Pathways to Innovation: Modelling University-to-Firm Research Development

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ABSTRACT

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Research and development activities conducted at universities and firms fuel economic growth and play a key role in the process of innovation. Specifically, prior research has investigated the widespread university-to-firm research development path and concluded that universities are better suited for early stage of research while firms are better positioned for later stages. This thesis aims to present a novel explanation for the pervasive university-to-firm research development path. The model developed uses game theory to visualize and analyze interactions between a firm and university under different strategies. The results reveal that as academic research signals knowledge it helps attract tuition paying students. Generating these tuition revenues is facilitated by university research discoveries, which, once published, a firm can build upon to make new innovative products. In an environment of weak intellectual property rights, moreover, the university-to-firm research development path enables firms to bypass the hefty costs that are involved in basic research activities. The model also provides a range of solution scenarios where a university and firm may find it viable to initiate a research line.

Keywords: Research and development, Basic research, Applied research, Commercializable product, University to-firm research path, Intellectual property rights, Tuition revenues, Game theory, Extensive form games, Nash equilibrium.

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1. Introduction

Research and development has co-existed in universities and firms, driven by different economic dynamics, fueling a debate over the efficiency of academic tenure contracts, creative freedom, and their impact on knowledge production. The major contention arising from such debate can be summed up in the following questions: How does the complex relationship between universities and firms affect the process of innovation? How can we explain the prevalence of the university-to-firm research development path? For one, universities have always been considered beacons of knowledge creation and dissemination. The central role academic institutions have played in the twentieth century to advance mankind's knowledge is indisputable and has been used as an argument to justify government's funding. In the United States, for instance, research and development carried out in universities greatly helped the country's military effort and bolstered their chances to win World War II, and subsequently entrenched its position as a leading nation in different fields. It was this "huge success of science in supplying practical results during World War II in one sense supplied its own legitimation for science" and justified government investment in academia (Etzkowitz & Leydesdorff, 2000, p.116). As Mowery et al. (2001) suggest, academic research played a crucial role in providing many industries with practical solutions and applications to different kinds of problems. In fact, X-ray and lasers, just the tip of the iceberg of innovations, reveal the wide array of the many inventions that owe their existence to research held in university laboratories.

At the same time, economists have argued that the university's continuing role in knowledge production and innovation remains dependent on a unique nature of incentives set. In analyzing the economics of academic systems, Antonnelli (2008) argues that Dasgupta's and David's work provides a comprehensive analysis of the economic foundation of the academic system that has "shown that the academic system provides a viable institutional setup to combine the incentives to the dissemination and the generation of new knowledge" (p. 3). Universities' research mission is reflected in uniquely offering a system of compensation, after a probationary period, where a professor is guaranteed a job for life. The promotion is offered to faculty members hired as tenure track and whose research productivity meets a certain threshold in the first five years of employment. Cater, Lew and Pivot (2017) argue that a government would choose to subsidize research in a university "where professors also teach" because revenues are generated from research in the form of tuition, whereas in a firm, scientists do not teach and no revenues could be derived. While research productivity declines with age, the accumulated research knowledge is transmitted to tuition paying students through teaching, which explains that a professor who fails to meet their teaching duties would be fired. Faculty research thus signals knowledge and helps attract tuition paying students.

According to Shin, Toutkoushian and Teichler (2010), the fierce competition among universities, to attract tuition paying students, funding and professors, centered around their reputation before the introduction of surveying systems that aimed to rank universities based on different areas of performance. Regardless of whether these ranking metrics capture the whole story about a university's performance, they remain very popular amongst policy makers and leaders seeking to gauge the quality of universities. Such popular metrics "help consumers see the value of their investment… and provide students with comparisons of institutions in different countries" (Shin, Toutkoushian and Teichler, 2010, p. 3). For example, studies show that affluent families particularly in South Asia are sensitive to these rankings and rely on them to make college decisions (e.g., Dill & Soo, 2005).

The private sector, on the other hand, innovates by engaging in various activities among which "the acquisition of new process technologies, incremental engineering to increase productivity, the combination of existing knowledge in new ways, and investment in R&D to increase the stock of knowledge and to apply this knowledge to create new or improved products and processes" (Huang, Arundel, Hollanders, 2010, p. 5). In fast growing industries such as pharmaceuticals, automobiles, and communications, innovation is instrumental to maintaining and promoting growth in a globalized world where needs and technologies continuously evolve. The demise of Blockbuster, for instance, and many other big corporations reveals how the market landscape can shift swiftly resulting in an outdated business model that fails to predict and seize new opportunities or prevent new entrants from dominating the market. Netflix is a good example of how establishing a culture of innovation enabled the company to pioneer the online streaming industry. Netflix has taken an innovative step by producing its own content, which reduces suppliers' power and at the same time diversifies its portfolio.

In this regard, investing in innovation yields prestige, power and profits. In addition to that, harnessing intellectual property rights and turning them into marketable products generates profits and also opens up untapped opportunities. Makri, Lane and Gomez-Mejia (2006) explain how "intellectual capital and innovation have become the key sources of competitive advantage in a wide range of industries" (p. 1073). Pharmaceutical companies, for instance, investing in a new innovative technology to fight cancerous cells called CAR T cells saw their share price increase significantly after the Food and Drug Administration (FDA) approval of the new drug (Cheng, 2017). Kite Pharma, whose product therapy has already been approved by the FDA, has been sold to Gilead Sciences for $11.9 billion (Cheng, 2017). The innovative therapy has positioned Gilead Sciences as the market leader in cellular therapy and opens up more opportunities for innovation (Cheng, 2017).

While the private sector invests in research and development (internally), relying on academic research remains predominant. In today's fiercely competitive market, firms invest in research and development because innovation yields sustained competitive advantage that is very much needed to survive. Data collected by Mansfield (1991) reveal that 11% of firms' new products and 9% of new processes "would not have been developed (without substantial delay) in the absence of recent academic research"(Mansfield, 1991, p.2).

