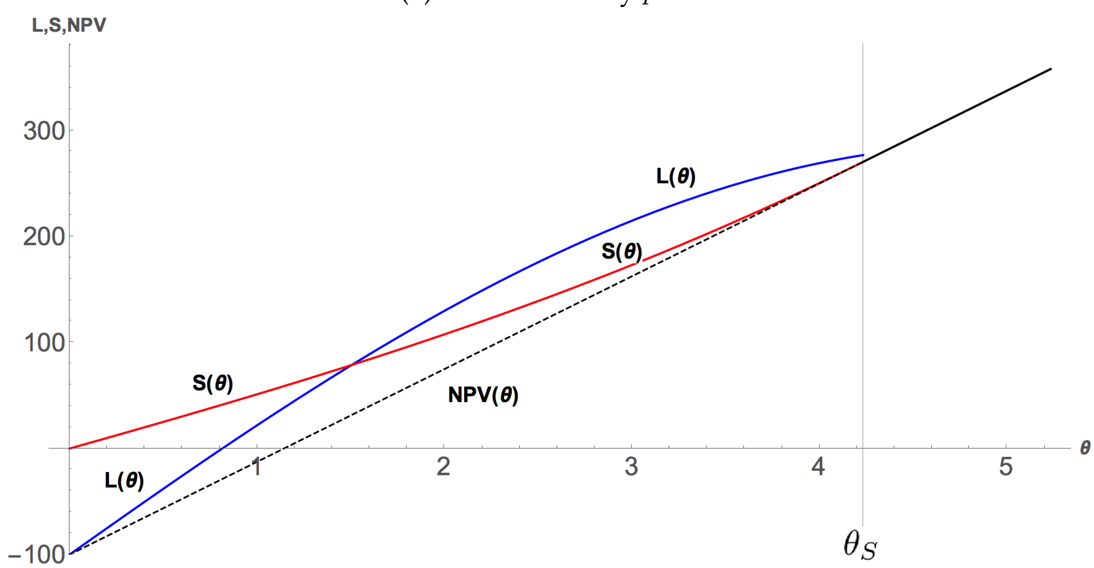
Weeds (2002) states the conditions for each type of equilibrium:

(a) If $\exists\theta < \theta_S$ such that $\phi(\theta, p) > 0$, there exists two asymmetric leader-follower equilibria. The first one where firm 1 invests as the leader at θ_L and firm 2 invests as the follower at θ_{F1} or at θ_{F2} depending on the leader's outcome. And the second one, when the firm's identities are reversed.

(b) If $\phi(\theta, p) \leq 0 \; \forall\theta < \theta_S$, two types of equilibria exist. The first one, the leader-follower equilibria as described before. The second one where both firms invest simultaneously at θ_S.



(a) No uncertainty $p = 1$



(b) $p = 0.5$

Figure 5.18: Value functions in the pre-investment stage: leader and simultaneous ($I = 100, D_{12} = 1, D_{11} = 2, D_{22} = 3, D_{21} = 8$)

Note that whenever the simultaneous equilibrium exists it Pareto-dominates the asymmetric sequential equilibrium (Fudenberg and Tirole, 1985).

Proposition 5. *There exists p^* which if the solution to the following equation*

$$\beta[p^* \left(D_{22} - D_{21}\right) \left(\frac{D_{21}-D_{11}}{D_{22}-D_{12}}\right)^{1-\beta} + (p^* - 1)(D_{11} - D_{12}) + D_{21} - D_{11}]$$
$$- \left[D_{21} - D_{11}\right]^{1-\beta} \left[D_{11}(p^* - 2) - \left(D_{12} + D_{21}\right)\left(p^* - 1\right) + D_{22}p^*\right]^{\beta} = 0$$

that determines the regions of the simultaneous and the sequential investment equilibria.

(a) For $p < p^*$ the simultaneous investment dominates.

(b) For $p \geq p^*$ only the sequential investment occurs.

Proof. Appendix D. ■

Note that Proposition 5 is the result of $L(\theta) - S(\theta) = 0$ that divides the regions of sequential and simultaneous equilibria.

Figure 5.19 presents the regions of the sequential and simultaneous investment equilibria. The horizontal axis is $(D_{22} - D_{12})$.

Recall that $FMA = D_{21} - D_{11} - (D_{22} - D_{12})$. Thus, by fixing the maximum value of the horizontal axis as $D_{21} - D_{11}$, as we move from the first value of $(D_{22} - D_{12})$ towards the right, the FMA is decreasing. In this way, the regions are divided by focusing only in the FMA. The red line that separates both regions is p^* for each value of FMA.

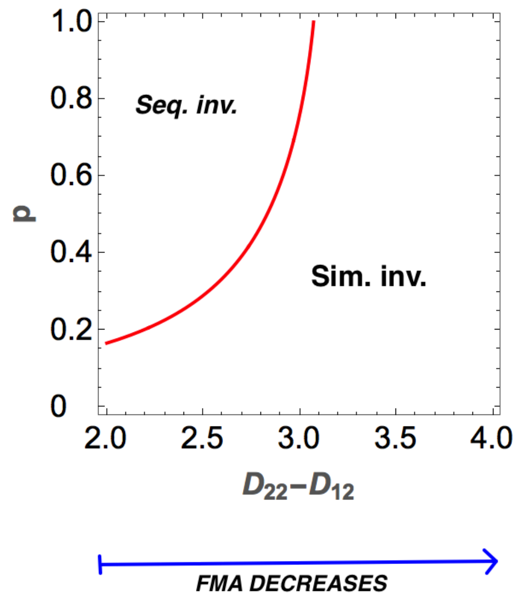


Figure 5.19: Regions of sequential and simultaneous investment equilibria
$(I = 100, D_{12} = 1, D_{11} = 2, D_{21} = 6)$

In Figure 5.19, $D_{21} - D_{11}$ is equal to 4. Assumption 1, implies that the first possible value of $D_{22} - D_{12}$ should be more than 2, since $D_{12} = 1$. When the FMA is narrow (≈ 1), regardless of the probability of success, both firms will invest at the same time. This means that, because there is actually not much to lose or to win if one firm moves first, both firms will invest at the same time.

Figure 5.20 shows the regions when $D_{21} - D_{11} = 7$. As before, when the FMA is large, the sequential investment equilibria are predominant, unless $p \approx 0$.

In both figures, we observe that as the FMA increases, the probability of success that is needed to support a joint investment decreases. When there is a significant expected prize to the one that moves first, only when both firms are unlikely to be successful in launching the new product, they are going to invest at the same time. As $p \to 1$, the sequential investment will occur whenever the FMA is bigger (> 1).

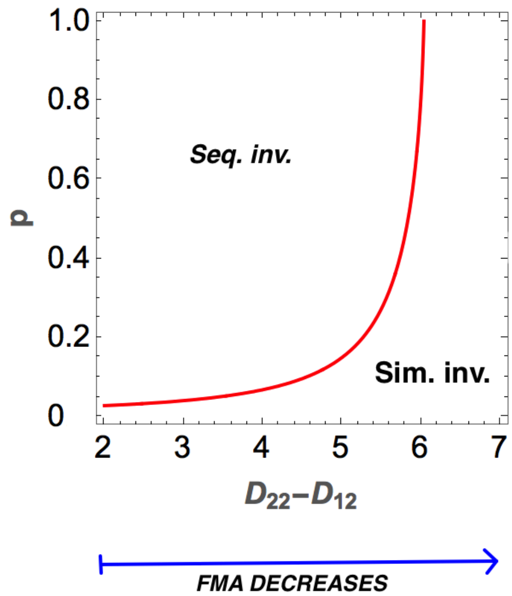


Figure 5.20: Regions of sequential and simultaneous investment equilibria ($I = 100, D_{12} = 1, D_{11} = 2, D_{21} = 9$)

To identify the regions of the sequential and simultaneous investment is one of the most significant results of this chapter since it provides the rationale behind some business decisions that at first sight may be considered as not worth investing.

For instance, when the probability of success is near to zero, one would expect for both firms to wait until the value of the project increases. However, this may not be the case since the opportunity to invest could be attractive for both firms when the FMA is small, giving place to a simultaneous investment. Furthermore, when the probability of success is subtle, but the FMA is large, one firm will deviate and invest strictly before the other to catch the profit gains.

5.6.2 Value of the firm

Before any investment takes place, each firm needs to consider the value of the different investment opportunities: sequential and simultaneous.

For the sequential investment, in the pre-investment stage, the relevant value of the firm to consider for the leader's case is:

$$V_0(\theta, p) = \frac{\theta D_{11}}{\delta} + \left[L\left(\theta_L, p\right) - \frac{\theta_L D_{11}}{\delta} \right] \left(\frac{\theta}{\theta_L} \right)^{\beta} \tag{5.48}$$

$V_0(\theta, p)$ is derived in Appendix D.

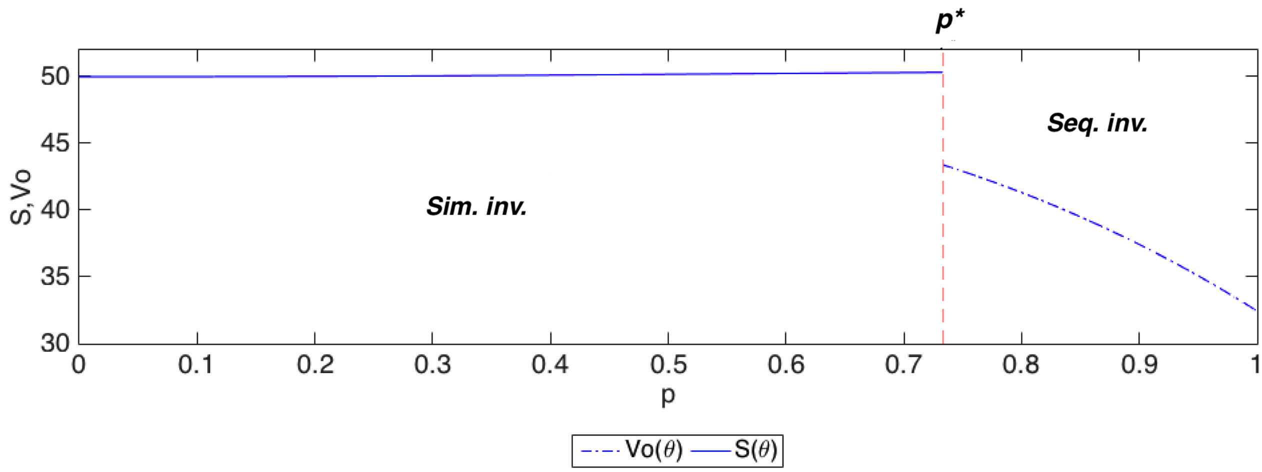
From Proposition 5, if $p \geq p^*$, the sequential investment occurs. For values of $p < p*$, the value of the firm is the one of the simultaneous case, $S(\theta, p)$.

Moreover, the value of each firm is discontinuous at $p*$:

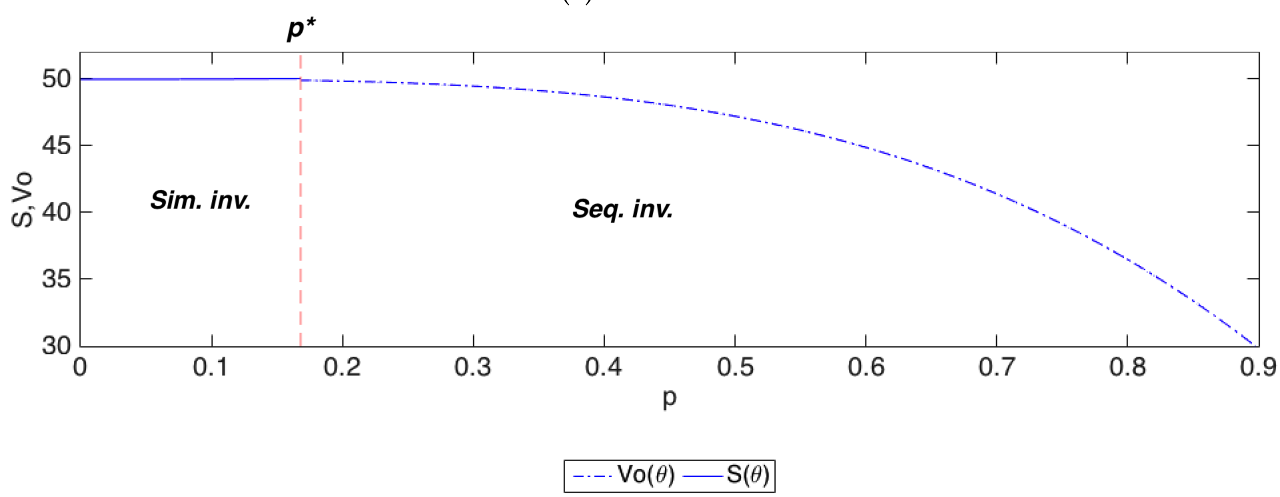
(a) In the simultaneous investment region, the effect of the probability of success is almost null.

(b) For values of $p \geq p^*$, the leader will invest at θ_L rather than at θ_S, but the value of the firm will decrease at $p \to 1$.

Figure 5.21 shows the value of the firm in each region for two values of FMA. The critical value of p that divides the investment regions decreases as the FMA increases, which is consistent with Figures 5.19 and 5.20.



(a) FMA=1



(b) FMA=2

Figure 5.21: Value of the firm corresponding to the regions of sequential and simultaneous investment $(I = 100, D_{12} = 1, D_{11} = 2, D_{22} = 3, \theta = 1)$

It is worth noting that the discontinuity is more pronounced at $p*$ whenever the FMA is smaller. This discontinuity vanishes as the FMA increases.

V_0 results decreasing in p. One possible explanation is that as the probability of success increases, θ_L decreases rapidly. Thus, an earlier investment will take place, destroying much of the option to wait. This preemptive behaviour diminishes the value of the firm, instead of increasing it. As $p \to 1$, the value of the firm in the sequential region decreases more rapidly than when p is closer to 0.

Contrary to the results in the existing literature (e.g. Pawlina and Kort, 2006), the value of the leader does not increase. On the contrary, the value decreases as the probability of success increases since the trigger point declines rapidly, deteriorating the value of the project.

5.7 Conclusions

In this chapter, the role of uncertainty in a NPD project is introduced when two competitors, of the same size, are deciding the optimal timing of investment. This uncertainty was empirically discussed in the previous chapter where I analysed the latest major NPD projects of Boeing and Airbus. In that industry, both parties are of the same size, competing to introduce a new product, and facing high uncertainty in the R&D process and the market conditions.

The framework of Dixit and Pindyck (1994) and Pawlina and Kort (2006) are used in this paper, with the difference that I consider identical investment cost for both firms and both firms are already operating in the market. Profit uncertainty comes through a stochastic shock, common to the industry, which follows a Geometric Brownian motion.

Each firm observes at each time the current state of their profits depending on the present value of the stochastic shock and decides whether to invest or not and unlike other related papers, I consider that uncertainty comes through the stochastic shock and the probability of success of the NPD. In the previous two chapters, I discussed that a NPD faces the possibility of failure due to many factors inside and outside the firm.

Unlike a Stackelberg model where the leader is predetermined, in this chapter, I consider that any of the two firms could potentially invest first depending on the potential gains of being the leader, considering both the probability of success and the current state of the profits. This condition may give place to a simultaneous investment, where both firms decide to invest at the same time.

A firm will decide to invest depending on the net present value of the project and the probability of success. If the probability of success of the NPD is close to zero, even if the potential profits are significant, the firm may decide to postpone the investment. Moreover, not only its probability of success matter but also the one of its competitor.

Two types equilibria are discussed (sequential and simultaneous). I found the regions of investment in each type in function of the first mover advantage. When FMA is small, the simultaneous investment will only occur for low probability of technology success; if the probability of success is higher, even a small prize for being the first to move will trigger a sequential investment.

One interesting finding is that higher probability of success does not mean higher value for the firm. A possible explanation is that since fewer uncertainty results in earlier investment, the preemption behaviour lowers the value of the investment opportunity, rather than increasing it as one would normally expect.

Moreover, first mover advantage increases the critical value of the probability of success needed to sustain a simultaneous equilibrium. Thus, whenever there is a significant expected prize attached to the firm that moves first, only when both firms are unlikely to be successful in launching a new product, both firms will invest at the same time, and a simultaneous equilibrium will occur. Otherwise, there is an incentive to deviate occurring a sequential equilibrium where preemptive behaviour will lower the value of the project for both firms.