The increasingly widespread university-to-firm research development path ignited the debate about how the lack of appropriability in academia created a free rider situation where firms can access breakthrough ideas for free. The Bayh-Dole act in 1980 came to embolden the universities' stance in the process of innovation and address this market failure. The enactment meant that industry could no longer have free access to knowledge created in academia. Several studies have sought to investigate the impact of the Act on the process of innovation. Opponents claim that strengthening intellectual property rights would lead to less innovation as some ideas are better left off in the public domain where they can flourish and evolve to promising research lines. By claiming that it is optimal for research to start in university and end in the private sector, Aghion, Dewatripont and Stein (2008) seek to further reveal the drawbacks of early privatization of ideas.

1.1 Significance and Research Scope

The ability to innovate is a major contributor to the development of economies. Innovative nations are major players in the world stage, whereas those who do not lose on all fronts. Developed countries rely on research in academia to serve the common good and provide practical solutions to many problems. Yet, the increased global competition has dictated that the success of private corporations hinges upon their ability to continuously innovate despite escalating research and development costs. In such a world, partnerships with research universities provide a means to save on costs and at the same time advance current research.

In an effort to explain the complex relationship between universities and firms with regards to the process of innovation, Aghion, Dewatripont and Stein (2008) argue that while universities are well disposed to host academic research in the early stages of development, firms seem to be in a better position for later stages. University researchers value more freedom and as such are willing to accept lower wages compared to their counterparts in the private sector that have to forgo such freedom in exchange for higher wages. This thesis seeks to present a different explanation as to the prevalence of the university-to-firm research development path without relying on the assumption of low wages and answers the following research questions:

- How can we explain the prevalence of the university to a firm innovation path without assuming that universities pay lower wages?
- Why universities are inclined to share their research rather than keep it secret?
- If it is efficient for a research line to end in the private sector, shouldn't it be efficient to begin there in the first place?

Answering the research questions involved using game theory to model the different interactions between a university and firm based on several strategies. The model will be based on the assumption that wages for researchers in academia are the same as in the private sector and aims to study the feasibility and profitability of a research line depending on the value of the commercializable product and wages. The analysis reveals a range of scenarios where it is optimal for a research line to be initiated either by a university or a firm and most importantly explains why firms rely on academic research to generate innovative products.

1.2 Organization of Thesis

This thesis covers six main chapters. The introductory chapter serves as a road map for the entire thesis by laying the background about innovation both in academia and the private sector. It also encompasses the research questions and the significance of the study. The literature review chapter aims to review the current literature around the university-to-firm development path and discusses gaps in existing literature. The model chapter explains the two stage process of research and development, assumptions and the dynamics of the game between a firm and a university. The results chapter reveals the game trees based on each strategy, the expected profit for the firm and university as well as provides several numerical examples. The discussion section explains the model's results, implications and discusses how this work could be further expanded in the future. Finally, the conclusion summarizes the main findings and implications of this thesis.

2. Literature Review

Different scholars beginning with Schumpeter in the beginning of the twentieth century sought to determine which factors most impede or promote innovation. The economic literature is abundant in these studies, but this review focuses on three major areas. The first part seeks to shed light on how economists view appropriability and its impact on the process of innovation. The second section probes the link between appropriability and funding for research and development activities. Finally, a review of the Aghion, Dewatripont and Stein (2008) process of innovation model that promotes the university-to-firm development path.

2.1 Research and Development and Intellectual Property Rights

Neoclassical economists consider knowledge as a commodity, which once produced is available for free to everyone. A free rider problem arises in this instance where an "individual may be able to obtain the benefits of a good without contributing to the cost" (Pasour, 1981, p. 453). Firms, individuals, or other entities are driven by self-interest and have "an economic incentive to free ride at the expense of others in the group who attempt to promote self-interest through group behavior" (Pasour, 1981, p. 454). To solve this market failure, enacting stronger intelctual property should redress this free-rider problem. However, Rosenberg (2010) argues that appropriation is far from being the optimal solution even for firms as "allowing firms to appropriate the findings of research - create an equally serious problem because they impose restrictions upon the use of valuable knowledge that has already been produced" (p. 166). Opponents of strong intellectual property rights policies suggest that these measures would lead to less innovation especially in pharmaceuticals and biotechnology (Aghion, Dewatripont, & Stein, 2008).

The debate around protecting knowledge through strong intellectual property rights and the fear to impede access to new information has been ignited as the efficiency of such policies to spur innovation has been put into question. Pro-intellectual property rights for academia claim that these measures empower universities whose research have long been available for free and thus created a major free-rider problem. By revealing that competition and intellectual property rights are complements in promoting innovation, Spulber (2013) ascertains that "markets for intellectual property rights form as the returns of these activities are fully appropriable. Strong intellectual property rights correct the market failure caused by the free riders' problem as producers of knowledge get returns on their inventions, which leads to more innovation" (p. 1008).

The enactment of the Bayh-Dole Act (1980) in the United States provides a case study of the impact of strong intellectual property rights on innovation. The act has marked a new era that gave universities the right to patent inventions created from government grants. It "provided blanket permission for performers of federally funded research to file for patents on the results of such research and to grant licenses for these patents, including exclusive licenses, to other parties" (Mowery, et al., 2001, p. 7). As Etzkowitz explains, research universities were "active in technology transfer … lobbied for the passage of the law in order to obtain a stable, regulated environment for the disposition of intellectual property rights emanating from federally funded research" (cited in Etzkowitz, 2003, Etzkowitz et al., 2001, p. 118). According to Lach and Schankerman (2008), "the number of U.S. patents awarded to university inventors annually increased from 500 in 1982 to 3255 in 2004" (p. 404).

Mowery, et al. (2001), however, used empirical data to reveal that there is little evidence that suggests a causal relationship between the Bayh-Dole Act and the increase in licensing activities. In fact, “the growth in federal financial support for basic biomedical research in universities that began in the late 1960s, along with the related rise of research in biotechnology that began in the early 1970s, contributed to growth in university patents and licenses" (Mowery, et al., 2001, p. 2). These research activities made universities establish independent technology transfer offices prior to the Act as a way of channeling income sources originating from basic research activities with promising industrial applications. Based on these studies, it is reasonable to assume that the surge in patents in top research universities would still have happened regardless of the passing of the Bayh-Dole Act. Also, instead of assuming that the Act hurt innovation by way of early privatization, it isn't possible to view the enactment of the act as a way to fix a market failure caused by free riders i.e. firms who could no longer have free access to new knowledge?

If we assume that universities’ central role in knowledge creation and dissemination might be negatively affected when intellectual property rights regimes are strong, would firms still be inclined to innovate in the absence of mechanisms that protect the development of new products and processes? If evidence suggests that firms need greater appropriability to protect the knowledge they create, how can we explain academia’s commitment to research and development activities regardless of the status of appropriability? Firms need greater appropriability because the only way to generate revenues is through product development, whereas for universties, practically any type of research produces revenues thanks to their unique tenure system where a professor teaches and does research at the same time.

2.2 Funding Research and Development

The merits of research and development activities has always been uncontested, however, funding has always been hard to secure in a competitive market (Hall, 2012). The traditional view advanced by Nelson (1959) and Arrow (1962) states that weak intelectual property rights would cause the private sector to underinvest in basic research activities as firms would be unable to exclude incumbents from using that knowledge. In fact, strong government support for research and development activities and intellectual property rights finds its roots in endogenous macroeconomic growth models that were built on the "increasing returns principle implied by Arrow's argument that one person's use of knowledge does not diminish its utility to another (cited in Hall, 2012, Aghion and Howitt, 1997, p. 36). Public policy makers relied on these models to justify the necessity of government intervention to solve the market failure associated with research and development underinvestment. The widely held belief that attributes higher social returns associated with basic research justified why these activities remain largely funded by taxpayers.

For the private sector, Rosenberg (2010) argues that basic research activities are concentrated in firms with strong market position as they are the only ones that can afford to finance research where outcomes have a high degree of uncertainty and whose payoff is in the long run. Universities on the other hand finance research activities through government grants, internal funds, and by developing partnerships with the private sector. Auranen and Nieminen (2010) claim that while funding for research in academia has shifted in many different countries with industrial funding compensating for the decreasing government funding, the latter remains "the predominant source of funding for university research" (p. 822).

Government funding for academia sought to solve the underinvestment problem, however nothing would have precluded the government from directing these funds to the private sector. In fact, Cater, Byron and Pivato (2017) argue that when research is conducted at the university, tuition revenues could partially cover the cost even when product development does not happen. A different story transpires in the firm where revenues are expected only when research leads to product development, which makes the government liable for the entire cost if it chooses to subsidize research in the private sector. If academia's basic research involvement was justified in the context of weak intellectual property rights, what makes these activities continue in universities even in the presence of stronger copyright laws?

2.3 Creative Freedom, Wages and the Process of Innovation

In probing the process of innovation in the private sector vs. academia, Aghion, Dewatripont and Stein (2008) developed a model that reveals respective advantages and disadvantages of academic and private sector research. The authors distinguish between two types of research depending on where it was carried out. While the first type is organized in universities where scientists enjoy creative control i.e. freedom, the second type is conducted in private firms where entrepreneurs dictate the type of research strategies scientists need to focus on. The authors claim that the main tradeoff between academia and private sector is that of creative control vs. focus. Furthermore, they argue that given the cost structure of universities vs. firms, academia is essential only for early-stage research whereas the private sector is better positioned for later-stage research.

Some of the arguments and assumptions in the model are not well backed by current research. Aghion, Dewatripont and Stein (2008) argue that academia is well positioned to offer scientists freedom due to its non-profit nature and that "supervisory effort (the resources devoted to monitoring and directing scientists) as endogenous, it is plausible that academic administrators have much lower incentives to exert such effort than, e.g., a corporate CEO, whose compensation can be linked to the share price" (p. 621). At first, this argument might seem reasonable given that academic administrators receive no immediate monetary compensation when a scientist develops an economically profitable product, while top executives in corporations do receive monetary incentives when similar achievement is accomplished. In academia, administrators have greater implicit rewards that far exceed financial compensation when scientists pursue a strategy with a positive outcome. First, these departments can benefit from funding and grants that would help other scholars fund their research agenda. Second, the stellar reputation of the program due largely to researchers' achievements would mean that brilliant students would compete fiercely to join the program and increase student retention. The quality of students and professors is of utmost importance as they both boost the reputation and ranking of the university worldwide. Third, more student enrollment increases tuition revenues as well as helps the university become more independent.

According to Aghion, Dewatripont and Stein scientists in academia are free to conduct whatever type of research they prefer and no one interferes in the choice of their research strategy, "we take the defining characteristic of this organizational form to be that it represents a precommitment to leave control over the choice of research strategy in the hands of individual scientists (Aghion, Dewatripont, & Stein 2008, p. 618)." As a result, the authors believe that unlike the private sector which is better positioned for later stage research thanks to its ability to impose specific research activities geared toward higher returns, academia is better positioned for early stage of research due to their pre-commitment to academic freedom. There are several issues with these two statements. While it is true that scientists are guaranteed research freedom in academia, this freedom is contingent upon financial resources needed to run their laboratories. Specifically, funding agencies have priority research areas with which researchers' agendas and grant application have to fit. Because scientists rely largely on grants to fund their projects, their research topic and strategy have to be aligned with the requirement of the grant to get the necessary funds. According to Azoulay, Zivin, and Manso, scientists applying for a specific type of grants called R01 from the National Institutes of Health (NIH) are offered a cycle that "lasts only three years, and renewal is not very forgiving of failure. Feedback on performance is limited in its depth. Most importantly, the NIH funds projects with clearly defined deliverables, not individual scientists" (Azoulay, Zivin, & Manso, 2011, p. 3). This statement contradicts the paper's hypothesis and reveals that scientists in academia just like their counterpart in private corporations are more inclined to follow a specific strategy that would yield the desirable outcome.