These results are not constrained to the case of a new product development, and they can also be used in the case of a process improvement, since we assume that when firms engage in a process improvement is in order to reduce costs and in turn increase profit, the same logic of this paper applies to that.

One natural extension of this paper is to consider different probabilities of technological success, one for each firm, to assess the effect of the asymmetry in the patterns of investment.

Chapter 6

Conclusions

This thesis introduced various topics on innovation. The final chapter is a summary of this study. It looks at the work presented, summarises the main contributions, and looks at further research.

6.1 Summary

In the present dissertation, I discussed three different aspects of an innovation system: how to incentivise it, how to organise it, and how decision-making occurs. The first two aspects are empirically studied using mainly patent information, while the last one is investigated theoretically.

In Chapter 1, I discuss the role of universities on innovation and whether private firms act as substitutes or complements to fundamental research. One fundamental reason in favour of public funding directed at universities and public centres R&D activities has been that in the absence of such intervention, the private market would not adequately supply certain types of research. The appropriability problem of basic research provides a strong argument in favour of the intervention of the government.

In Chapter 2, I analyse whether university research is of wider use compared to private firms research, both measured as the number of future citations of their corresponding patents by third-parties. Public policy towards university research is mainly tailored to specific areas. As the government controls the allocation of federal funds, it can decide whether or not a certain field of research is worth of a subsidy.

In particular, the study differs from others since I use a particular technology area, where universities and private firms have been engaged from the beginning and have been active until recently. I find that if private firms and academia are equally involved in a technological area, research agreements between the two may result beneficial for both and that universities do indeed act as the starting point.

In Chapter 3, I introduce the concept of New Product Development that involves several phases where a final manufacturer decides not only its internal R&D organisation but also the relationship between the suppliers and their respective degree of involvement in the project. The role of a supplier may range from a contractual one where simple parts are sold to the final manufacturer, to a major partner in charge of an entire subsystem.

Chapter 4 presents empirical evidence of the different innovation attitudes of Boeing and Airbus by tracking the careers of the inventors that have been present in at least one patent owned by any of these firms. By doing this, I am able to show that Boeing's inventors have been present not only in the innovations of the same firm but also in innovations of other firms, while been employees of Boeing, and that some other inventors have patents that are assigned to Boeing while they have never been employees of the firm. I do not find this behaviour with the inventors involved in the patents of Airbus.

To my best knowledge, the main contribution of Chapter 4 is that it provides evidence of a firm's innovation path, where by looking in detail at each of Boeing's and Airbus' practices, I can identify their R&D approaches by using patent information analytically. The methodology is original and can be adapted to any other firm of interest.

Finally, in Chapter 5, I present a dynamic duopoly model using real options analysis that in contrast to the method of Net Present Value, reversibility and postponement of the project are considered, along with market conditions that are changing continuously. Thus, the use of real options is a tool to decide the optimal timing of investment has gain great popularity since it considers flexibility. Each firm observes at each time the current state of their profits depending on the current value of the stochastic shock and decides whether to invest or not and unlike other related papers, I consider that uncertainty comes through the stochastic shock and the probability of success of the NPD.

Two types equilibria are discussed (sequential and simultaneous). I find the regions of investment in each type in function of the first mover advantage. One interesting finding is that higher probability of success does not mean higher value for the firm. A possible explanation is that since fewer uncertainty results in an earlier investment, the preemption behaviour lowers the value of the investment opportunity, rather than increasing it as one would normally expect. Moreover, first mover advantage increases the critical value of the probability of success needed to sustain a simultaneous equilibrium.

6.2 Further research and limitations

Although Chapter 2 does provide a detailed study on the difference between university and patents of private firms, the study is constrained to one technology field. One possible extension would be to explore different technology areas where both universities and private firms have been involved. In this way, one would be able to reinforce the results of the Chapter or to provide further tools to policymakers.

Furthermore, in Chapter 2, I use controls such as examiners, attorneys and countries; however, there are some other variables that the USPTO provides that could be utilized as controls, for instance, the number of claims, U.S. class or whether the patent cites a gene or a method.

Chapter 4 is limited to one single duopoly, Boeing and Airbus, but the methodology is not constrained to this market. It could be worth exploring a different set of firms within the same industry to explore the innovation path of each using their corresponding patent information to compare the results of the chapter.

For any extensions or modifications of Chapters 2 and 4, the first step would be to obtain the information from the government patent office. However, one should first customise a scraping program to extract the information from the websites, since there are only limited patent databases that are readily available and the information is updated continuously. Moreover, it is important to mention that the approaches used in Chapters 2 and 4 are time-consuming and require careful data mining. One should be aware of this issue at the moment of the creation of the database.

Finally, Chapter 5 presents a duopoly model using real options analysis and assumes that the new product replaces completely the old one; however, one possible modification, probably more realistic in many industries, would be to assume that both products coexist at least for a time until the firm decides to discontinue the old one. Also, I assume one single exogenous probability of success for both firms, but it could be analysed how the equilibria changes in the case where each firm faces a different probability of success, possibly endogenous and dependent on the time and money spent on the R&D phase.

Appendix

6.3 Appendix A: estimation with references cited

Table 6.1: Results considering the change in 2001

Dependent variable: net citations first four years after issue date

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML
Year filed$\geq$2001	0.425*	0.941***	0.435	0.355*	0.973***	0.114	0.095	0.487*	0.047	0.398*	0.916***	0.380
	(0.186)	(0.227)	(0.325)	(0.175)	(0.214)	(0.250)	(0.171)	(0.197)	(0.266)	(0.187)	(0.226)	(0.323)
Distance	-0.140***	-0.070***	-0.122***	-0.139***	-0.061***	-0.114***	-0.133***	-0.054**	-0.117***	-0.139***	-0.066***	-0.117***
	(0.018)	(0.018)	(0.016)	(0.015)	(0.015)	(0.013)	(0.017)	(0.017)	(0.015)	(0.018)	(0.018)	(0.016)
University	-0.072	-0.021	-0.014	-0.110	-0.067	-0.088	-0.112	-0.038	-0.013	-0.192	-0.122	-0.134
	(0.127)	(0.116)	(0.119)	(0.130)	(0.119)	(0.134)	(0.120)	(0.108)	(0.119)	(0.134)	(0.122)	(0.135)
Government	-0.513*	-0.535*	-0.531*	-0.013	-0.110	-0.205	-0.340	-0.350	-0.427*	0.085	0.017	-0.120
	(0.252)	(0.240)	(0.242)	(0.297)	(0.296)	(0.238)	(0.276)	(0.262)	(0.211)	(0.299)	(0.296)	(0.237)
Individual	0.066	-0.024	-0.129	0.092	-0.038	-0.248	0.089	-0.006	-0.081	0.135	0.052	-0.132
	(0.243)	(0.221)	(0.235)	(0.255)	(0.231)	(0.244)	(0.253)	(0.225)	(0.223)	(0.253)	(0.232)	(0.236)
University*Year01	-0.425	-0.564	-0.562	-0.558*	-0.830*	-0.562	-0.073	-0.192	-0.285	-0.386	-0.585	-0.477
	(0.269)	(0.339)	(0.381)	(0.266)	(0.329)	(0.374)	(0.255)	(0.307)	(0.338)	(0.272)	(0.336)	(0.381)
Government*Year01	-1.054	-0.925	-1.047	-1.029	-1.097	-0.940	-0.348	-0.111	-0.348	-1.043	-0.896	-1.004
	(0.559)	(0.710)	(0.582)	(0.573)	(0.706)	(0.569)	(0.525)	(0.633)	(0.560)	(0.580)	(0.758)	(0.586)
Individual*Year01	0.113	0.258	0.189	-0.094	-0.233	0.273	0.499	1.002	0.443	0.163	0.608	0.222
	(0.494)	(0.667)	(0.643)	(0.483)	(0.592)	(0.632)	(0.498)	(0.718)	(0.651)	(0.498)	(0.726)	(0.668)
Agents	Yes	Yes	Yes	Yes	Yes	Yes				Yes	Yes	Yes
Examiners	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes
Countries				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.812***	1.031***	1.418***	1.769***	0.889*	1.411***	1.911***	1.003***	1.542***	1.897***	1.062***	1.455***
	(0.318)	(0.283)	(0.256)	(0.393)	(0.375)	(0.315)	(0.307)	(0.273)	(0.231)	(0.321)	(0.287)	(0.259)
Ln(alpha)	0.894***	0.140		0.932***	0.150		1.017***	0.258*		0.848***	0.093	
	(0.062)	(0.114)		(0.061)	(0.108)		(0.060)	(0.106)		(0.062)	(0.114)	
Inflate												
Distance		0.295***			0.305***			0.297***			0.301***	
		(0.025)			(0.023)			(0.023)			(0.025)	
Constant		-5.850***			-5.983***			-5.825***			-6.015***	
		(0.569)			(0.531)			(0.527)			(0.589)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412	3428	3428	3364