One of the most important assumptions in Aghion, Dewatripont and Stein's model is that researchers in academia get lower wages when compared with scientists working in the private sector. This argument is backed by findings from study conducted by Stern in 2004 that reveal "wages are substantially lower in jobs that promise scientists either some freedom to pursue their own individual research agendas, or that encourage the publication of this work" (Aghion, Dewatripont, & Stein, 2008, p. 618). Based on this study, the authors hypothesize that the wage structure of both scientists working in academia and private sector remains constant with scientists in academia getting paid less. This important assumption in the model is only true for entry-level jobs where private sector corporations offer more monetary incentives than academia. For instance, senior prominent scientists working in top academic institutions in the United States whose contributions have revolutionized the world receive seven-figure income (The best schools, 2013). Dr. David N. Silvers for example from Columbia University received an income of $4.33 million (The best schools, 2013). Furthermore, if a university's early stage research efficiency lies in offering lower wages and a firm's efficiency is derived due to higher wages, the equilibrium is not sustained as a firm would deviate and change its strategy. As a result, the difference in wages cannot be part of the equilibrium.

3. Rationale and Research Questions

A review of current literature reveals that interest in research and development stems from the importance of these activities and their impact on the economy and society. Economists have investigated the process of innovation and sought to get a better understanding of various push and pull factors and how they stimulate or impede innovation. While the economic literature is very rich with studies probing innovation, this thesis seeks to provide a different explanation as to the reasoning behind the university-to-firm research development path. Specifically, this thesis focuses on addressing the gaps outlined below.

It has long been considered that since knowledge is a common good, it is better left off in the public domain. This idea finds its roots in the work of Arrow (1959) and Nelson (1962) who both believed that it is very hard to appropriate knowledge without the adverse effect of being divulged. This issue creates a problem of underinvestment, which necessitates governments' intervention. In this context, strengthening intellectual property rights would hurt the process of innovation in academia because it would lead to some ideas being patented too early. The vast majority of studies that aimed to probe the impact of intellectual property rights on innovation are centered on industry rather than academia. This thesis aims to determine the reasons behind academia's involvment in research regardless of weak or strong intellectual property rights and to provide a different rationale for the university-to-firm research development path.

The private sector and academia also offer different kinds of incentives to promote research activities. Universities offer tenured positions because students value professors' knowledge, which explain why professors are retained even after declining research productivity. Firms, in contrast to universities, offer lucrative packages to top executives to create a culture of innovation where everyone is encouraged to push traditional boundaries and to think outside the box. Several studies have examined these incentives and concluded that researchers in academia enjoy more freedom when it comes to their research agenda, which explains why researchers in academia are willingly to accept lower wages (Aghion, Dewatripont, & Stein, 2008). Since this arrangement helps universities save on wages, what precludes firms from adopting the same compensation system to save on wages? More specifically, this thesis addresses the following research questions:

- How can we explain the prevalence of the university to a firm innovation path without assumuning that universities pay lower wages?
- What kind of incentives encourage a university to share a discovery rather than keep it secret?
- If it is efficient for a research line to end in the private sector, shouldn't it be efficient to begin there in the first place?

This thesis builds upon the work of Cater, Lew, and Pivato (2017) that examined the efficiency of tenure contracts in universities. By using a two-stage research and development model, this thesis probes the viability and profitability of different research lines in academia and the private sector and examines the factors that affect the university-to firm research development path.

4. Model

The Frascati Manual defines research and development as a process that includes "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge"(OECD, 2015, p. 44). It incorporates basic research, applied research and experimental development. In this thesis, research and development is modeled as a two-stage process. Basic research and applied research make up the first stage and experimental development referred to as product commercialization happens in the second stage. A firm and university invest in these activities for various reasons and their interactions are modeled as a game that depicts the strategies, actions as well as the probabilities and the outcomes.

The expected profit for each game varies depending on each strategy. The first strategy models a firm initiating a research line alone. The second strategy reflects an environment of weak intellectual property rights where a firm can remain dormant during stage one and enters only in stage two when the university publishes an applicable result and then directs its scientist to work exclusively on that line of research to maximize the chances of commercialization. The third strategy encompasses the case where a firm can either choose to enter during stage one or remain dormant until an applicable result is published from a university.

At the begininng of the game i.e. first stage, a firm and university are presented with a research line opportunity. This opportunity of research is available to the firm and university at a cost (w), which reflects the wages a university and firm have to pay if they were to hire a professor and a scientist respectively. In this model, it is assumed that the university and firm pay the same wages. The rationale behind this major assumption is to make sure that any differences that will arise are not attributed to the change in wages. The firm and university achieve a basic result with probability p_f and p_u and no basic result with probability $(1 - p_f)$ and $(1 - p_u)$ respectively. Successfully realizing a basic result would lead to a practical application with probability (α) and no practical application with probability $(1 - \alpha)$. Unlike the firm, the professor enjoys creative freedom which is captured by the parameter c. As such, the practical project is chosen with probability $(1 - c)$ and the basic project is chosen with probability (c). Because the professor splits her time between teaching and research, it is assumed that she 50% of her time doing research. During the second stage, a firm and university can reach a commercializable product with probability p_f and p_u. Failing to achieve a commercializable product is denoted $(1 - p_u)$ and $(1 - p_f)$ for the university and firm.

The probability of engaging in the same research line at the same time is negligible, but it is not nil, which explains including the possibility of both university and firm achieving the same commercializable product. For the firm, the profit earned includes only the value of the commercializable product (V) and wages (w) as the publication of any type of research would not lead to any additional revenues. The university's profit function is a bit different as it encompasses the value of the commercializable product, wages, as well as tuition revenues denoted (R). Publishing any type of basic or applied result by the professor helps attract tuition paying students and translates into tuition revenues. When the university reaches a commercializable product, tuition revenues are realized both at the first and second stage. The difference between a university and firm is immutable as it relates to their mission. The firm seeks product development to derive revenues whereas the university's teaching and research missions allows it to profit from both product development as well as tuition revenues.