Standard errors in parentheses

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

Table 6.2: Results considering the change in 2001 and dummies for Examiners, Agents and Countries

Dependent variable: net citations first four years after issue date

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML
Year filed≥2001	0.425*	0.941***	0.435	0.355*	0.973***	0.114	0.095	0.487*	0.047
	(0.186)	(0.227)	(0.325)	(0.175)	(0.214)	(0.250)	(0.171)	(0.197)	(0.266)
Distance	-0.140***	-0.070***	-0.122***	-0.139***	-0.061***	-0.114***	-0.133***	-0.054**	-0.117***
	(0.018)	(0.018)	(0.016)	(0.015)	(0.015)	(0.013)	(0.017)	(0.017)	(0.015)
University	-0.072	-0.021	-0.014	-0.110	-0.067	-0.088	-0.112	-0.038	-0.013
	(0.127)	(0.116)	(0.119)	(0.130)	(0.119)	(0.134)	(0.120)	(0.108)	(0.119)
Government	-0.513*	-0.535*	-0.531*	-0.013	-0.110	-0.205	-0.340	-0.350	-0.427*
	(0.252)	(0.240)	(0.242)	(0.297)	(0.296)	(0.238)	(0.276)	(0.262)	(0.211)
Individual	0.066	-0.024	-0.129	0.092	-0.038	-0.248	0.089	-0.006	-0.081
	(0.243)	(0.221)	(0.235)	(0.255)	(0.231)	(0.244)	(0.253)	(0.225)	(0.223)
University*Year01	-0.425	-0.564	-0.562	-0.558*	-0.830*	-0.562	-0.073	-0.192	-0.285
	(0.269)	(0.339)	(0.381)	(0.266)	(0.329)	(0.374)	(0.255)	(0.307)	(0.338)
Government*Year01	-1.054	-0.925	-1.047	-1.029	-1.097	-0.940	-0.348	-0.111	-0.348
	(0.559)	(0.710)	(0.582)	(0.573)	(0.706)	(0.569)	(0.525)	(0.633)	(0.560)
Individual*Year01	0.113	0.258	0.189	-0.094	-0.233	0.273	0.499	1.002	0.443
	(0.494)	(0.667)	(0.643)	(0.483)	(0.592)	(0.632)	(0.498)	(0.718)	(0.651)
Agents	Yes	Yes	Yes						
Examiners							Yes	Yes	Yes
Countries							Yes	Yes	Yes
Constant	1.812***	1.031***	1.418***	1.769***	0.889*	1.411***	1.911***	1.003***	1.542***
	(0.318)	(0.283)	(0.256)	(0.393)	(0.375)	(0.315)	(0.307)	(0.273)	(0.231)
Ln(alpha)	0.894***	0.140		0.932***	0.150		1.017***	0.258*	
	(0.062)	(0.114)		(0.061)	(0.108)		(0.060)	(0.106)	
Inflate									
Distance		0.295***			0.305***			0.297***	
		(0.025)			(0.023)			(0.023)	
Constant		-5.850***			-5.983***			-5.825***	
		(0.569)			(0.531)			(0.527)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412
		0.100							

Standard errors in parentheses

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

Table 6.2: Results considering the change in 2001 and dummies for Examiners, Agents and Countries

Dependent variable: net citations first four years after issue date

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML
Year filed≥2001	0.407*	0.882***	0.425	0.341	0.931***	0.104	0.155	0.543**	0.047	0.387*	0.872***	0.377
	(0.187)	(0.225)	(0.322)	(0.176)	(0.214)	(0.252)	(0.172)	(0.197)	(0.261)	(0.188)	(0.225)	(0.318)
Distance	-0.159***	-0.088***	-0.134***	-0.155***	-0.077***	-0.123***	-0.150***	-0.072***	-0.131***	-0.154***	-0.081***	-0.128***
	(0.018)	(0.018)	(0.017)	(0.016)	(0.016)	(0.013)	(0.017)	(0.017)	(0.015)	(0.018)	(0.018)	(0.017)
References Cited	0.580***	0.501***	0.423***	0.470***	0.382***	0.376***	0.575***	0.531***	0.511***	0.533***	0.457***	0.398***
	(0.100)	(0.108)	(0.099)	(0.098)	(0.102)	(0.101)	(0.093)	(0.097)	(0.093)	(0.100)	(0.107)	(0.097)
References Cited^2	-0.050***	-0.044***	-0.040**	-0.040***	-0.033**	-0.036**	-0.049***	-0.047***	-0.046***	-0.046***	-0.041***	-0.039**
	(0.011)	(0.012)	(0.013)	(0.011)	(0.011)	(0.013)	(0.011)	(0.011)	(0.012)	(0.011)	(0.012)	(0.013)
University	-0.047	-0.014	0.008	-0.060	-0.041	-0.037	-0.060	-0.003	0.018	-0.135	-0.089	-0.085
	(0.127)	(0.115)	(0.121)	(0.130)	(0.119)	(0.135)	(0.119)	(0.108)	(0.118)	(0.134)	(0.122)	(0.136)
Government	-0.388	-0.432	-0.473	0.055	-0.038	-0.177	-0.268	-0.289	-0.394	0.159	0.100	-0.087
	(0.253)	(0.242)	(0.245)	(0.297)	(0.295)	(0.240)	(0.275)	(0.262)	(0.208)	(0.299)	(0.296)	(0.240)
Individual	0.184	0.068	-0.077	0.172	0.026	-0.212	0.197	0.098	-0.033	0.232	0.128	-0.089
	(0.243)	(0.221)	(0.237)	(0.254)	(0.232)	(0.248)	(0.251)	(0.225)	(0.227)	(0.252)	(0.232)	(0.238)
University*Year01	-0.356	-0.479	-0.520	-0.520	-0.779*	-0.534	-0.118	-0.238	-0.291	-0.341	-0.515	-0.453
	(0.272)	(0.337)	(0.379)	(0.268)	(0.328)	(0.373)	(0.256)	(0.305)	(0.336)	(0.274)	(0.334)	(0.379)
Government*Year01	-0.869	-0.783	-0.934	-0.919	-0.986	-0.866	-0.353	-0.130	-0.316	-0.926	-0.815	-0.936
	(0.560)	(0.694)	(0.591)	(0.573)	(0.702)	(0.574)	(0.525)	(0.626)	(0.564)	(0.582)	(0.746)	(0.592)
Individual*Year01	0.206	0.401	0.267	-0.047	-0.189	0.328	0.504	1.019	0.520	0.243	0.706	0.299
	(0.494)	(0.661)	(0.641)	(0.483)	(0.590)	(0.635)	(0.491)	(0.711)	(0.650)	(0.497)	(0.724)	(0.665)
Agents	Yes	Yes	Yes	Yes	Yes	Yes				Yes	Yes	Yes
Examiners	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes
Countries				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.785***	1.008***	1.387***	1.820***	0.932*	1.452***	1.829***	0.936***	1.477***	1.828***	1.006***	1.407***
	(0.320)	(0.286)	(0.251)	(0.390)	(0.375)	(0.314)	(0.306)	(0.273)	(0.223)	(0.323)	(0.289)	(0.253)
Ln(alpha)	0.870***	0.165		0.911***	0.179		0.974***	0.267**		0.828***	0.113	
	(0.062)	(0.110)		(0.061)	(0.105)		(0.060)	(0.102)		(0.063)	(0.112)	
inflate												
Distance		0.296***			0.309***			0.302***			0.303***	
		(0.025)			(0.024)			(0.024)			(0.026)	
Constant		-5.975***			-6.156***			-6.022***			-6.127***	
		(0.589)			(0.552)			(0.550)			(0.605)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412	3428	3428	3364

Standard errors in parentheses

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

Table 6.3: Results including dummies for Examiners, Agents and Countries

Dependent variable: net citations on the first four years after issue date

	(1) NB	(2) ZINB	(3) PPML	(4) NB	(5) ZINB	(6) PPML	(7) NB	(8) ZINB	(9) PPML
Distance	-0.103***	-0.018	-0.095***	-0.106***	-0.006	-0.103***	-0.120***	-0.025	-0.111***
	(0.016)	(0.017)	(0.023)	(0.013)	(0.014)	(0.018)	(0.014)	(0.015)	(0.019)
University	0.920*	1.015**	0.741	0.979*	0.966*	0.508	0.513	0.657	0.431
	(0.419)	(0.386)	(0.416)	(0.430)	(0.389)	(0.382)	(0.413)	(0.376)	(0.378)
Government	1.585	1.315	1.700	2.472*	2.104	1.968*	0.199	-0.143	0.282
	(1.046)	(1.030)	(1.084)	(1.188)	(1.156)	(0.943)	(0.946)	(0.880)	(0.832)
Individual	-0.592	-0.920	-0.838	-0.547	-0.666	-1.045	-0.905	-1.280	-0.914
	(0.792)	(0.747)	(0.553)	(0.821)	(0.725)	(0.575)	(0.804)	(0.738)	(0.507)
University*Distance	-0.065**	-0.072**	-0.055*	-0.072**	-0.074**	-0.044	-0.038	-0.047*	-0.031
	(0.024)	(0.025)	(0.028)	(0.025)	(0.024)	(0.025)	(0.023)	(0.023)	(0.024)
Government*Distance	-0.131*	-0.120*	-0.143*	-0.151*	-0.141*	-0.135*	-0.035	-0.014	-0.047
	(0.057)	(0.060)	(0.064)	(0.063)	(0.065)	(0.055)	(0.051)	(0.052)	(0.051)
Individual*Distance	0.039	0.058	0.047	0.034	0.038	0.054	0.064	0.087	0.057
	(0.044)	(0.046)	(0.036)	(0.045)	(0.044)	(0.036)	(0.045)	(0.046)	(0.034)
Agents	Yes	Yes	Yes						
Examiners							Yes	Yes	Yes
Countries							Yes	Yes	Yes
Constant	1.226***	0.301	1.065**	1.301***	0.161	1.182**	1.693***	0.589*	1.441***
	(0.316)	(0.292)	(0.329)	(0.384)	(0.377)	(0.371)	(0.290)	(0.267)	(0.282)
Ln(alpha)	0.889***	0.141		0.924***	0.141		1.012***	0.249*	
	(0.062)	(0.116)		(0.061)	(0.111)		(0.060)	(0.107)	
Inflate									
Distance		0.279***			0.283***			0.287***	
		(0.023)			(0.021)			(0.022)	
Constant		-5.538***			-5.540***			-5.618***	
		(0.536)			(0.482)			(0.501)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412

Standard errors in parentheses

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

Table 6.4: Result including dummies for Examiners, Agents and Countries

Dependant variable: net citations first four years after issue date

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML	NB	ZINB	PPML
main												
Years from start of												
technological cycle (Distance)	-0.123***	-0.039*	-0.108***	-0.124***	-0.024	-0.114***	-0.134***	-0.041**	-0.125***	-0.121***	-0.034	-0.105***
	(0.016)	(0.017)	(0.024)	(0.013)	(0.015)	(0.019)	(0.014)	(0.015)	(0.019)	(0.016)	(0.017)	(0.023)
References Cited	0.577***	0.512***	0.426***	0.468***	0.395***	0.377***	0.579***	0.531***	0.518***	0.533***	0.468***	0.402***
	(0.100)	(0.108)	(0.100)	(0.098)	(0.103)	(0.102)	(0.093)	(0.097)	(0.094)	(0.100)	(0.107)	(0.098)
References Cited^2	-0.051***	-0.047***	-0.042**	-0.041***	-0.037**	-0.037**	-0.050***	-0.049***	-0.047***	-0.047***	-0.044***	-0.040**
	(0.011)	(0.012)	(0.014)	(0.011)	(0.011)	(0.013)	(0.011)	(0.011)	(0.013)	(0.011)	(0.012)	(0.013)
University	0.836*	0.947*	0.717	0.956*	0.926*	0.495	0.619	0.731	0.490	0.698	0.830*	0.545
	(0.419)	(0.387)	(0.412)	(0.431)	(0.392)	(0.373)	(0.412)	(0.376)	(0.368)	(0.428)	(0.394)	(0.407)
Government	1.345	1.194	1.586	2.262	1.979	1.907*	0.170	-0.151	0.262	2.252	1.892	2.078*
	(1.039)	(1.022)	(1.115)	(1.184)	(1.152)	(0.945)	(0.941)	(0.878)	(0.809)	(1.172)	(1.161)	(1.006)
Individual	-0.649	-0.980	-0.891	-0.607	-0.713	-1.116	-0.872	-1.264	-0.974	-0.716	-1.168	-0.903
	(0.789)	(0.747)	(0.556)	(0.820)	(0.729)	(0.579)	(0.793)	(0.738)	(0.509)	(0.798)	(0.763)	(0.574)
University*Distance	-0.058*	-0.067**	-0.051	-0.067**	-0.069**	-0.039	-0.042	-0.050*	-0.033	-0.054*	-0.064**	-0.046
	(0.024)	(0.025)	(0.027)	(0.025)	(0.025)	(0.024)	(0.023)	(0.023)	(0.024)	(0.025)	(0.025)	(0.027)
Government*Distance	-0.109	-0.105	-0.132*	-0.134*	-0.128*	-0.129*	-0.030	-0.010	-0.043	-0.128*	-0.114	-0.137*
	(0.057)	(0.059)	(0.066)	(0.063)	(0.065)	(0.056)	(0.051)	(0.052)	(0.050)	(0.063)	(0.066)	(0.061)
Individual*Distance	0.050	0.069	0.054	0.043	0.045	0.061	0.068	0.093*	0.065	0.057	0.087	0.055
	(0.044)	(0.046)	(0.036)	(0.045)	(0.044)	(0.036)	(0.044)	(0.046)	(0.034)	(0.045)	(0.047)	(0.037)
Agents	Yes	Yes	Yes	Yes	Yes	Yes				Yes	Yes	Yes
Examiners	Yes	Yes	Yes				Yes	Yes	Yes	Yes	Yes	Yes
Countries				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.252***	0.321	1.052**	1.390***	0.245	1.250***	1.563***	0.493	1.370***	1.318***	0.344	1.113***
	(0.316)	(0.293)	(0.327)	(0.380)	(0.375)	(0.371)	(0.287)	(0.267)	(0.276)	(0.320)	(0.295)	(0.319)
Ln(alpha)	0.866***	0.160		0.903***	0.169		0.969***	0.260*		0.823***	0.110	
	(0.062)	(0.113)		(0.062)	(0.109)		(0.061)	(0.104)		(0.063)	(0.115)	
Inflate												
Distance		0.279***			0.287***			0.291***			0.285***	
		(0.024)			(0.022)			(0.023)			(0.025)	
Constant		-5.639***			-5.704***			-5.789***			-5.781***	
		(0.554)			(0.503)			(0.524)			(0.572)	
Observations	3428	3428	3380	3428	3428	3364	3428	3428	3412	3428	3428	3364

Standard errors in parentheses

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

6.4 Appendix B: expected payoff

6.4.1 Follower (Case 1): leader was unsuccessful in R&D with probability $1-p$

Before the follower invests, the firm has current profits:

$$\mathcal{E}_t\left(\int_t^{\infty}\pi_{11}(\theta_k)e^{-r(k-t)}\,dk\right)=\mathcal{E}_t\left(\int_t^{\infty}\theta_k D_{11}e^{-r(k-t)}dk\right)=\frac{D_{11}\theta}{r-\alpha}=\frac{D_{11}\theta}{\delta}$$

Where θ represents the state of θ_t at time t.