5. Results

In this thesis, the interactions between a university and a firm are modelled as a game where the former's strategy boils down to either initiating a research line or not. As for the firm, applicable result can be derived through three strategies. The first one sees a firm initiating its own research line and reaching its own applicable result. The second strategy relies on a university's applicable result and the third strategy is a combination of the first two strategies where a firm can either initiate a research line or wait for an applicable result from the university. To solve these games, Nash equilibrium concept is used to find the strategy profile for which a player (a firm or university) cannot increase their expected profit and has no incentive to deviate from their own strategy while the other player maintains theirs. The equilibria will be altered as the numerical examples change to shed light on the optimal strategy for the university and firm shifts under different scenarios.

1. Strategies

- Strategy 1: Firm and university, alone, initiating a research line denoted respectively **(F_1_U_0 and U_1_F_0)**

The first figure depicts the firm choosing to initiate a research line whereas the university choosing not to. During the first stage, successfully achieving a basic result leads to a practical application. The firm enters the second stage and uses the practical result to build upon a commercializable product. The different payoffs at the first stage and second stage of the game for the university and the firm are shown at the terminal nodes. The second figure on the other hand, shows the different payoffs when the firm does not initiate a research line while the university enters at the first and second stage. The only difference is the professor at the university enjoys creative freedom and can either choose the applicable or basic project which is not the case for the scientist at the firm. Also, the university's ability to generate tuition revenues from any type of research.

Figure 1: Strategy $F_1\_U_0$ tree diagram

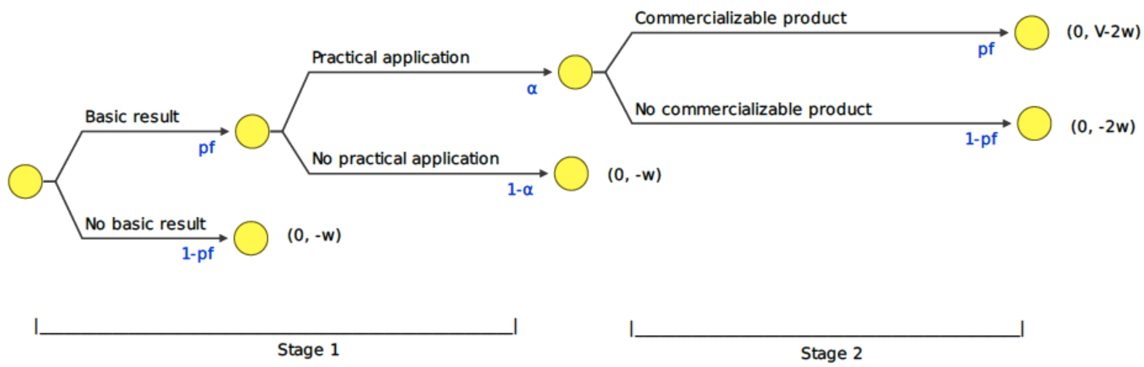
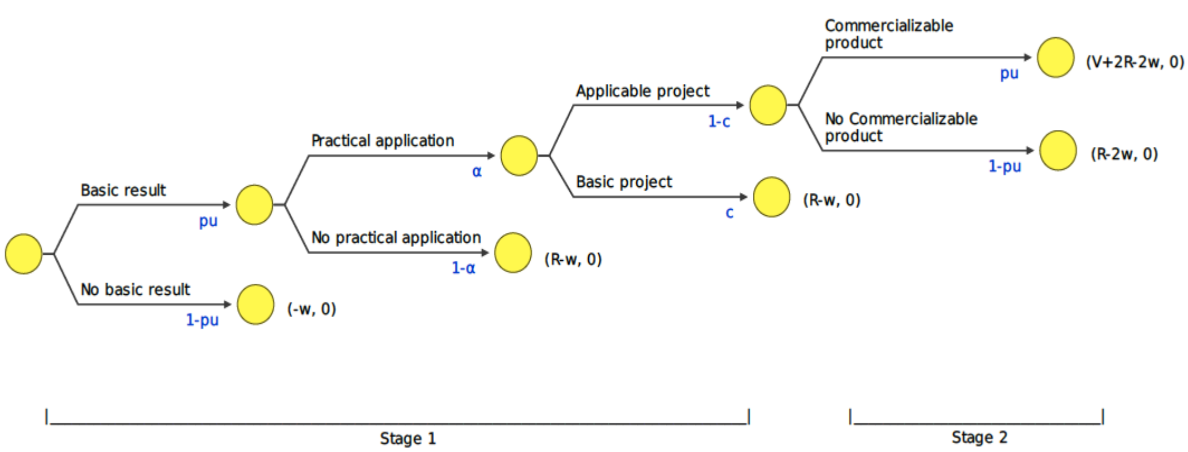


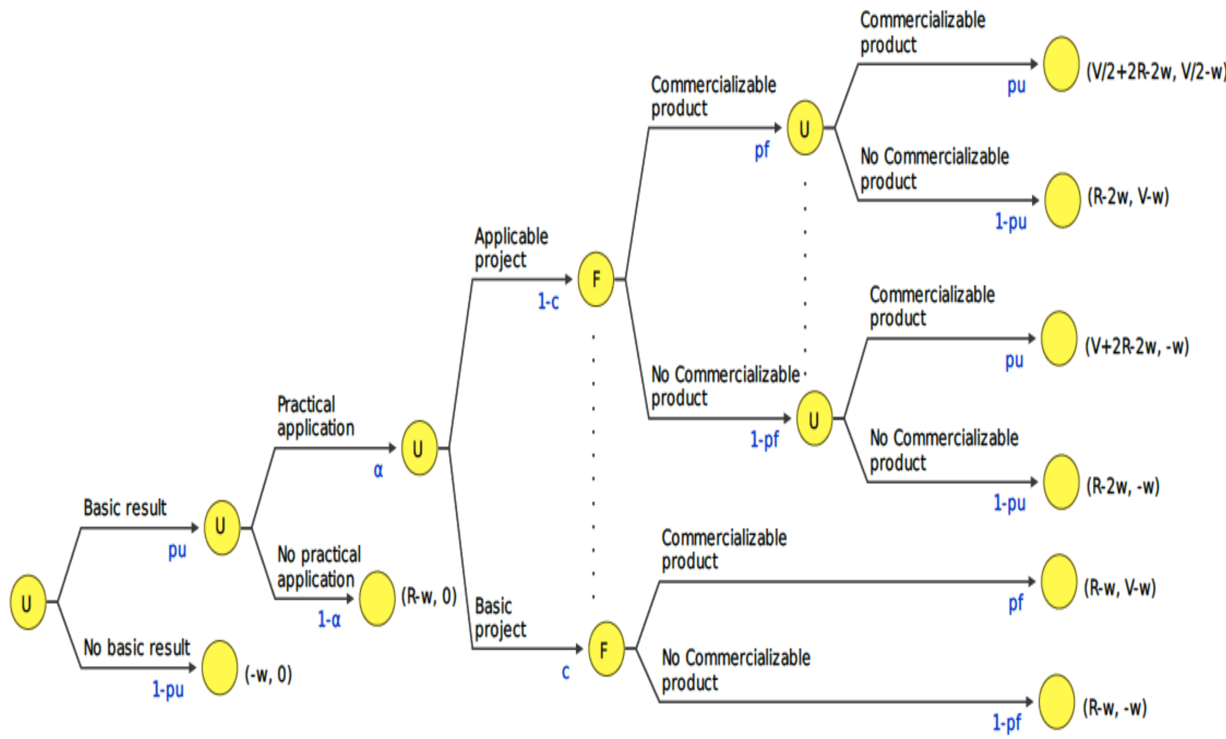
Figure 2: Strategy $U_1\_F_0$ tree diagram



➢ Strategy 2: Firm waits for an applicable result from university ($F_2\_U_1$)

The dynamics of the game between the university and the firm have to be described jointly under this strategy. The first stage encompasses a university initiating a research line, reaching a basic result and applicable result. The end of the first stage is marked by a scientist either choosing the applicable project with probability (1-c) or basic project with probability (c). The firm enters once an applicable result is published and is unaware of the university's professor actions, which gives rise to the first information set in the game. If the professor at the university chooses the applicable project and reaches a commercializable product or not and the firm reaches a commercializable product or not, a second information set is recorded as the university's professor cannot observe the actions taken by the scientist at the firm.

Figure 3: Strategy $F_2\_U_1$ extensive form game



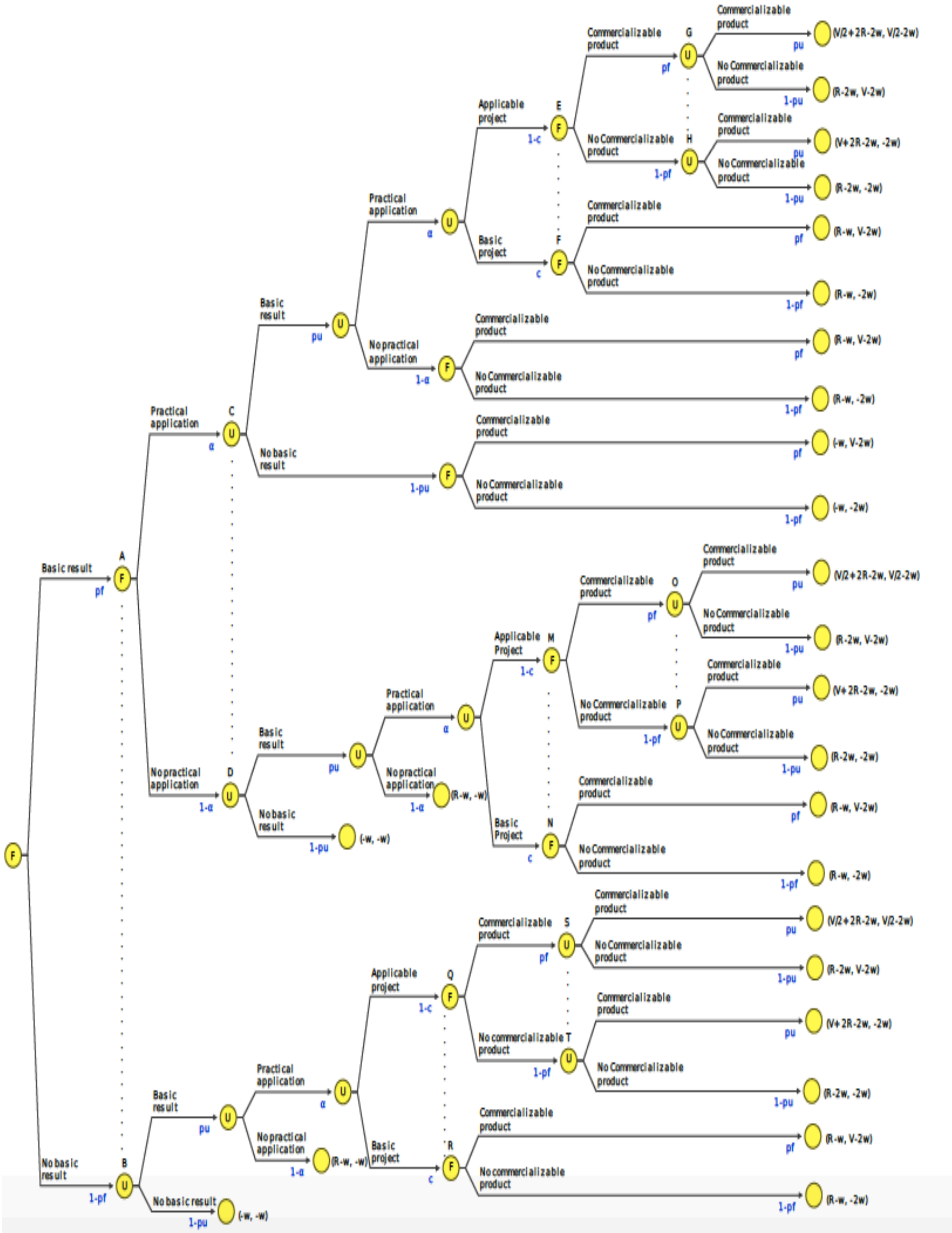
- Strategy 3: Firm gets an applicable result either from it own basic result or from university ($F_1\_U_1$)