After the follower invests, the profits of the firm are given by:

$$p\mathcal{E}_t\left[\int_t^{\infty}\pi_{21}(\theta_k)e^{-r(k-t)}dk\right]+(1-p)\,\mathcal{E}_t\left[\int_t^{\infty}\pi_{11}(\theta_k)e^{-r(k-t)}dk\right]-I=$$
$$p\frac{\theta D_{21}}{\delta}+(1-p)\,\frac{\theta D_{11}}{\delta}-I=\frac{\theta}{\delta}\left[pD_{21}+(1-p)\,D_{11}\right]-I$$

6.4.2 Follower (Case 2): leader was successful in R&D with probability p

Before the follower invests, the firm is receiving:

$$\mathcal{E}_t\left(\int_t^{\infty}\pi_{12}(\theta_k)e^{-r(k-t)}\,dk\right)=\mathcal{E}_t\left(\int_t^{\infty}\theta_k D_{12}e^{-r(k-t)}dk\right)=\frac{D_{12}\theta}{r-\alpha}=\frac{D_{12}\theta}{\delta}$$

plus the option to invest in R&D and, if successful, the profits are given by:

$$p\mathcal{E}_t\left[\int_t^{\infty}\pi_{22}(\theta_k)e^{-r(k-t)}dk\right]+(1-p)\,\mathcal{E}_t\left[\int_t^{\infty}\pi_{12}(\theta_k)e^{-r(k-t)}dk\right]-I=$$
$$p\frac{\theta D_{22}}{\delta}+(1-p)\,\frac{\theta D_{12}}{\delta}-I=\frac{\theta}{\delta}\left[pD_{22}+(1-p)\,D_{12}\right]-I$$

6.4.3 Leader (Case 1): firm is unsuccessful in R&D with probability $1-p$

Before the follower invests, the profits of the leader are given by:

$$\mathcal{E}_t\left(\int_t^{\infty}\pi_{11}(\theta_k)e^{-r(k-t)}\,dk\right)-I=\mathcal{E}_t\left(\int_t^{\infty}\theta_k D_{11}e^{-r(k-t)}dk\right)-I=$$
$$\frac{D_{11}\theta}{r-\alpha}-I=\frac{D_{11}\theta}{\delta}-I$$

and the possible profits after the follower invests:

$$p\mathcal{E}_t\left[\int_t^{\infty}\pi_{12}(\theta_k)e^{-r(k-t)}dk\right]+(1-p)\,\mathcal{E}_t\left[\int_t^{\infty}\pi_{11}(\theta_k)e^{-r(k-t)}dk\right]-I$$
$$=p\frac{\theta D_{12}}{\delta}+(1-p)\,\frac{\theta D_{11}}{\delta}-I=\frac{\theta}{\delta}\left[pD_{12}+(1-p)\,D_{11}\right]-I$$

6.4.4 Leader (Case 2): firm is successful in R&D with probability p

The current profits of the leader, before the follower invests:

$$\mathcal{E}_t\left(\int_t^{\infty}\pi_{21}(\theta_k)e^{-r(k-t)}\,dk\right)=\mathcal{E}_t\left(\int_t^{\infty}\theta_k D_{21}e^{-r(k-t)}dk\right)-I$$
$$=\frac{D_{21}\theta}{r-\alpha}-I=\frac{D_{21}\theta}{\delta}-I$$

and the possible profits after the follower invests:

$$p\mathcal{E}_t\left[\int_t^{\infty}\pi_{22}(\theta_s)e^{-r(k-t)}dk\right]+(1-p)\,\mathcal{E}_t\left[\int_t^{\infty}\pi_{21}(\theta_k)e^{-r(k-t)}dk\right]-I=$$
$$p\frac{\theta D_{22}}{\delta}+(1-p)\,\frac{\theta D_{21}}{\delta}-I=\frac{\theta}{\delta}\left[pD_{22}+(1-p)\,D_{21}\right]-I$$

6.4.5 Simultaneous Case

To analyse this case, one needs to consider the current profit of each firm, before they simultaneously invest:

$$\mathcal{E}_t\left(\int_t^{\infty}\pi_{11}(\theta_k)e^{-r(k-t)}\,dk\right)=\mathcal{E}_t\left(\int_t^{\infty}\theta_k D_{11}e^{-r(k-t)}dk\right)=\frac{D_{11}\theta}{r-\alpha}=\frac{D_{11}\theta}{\delta}$$

and the possible profits, same for each firm, after investment:

$$p^2\mathcal{E}_t\left[\int_t^\infty \pi_{22}(\theta_k)e^{-r(k-t)}dk\right] + p(1-p)\mathcal{E}_t\left[\int_t^\infty (\pi_{21}(\theta_s)+\pi_{12}(\theta_s))e^{-r(k-t)}dk\right]$$
$$+ (1-p)^2\mathcal{E}\left[\int_t^\infty \pi_{11}(\theta_k)e^{-r(k-t)}dk\right] - I =$$
$$p\frac{\theta D_{22}}{\delta} + p(1-p)\frac{\theta(D_{21}+D_{12})}{\delta} + (1-p)\,\frac{\theta D_{11}}{\delta} - I =$$
$$\frac{\theta}{\delta}\left[pD_{22} + p(1-p)(D_{21}+D_{12}) + (1-p)\,D_{11}\right] - I$$

6.5 Appendix C: value functions

6.5.1 Follower's value function: Case 1

6.5.1.a Pre-investment in R&D: $V_{F1}(\theta)$

Before the Follower decides to invest, the firm knows that the Leader has not been successful in R&D and has not launched a new product in the market. Thus, the old product is the only one in the market. The value function of the pre-investment region is given by:

$$V_{F1}(\theta) = \frac{D_{11}\theta}{\delta} + B_1\theta^\beta \tag{6.1}$$

where B_1 is a parameter to be found and $\theta < \theta_{F1}$.

6.5.1.b Post-investment in R&D: $NPV_{F1}(\theta)$

After the optimal trigger point (θ_{F1}), the follower is successful in R&D and launches the new product with probability p, receiving monopoly profit; or with probability $(1-p)$ fails to have the new product and receives profits from the old product, since it is the only one in the market:

$$NPV_{F1}(\theta) = p\left(\frac{D_{21}\theta}{\delta}\right) + (1-p)\left(\frac{D_{11}\theta}{\delta}\right) \tag{6.2}$$

6.5.1.c Boundary conditions

To obtain the optimal time of investing, the firm needs to find when the expected profit before investing is equal to the expected profit after investing, minus the total investment cost.

$$V_{F1}\left(\theta_{F1}\right) = NPV_{F1}\left(\theta_{F1}\right) - I \tag{6.3}$$

$$V'_{F1}\left(\theta_{F1}\right) = NPV'_{F1}\left(\theta_{F1}\right) \tag{6.4}$$

Conditions (6.3) and (6.4) come from the optimal time to invest θ_{F1}. Condition (6.3) is the value-matching which implies that the optimal investment time is when the pre-investment expected payoff is equal to the post-investment expected payoff. Equation(6.4) is the "smooth-pasting" condition.

As discussed in Dixit and Pindyck (1994), the parameter B_1 and θ_{F1} can be obtained from the boundary conditions:

$$B_1 = \left[\frac{p\left(D_{21} - D_{11}\right)}{\beta\delta}\right]\left(\theta_{F1}\right)^{1-\beta} \tag{6.5}$$

$$\theta_{F1} = \left(\frac{\beta}{\beta - 1}\right)\left[\frac{\delta I}{p\left(D_{21} - D_{11}\right)}\right] \tag{6.6}$$

where θ_{F1} can be understood as the first hitting time when $V_{F1}\left(\theta\right) \geq NPV_{F1}\left(\theta\right) - I$,

$$\theta_{F1} = \inf\{t \geqslant 0 | V_{F1}\left(\theta_{F1}\right) \geq NPV_{F1}\left(\theta_{F1}\right) - I\} \tag{6.7}$$

β is the positive root of the corresponding Bellman equation:

$$\frac{1}{2}\sigma^2\theta^2 V''_{F1}(\theta) + \alpha\theta V'_{F1}(\theta) - rV_{F1}(\theta) + \theta D_{11} = 0 \tag{6.8}$$

Substituting (6.5) into V_{F1} we obtain:

$$V_{F1}(\theta) = \frac{D_{11}\theta}{\delta} + \left(\frac{\theta}{\theta_{F1}}\right)^{\beta}\left[\frac{p\theta_{F1}\left(D_{21} - D_{11}\right)}{\beta\delta}\right] \tag{6.9}$$

The first term of the value function of the follower in case 1 represents the current cash-flow of the profits in perpetuity, while the second term represents the present value of the difference between investing or not, adjusted by the probability of success.

6.5.2 Follower's value function: Case 2

6.5.2.a Pre-investment in R&D: $V_{F2}(\theta)$

Before the Follower decides to invest, the firm knows that the leader has been successful in R&D and in turn has launched a new product in the market. Thus, the follower receives profits from the old product. The value function of the pre-investment region is given by:

$$V_{F2}(\theta) = \frac{D_{12}\theta}{\delta} + B_2\theta^{\beta} \tag{6.10}$$

where B_2 is a parameter to be found.

6.5.2.b Post-investment in R&D: $NPV_{F2}(\theta)$

After the optimal trigger point (θ_{F2}), the follower is successful in R&D and launches the new product with probability p_1, receiving duopoly profits; or with probability $(1 - p_1)$ fails to have the new product and receives profits from the old product:

$$NPV_{F2}(\theta) = p\left(\frac{D_{22}\theta}{\delta}\right) + (1-p)\left(\frac{D_{12}\theta}{\delta}\right) \tag{6.11}$$

6.5.2.c Boundary conditions

Again, as in case 1, to obtain the optimal time of investing, the firm needs to find when the expected profit before investing is equal to the expected profit after investing, minus the total investment cost:

$$V_{F2}\left(\theta_{F2}\right) = NPV_{F2}\left(\theta_{F2}\right) - I \tag{6.12}$$

$$V'_{F2}\left(\theta_{F2}\right) = NPV'_{F2}\left(\theta_{F2}\right) \tag{6.13}$$

Using conditions (6.12) and (6.13), we obtain B_2 and θ_{F2}:

$$B_2 = \left[\frac{p\left(D_{22} - D_{12}\right)}{\beta\delta}\right]\left(\theta_{F2}\right)^{1-\beta} \tag{6.14}$$

$$\theta_{F2} = \left(\frac{\beta}{\beta - 1}\right) * \left[\frac{\delta I}{p * \left(D_{22} - D_{12}\right)}\right] \tag{6.15}$$

θ_{F2} can be understood as the first hitting time when $V_{F2}\left(\theta\right) \geq NPV_{F2}\left(\theta\right) - I$,

$$\theta_{F2} = \inf\left\{t \geqslant 0 \left| V_{F2}\left(\theta_{F2}\right) \geq NPV_{F2}\left(\theta_{F2}\right) - I\right.\right\} \tag{6.16}$$

β is the positive root of the corresponding Bellman equation:

$$\frac{1}{2}\sigma^2\theta^2 V''_{F2}(\theta) + \alpha\theta V'_{F2}(\theta) - rV_{F2}(\theta) + \theta D_{12} = 0 \tag{6.17}$$

Substituting (6.14) into $V_{F2}(\theta)$ we obtain that:

$$V_{F2}(\theta) = \frac{D_{12}\theta}{\delta} + \left(\frac{\theta}{\theta_{F2}}\right)^{\beta}\left[\frac{p\theta_{F2}\left(D_{22} - D_{12}\right)}{\beta\delta}\right] \tag{6.18}$$

The first term of the value function of the follower in case 2 represents the current cash-flow of the profits in perpetuity, while the second term represents the present value of the difference between investing or not, adjusted by the probability of success.

6.5.3 Simultaneous value function

6.5.3.a Pre-investment value function

Before both firms invest, the old product is the only one in the market. The value function of the pre-investment region, for each firm, is given by:

$$V_S(\theta) = \frac{D_{11}\theta}{\delta} + B_5\theta^{\beta} \tag{6.19}$$

where B_5 is a parameter to be found and $\theta < \theta_S$.

Post-investment value function

After the optimal trigger point (θ_{S}), the value function for each firm is given by:

$$NPV_S(\theta) = p^2\left(\frac{D_{22}\theta}{\delta}\right) + p(1-p)\left[\frac{(D_{12}+D_{21})\theta}{\delta}\right] + (1-p)^2\left(\frac{D_{11}\theta}{\delta}\right) - I \tag{6.20}$$

6.5.3.b Boundary conditions

Similar to the follower's problem, to obtain the optimal time of investing in R&D, the firm needs to find when the expected profit before investing is equal to the expected profit after investing, minus the total investment cost.

$$V_{\mathrm{S}}\left(\theta_{\mathrm{S}}\right) = NPV_{\mathrm{S}}\left(\theta_{\mathrm{S}}\right) - I \tag{6.21}$$

$$V_{\mathrm{S}}'(\theta_{\mathrm{S}}) = NPV_{\mathrm{S}}'(\theta_{\mathrm{S}}) \tag{6.22}$$

Using the boundary conditions (6.21) and (6.22):

$$B_5 = \left[\frac{p*(D_{21} - D_{11})}{\beta\delta}\right](\theta_{F1})^{1-\beta} \tag{6.23}$$

Substituting (6.23) into $V_S(\theta)$ we obtain the optimal launching trigger time:

$$\theta_S = \frac{\beta\delta I}{p(\beta-1)*[D_{11}(p-2)+(1-p)(D_{21}+D_{12})+pD_{22}]} \tag{6.24}$$

where θ_S can be understood again as the first hitting time when $V_S(\theta) \geq NPV_{\mathrm{S}}(\theta) - I$,

$$\theta_{\mathrm{S}} = \inf\{t \geqslant 0 | V_S(\theta_S) \geq NPV_S(\theta_S) - I\} \tag{6.25}$$

β is the positive root of the corresponding Bellman equation:

$$\frac{1}{2}\sigma^2\theta^2 V_S''(\theta) + \alpha\theta V_S'(\theta) - rV_S(\theta) + \theta D_{11} = 0 \tag{6.26}$$

Substituting (6.23) into $V_S(\theta)$

$$V_S(\theta) = \frac{D_{11}\theta}{\delta} + \left(\frac{\theta}{\theta_S}\right)^{\beta}\left[\frac{p\theta_S((p-2)D_{11}+(1-p)(D_{21}+D_{12})+pD_{22})}{\beta\delta}\right] \tag{6.27}$$

6.6 Appendix D

6.6.1 Proof Proposition 1

Proof. If $D_{22} \geq \frac{1}{p}[(2-p)D_{11} - (1-p)(D_{12} + D_{21})]$, then $pD_{22} + (1-p)(D_{21} + D_{12} - D_{11}) - D_{11} \geq 0$.

Since $p \in (0, 1]$ and $\beta > 1$, the denominator of θ_S is positive.

The numerator of θ_S is always positive ($I > 0$). ■

6.6.2 Proof Lemma 2

Proof. Assumption 1 $\Rightarrow D_{12} - D_{11} < 0$ and $D_{22} - D_{21} < 0$.

$\Rightarrow (1-p)(D_{12} - D_{11}) + p(D_{22} - D_{21}) < 0$, since $0 < p \leq 1$.

Rearranging:

$\Rightarrow (1-p)(D_{12} + D_{21} - D_{11}) + pD_{22} - D_{11} < D_{21} - D_{11}$

Since $\beta > 1$

$\Rightarrow p(\beta - 1)[(1-p)(D_{12} + D_{21} - D_{11}) + pD_{22} - D_{11}] < p(\beta - 1) * D_{21} - D_{11}$, Since $I > 0$ and $\delta > 0$

$\Rightarrow \frac{I\delta\beta}{(\beta-1)D_{21}-D_{11}} < \frac{I\delta\beta}{p(\beta-1)[(1-p)(D_{12}+D_{21}-D_{11})+pD_{22}-D_{11}]}$

$\Rightarrow \theta_{F1} < \theta_S.$ ■

6.6.3 Proof Lemma 3

Proof. If $\frac{D_{11}-D_{12}}{D_{21}-D_{22}} \leq \frac{1-p}{2-p}$

$\Rightarrow (1-p)(D_{21}-D_{22}) \leq (2-p)(D_{11}-D_{12})$

Rearranging:

$\Rightarrow pD_{22} + (1-p)(D_{21}+D_{12}) - (2-p)D_{11} \leq D_{22} - D_{12}$

$\Rightarrow \frac{1}{D_{22}-D_{12}} \leq \frac{1}{pD_{22}+(1-p)(D_{21}+D_{12})-(2-p)D_{11}}$

Multiplying by $\beta\delta I$:

$\Rightarrow \frac{\beta\delta I}{D_{22}-D_{12}} \leq \frac{\beta\delta I}{pD_{22}+(1-p)(D_{21}+D_{12})-(2-p)D_{11}}$

$\Rightarrow \theta_{F2} \leq \theta_S$ ■

6.6.4 Proof Proposition 2

Proof. Using 5.45, and taking the partial derivative with respect to p:

$$\frac{\partial\theta_S}{\partial p} = \frac{I\beta\delta[2(1-p)D_{11}-(1-2p)(D_{12}+D_{21})-2pD_{22}]}{p^2(\beta-1)[pD_{22}+(1-p)(D_{12}+D_{21})-(2-p)D_{11}]^2}$$

The denominator is always positive since it is squared and $\beta > 1$. The numerator determines the sign of $\frac{\partial\theta_S}{\partial p}$.