Under this strategy, The firm either derives an applicable result through its own basic research or from the university. The game in figure 3 starts with the firm initiating a research line and then reaching a basic result. Failing to reach a basic result will see a firm waiting for an applicable result from the university. The latter cannot observe the actions taken by the firm which gives rise to the first information set in this game denoted $I_1\{A, B\}$. Once the firm achieves an applicable result through its own basic research, again the university is unaware of these actions which leads to the second information set $I_2\{C, D)$. When the university initiates a research line, reaches a basic result, an applicable result and the professor chooses an applicable project, the firm cannot observe the actions taken by the university which leads to the third information set $I_3\{E, F)$. During the second stage of the game, the university is unaware of the firm's actions which gives rise to the fourth information $I_4\{G, H\}$.

At the second information set $I_2\{C, D\}$, the firm can access an applicable result originating from the university. Again the firm cannot tell whether the university's professor chooses the applicable or basic project which explains the fifth information set $I_5\{M, N\}$. Because the university cannot observe whether the firm achieves or fails to realize a commercializable product, a sixth information set is recorded $I_6\{O, P\}$.

At the first information set $I_1\{A, B\}$, the firm might fail to achieve a basic result which makes it rely on an applicable result from the university. The firm is unable to know if the professor at the university chooses the basic project or applicable project which explains the seventh information $I_7\{Q, R\}$. The university is also unaware of whether or not the firm reaches a commercializable product which leads to the last information set $I_8\{S, T\}$.

Figure 4: Strategy $F_1\_U_1$ extensive form game



2. Expected Profit

- Strategy 1: F_1 _U_0 and U_1 _ F_0

The expected profit for the university is the profit weighed by the probability of reaching a commercializable product. Unlike the firm, the university's scientist enjoys creative freedom and spends time both teaching and doing research. The probability of reaching a commercializable product is thus lower than that of the scientist at the firm. This unique arrangement gives rise to tuition revenues, which the university achieves at the two stages of the process. The expected profit for the university is the sum of the payoffs at each terminal node weighed by their respective probability.

The expected profit for the university is:

$$Expectedprofit^{u}_{U_1F_0} = (V+2R-2w)*(p_u*\alpha*(1-c)*p_u)+(R-2w)*(p_u*\alpha*(1-c)*(1-p_u))+(R-w)*(p_u*\alpha*c) \quad (1)$$
$$+(R-w)*(p_u*(1-\alpha))+(-w)*(1-p_u)$$

The expected profit for the firm is the profit weighed by the probability of reaching a commercializable product. Because the firm's scientist spends the entirety of their time doing directed research, the probability of reaching a commercializable product is higher than that of the university ($P_f > P_u$). At the terminal node, (2w) represents the total wages incurred by the firm from the beginning until the end of the game.

The expected profit for the firm is:

$$Expectedprofit^{f}_{F_1U_0} = (V-2w)*(p_f*\alpha*p_f)+(-2w)*(p_f*\alpha*(1-p_f))+(-w)*(1-p_f*\alpha) \quad (2)$$

- Strategy 2: F_2 _U_1

To calculate the expected profit for each player, let $Y_1, \ldots, Y_k$ represent the terminal nodes, M the path in the game tree and $u_f(Y_i)$ and $u_u(Y_i)$ the profit for the firm and university respectively.

At any node M, the expected profit for the firm is given by:

$$Expected(profit^{f}{}_{F_2U_1}) = \sum_{i=1}^{k}(M,Y_i)u_f(Y_i) \tag{4}$$

The expected profit for the firm is:

$$\begin{aligned} Expected(profit^{f}{}_{F_2U_1}) &= (p_u*\alpha*(1-c)*p_f*p_u)*(\frac{V}{2}-w)+(p_u*\alpha*(1-c)*p_f*(1-p_u)*(V-w) \\ &+(p_u*\alpha*(1-c)*(1-p_f)*p_u)*(-w)+(p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))*(-w) \\ &+(p_u*\alpha*c*p_f)*(V-w)+(p_u*\alpha*c*(1-p_f))*(-w) \end{aligned} \tag{4}$$

At any node M, the expected profit for the university is given by:

$$Expected(profit^{u}{}_{F_2U_1}) = \sum_{i=1}^{k}(M,Y_i)u_u(Y_i) \tag{5}$$

The expected profit for the university is:

$$\begin{aligned} Expectedprofit^{u}{}_{F_2U_1} &= (\frac{V}{2}+2R-2w)*(p_u*\alpha*(1-c)*p_f*p_u)+(R-2w)*(p_u*\alpha*(1-c)*p_f*(1-p_u)) \\ &+(V+2R-2w)*(p_u*\alpha*(1-c)*(1-p_f)*p_u)+(R-2w)*(p_u*\alpha*(1-c)*(1-p_f)*(1-p_u)) \\ &+(R-w)*(p_u*\alpha*c*p_f)+(R-w)*(p_u*\alpha*c*(1-p_f))+(R-w)*(p_u*(1-\alpha)-w*(1-p_u) \end{aligned} \tag{5}$$

- Strategy 3: $F_1\_U_1$

Calculating the expected profit under this strategy is complicated given that the firm will either get an applicable result from its own basic research or from the university. I have divided the game into three parts. The first part encompasses the firm deriving an applicable result from its own research. The second part deals with the firm using an applicable result from the university because their basic research failed to yield an applicable result. Since the first and second part of the game is connected with the information set I2{C, D}, node X combines the payoffs derived from both branches of the information set. The last part of the game sees the firm relying on an applicable result derived from the university because it failed to achieve a basic result. The university initiating a research line when the firm fails to reach a basic result is denoted node Y. The expected profit for the firm at the initial node is the sum of the expected profit at nodes X and Y.