(a) Assume $\frac{\partial\theta_S}{\partial p} > 0$

$$\Rightarrow I\beta\delta[2(1-p)D_{11} - (1-2p)(D_{12}+D_{21}) - 2pD_{22}] > 0$$

$$\Rightarrow D_{22} < \frac{2(1-p)D_{11}-(1-2p)(D_{12}+D_{21})}{2p}$$

Proposition 1 requires

$$D_{22} \geq \frac{1}{p}[(2-p)D_{11} - (1-p)(D_{12}+D_{21})]$$

$$\Rightarrow (2-p)D_{11} - (1-p)(D_{12}+D_{21}) \leq (1-p)D_{11} - (\tfrac{1}{2}-p)(D_{12}+D_{21})$$

$$\Rightarrow 2D_{11} \leq D_{12}+D_{21}$$

(b) Using (a),if $2D_{11} > D_{12} + D_{21}$

$$\Rightarrow I\beta\delta[2(1-p)D_{11}-(1-2p)(D_{12}+D_{21})-2pD_{22}]<0$$

$$\Rightarrow \frac{\partial\theta_S}{\partial p}<0$$

■

6.6.5 Proof Proposition 4

Proof.

(a) $p\theta_{F1}=\left(\frac{\beta}{\beta-1}\right)\left(\frac{\delta I}{D_{21}-D_{11}}\right)\Rightarrow\frac{\partial(p\theta_{F1})}{\partial p}=0$

(b) $p\theta_{F2}=\left(\frac{\beta}{\beta-1}\right)\left(\frac{\delta I}{D_{22}-D_{12}}\right)\Rightarrow\frac{\partial(p\theta_{F2})}{\partial p}=0$

■

6.6.6 Proof Proposition 3

Proof. $p\theta_S=\frac{\beta\delta I}{(\beta-1)[pD_{22}+(1-p)(D_{21}+D_{12})-(2-p)D_{11}]}$

$$\Rightarrow\frac{\partial(p\theta_S)}{\partial p}=\frac{(\beta\delta I)(D_{21}-D_{11}-(D_{22}-D_{12}))}{(\beta-1)[pD_{22}+(1-p)(D_{21}+D_{12})-(2-p)D_{11}]^2}$$

By assumption 2, the numerator is always positive. Moreover, $\beta>1$, $\delta>0$ and $I>0$. The denominator is also always positive.

$$\Rightarrow\frac{\partial(p\theta_S)}{\partial p}>0$$

■

6.6.7 Proof Proposition 5

Proof. Consider the following system of equations:

$$\phi(\theta^*, p^*) = 0 \tag{6.28}$$

$$\frac{\partial \phi(\theta^*, p^*)}{\partial \theta}\Big|_{\theta=\theta^*} = 0 \tag{6.29}$$

Equations (6.28) and (6.29) look at the first pair of (θ, p) where the leader's and the simultaneous' value functions are tangent (Figure 6.1).

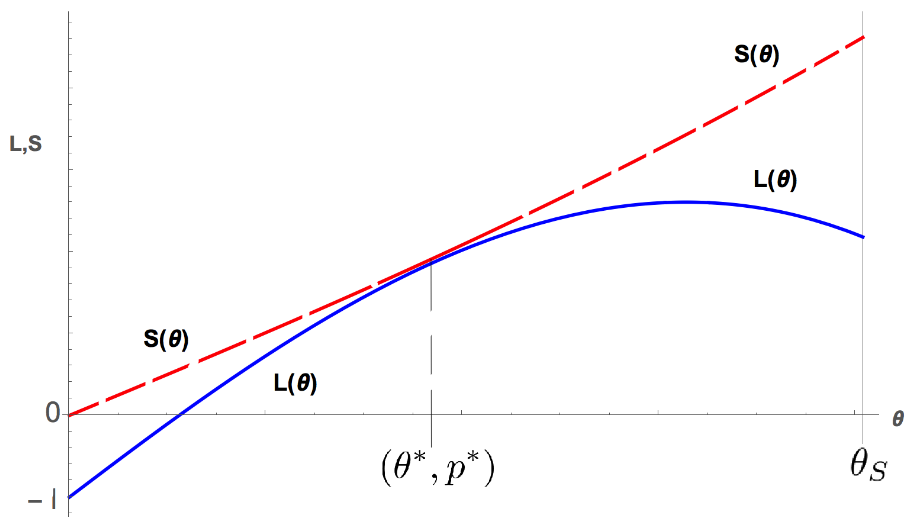


Figure 6.1: Tangency of leader's and simultaneous' value functions

Substituting $\phi(\theta^*, p^*)$ into (6.28):

$$\frac{p^*\theta^*(D_{21}-D_{11})}{\delta} - \left[\frac{p^*{\theta^*}^{\beta}}{\delta}\right]\left[p^*(D_{21}-D_{22})\theta_{F2}^{1-\beta} + (1-p^*)(D_{11}-D_{12})\theta_{F1}^{1-\beta}\right]$$
$$- I\left[1 + \frac{1}{\beta-1}\left(\frac{\theta^*}{\theta_S(p^*)}\right)^{\beta}\right] = 0 \quad (6.30)$$

Taking the partial derivative of $\phi(\theta^*, p^*)$ with respect to θ when $\theta = \theta^*$:

$$\frac{p^*(D_{21}-D_{11})}{\delta} - \left[\frac{\beta p^*{\theta^*}^{\beta-1}}{\delta}\right]\left[p^*(D_{21}-D_{22})\theta_{F2}^{1-\beta} + (1-p^*)(D_{11}-D_{12})\theta_{F1}^{1-\beta}\right]$$
$$- \left(\frac{\beta I}{(\beta-1)\theta^*}\right)\left[\frac{\theta^*}{\theta_S(p^*)}\right]^{\beta} = 0 \quad (6.31)$$

Multiplying equation 6.31 by $(\frac{\theta^*}{\beta})$ and subtracting it from Equation 6.30:

$$\frac{p^*\theta^*(D_{21}-D_{11})(\beta-1)}{\beta\delta} - I = 0 \quad (6.32)$$

Solving θ^* from Equation 6.32:

$$\theta^* = \frac{\delta I \beta}{p^*(D_{21}-D_{11})(\beta-1)} \quad (6.33)$$

Substituting θ^* in Equation 6.31 and rearranging:

$$\beta[p^* \left(D_{22} - D_{21}\right) \left(\frac{D_{21} - D_{11}}{D_{22} - D_{12}}\right)^{1-\beta} + (p^* - 1)(D_{11} - D_{12}) + D_{21} - D_{11}]$$
$$- \left[D_{21} - D_{11}\right]^{1-\beta} \left[D_{11}(p^* - 2) - \left(D_{12} + D_{21}\right)\left(p^* - 1\right) + D_{22}p^*\right]^{\beta} = 0 \quad (6.34)$$

■

6.6.8 Derivation of $V_0(\theta, p)$

Before any firm has invested, the value of each firm is given by the current profits plus the option to invest:

$$V_0(\theta, p) = \frac{D_{11}\theta}{\delta} + B\theta^{\beta} \quad (6.35)$$

It is also true that at the leader's trigger point, θ_L:

$$V_0\left(\theta_L, p\right) = L(\theta_L, p) \quad (6.36)$$

From Equations 6.35 and 6.36:

$$B = \theta_L^{-\beta}\left[L(\theta_L, p) - \frac{\theta_L D_{11}}{\delta}\right] \quad (6.37)$$

Substituting 6.37 in 6.35:

$$V_0(\theta, p) = \frac{\theta D_{11}}{\delta} + \left[L\left(\theta_L, p\right) - \frac{\theta_L D_{11}}{\delta}\right]\left(\frac{\theta}{\theta_L}\right)^{\beta} \quad (6.38)$$

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