The expected profit for the firm is:

$$
\begin{aligned}
&Expectedprofit^{f}_{F_1U_1}=(\frac{V}{2}-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*p_f*p_u)+(V-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*p_f*(1-p_u))\\
&+(-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*(1-p_f)*p_u)+(-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))\\
&+(V-2w)*(p_f*\alpha*p_u*\alpha*c*p_f)+(-2w)*(p_f*\alpha*p_u*\alpha*c*(1-p_f))+(V-2w)*(p_f*\alpha*p_u*(1-\alpha)*p_f)\\
&+(-2w)*(p_f*\alpha*p_u*(1-\alpha)*(1-p_f))+(V-2w)*(p_f*\alpha*(1-p_u)*p_f)-2w*(p_f*\alpha*(1-p_u)*(1-p_f))\\
&(\frac{V}{2}-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*p_f*p_u)+(V-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*p_f*(1-p_u))\\
&+(-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*(1-p_f)*p_u)+(-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))\\
&+(V-2w)*(p_f*(1-\alpha)*p_u*\alpha*c*p_f)+(-2w)*(p_f*(1-\alpha)*p_u*\alpha*c*(1-p_f))+(-w)*(p_f*(1-\alpha)*p_u*(1-\alpha))\\
&+(-w)*(p_f*(1-\alpha)*(1-p_u))+(\frac{V}{2}-2w)*((1-p_f)*p_u*\alpha*(1-c)*p_f*p_u)+(V-2w)*((1-p_f)*p_u*\alpha*(1-c)*p_f*(1-p_u))\\
&+(-2w)*((1-p_f)*p_u*\alpha*(1-c)*(1-p_f)*p_u)+(-2w)*((1-p_f)*p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))\\
&+(V-2w)*((1-p_f)*p_u*\alpha*c*p_f)+(-2w)*((1-p_f)*p_u*\alpha*c*(1-p_f))+(-w)*((1-p_f)*p_u*(1-\alpha))+(-w)*((1-p_f)*(1-p_
\end{aligned}
\tag{6}
$$

The expected profit for the university is:

$$
\begin{aligned}
&Expectedprofit^{u}_{F_1U_1}=(\frac{V}{2}+2R-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*p_f*p_u)+(R-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*p_f*(1-p_u))\\
&+(V+2R-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*(1-p_f)*p_u)+(R-2w)*(p_f*\alpha*p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))\\
&+(R-w)*(p_f*\alpha*p_u*\alpha*c*p_f)+(R-w)*(p_f*\alpha*p_u*\alpha*c*(1-p_f))+(R-w)*(p_f*\alpha*p_u*(1-\alpha)*p_f)\\
&+(R-w)*(p_f*\alpha*p_u*(1-\alpha)*(1-p_f))+(-w)*(p_f*\alpha*(1-p_u)*p_f)+(-w)*(p_f*\alpha*(1-p_u)*(1-p_f))\\
&(\frac{V}{2}+2R-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*p_f*p_u)+(R-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*p_f*(1-p_u))\\
&+(V+2R-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*(1-p_f)*p_u)+(R-2w)*(p_f*(1-\alpha)*p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))\\
&+(R-w)*(p_f*(1-\alpha)*p_u*\alpha*c*p_f)+(R-w)*(p_f*(1-\alpha)*p_u*\alpha*c*(1-p_f))+(R-w)*(p_f*(1-\alpha)*p_u*(1-\alpha))\\
&+(-w)*(p_f*(1-\alpha)*(1-p_u))+(\frac{V}{2}+2R-2w)*((1-p_f)*p_u*\alpha*(1-c)*p_f*p_u)+(R-2w)*((1-p_f)*p_u*\alpha*(1-c)*p_f*(1-p_u))\\
&+(V+2R-2w)*((1-p_f)*p_u*\alpha*(1-c)*(1-p_f)*p_u)+(R-2w)*((1-p_f)*p_u*\alpha*(1-c)*(1-p_f)*(1-p_u))\\
&+(R-w)*((1-p_f)*p_u*\alpha*c*p_f)+(R-w)*((1-p_f)*p_u*\alpha*c*(1-p_f))+(R-w)*((1-p_f)*p_u*(1-\alpha))+(-w)*((1-p_f)*(1-p_u))
\end{aligned}
\tag{7}
$$

3. Numerical Examples

Problems with high dimensionality just like Equations 1 to 7 are very difficult to visualize or solve analytically in a way that is easily interpreted. To get a better sense of the above equations, the following values were chosen arbitrarily $p_f = 0.6$, $p_u = 0.3$, alpha = 0.6, c = 0.9 and R = 35 and remain the same throughout the four examples. The values of the commercializable product and wages will vary and lead to different expected profits in order to gauge the model and see how the solution to the problem changes. The numerical examples were chosen on purpose to reveal a range of solution scenarios where it is optimal or not for the firm and university to initiate a research line. They also seek to illustrate how different kinds of behaviors emerge depending on the values of these parameters. Different ratios for the value of commercializable product, wages and tuition revenues could be calculated to derive the importance of one parameter versus the other; however, these ratios would fluctuate as the values change. Other things equal, the firm's viability would improves due to a higher value of commercializable product. As for the university, both tuition revenues and wages affect the viability of a research line.

Table 1: Summary of expected profit by strategy (V= 0 and w= 9)

Firm / University	F0	F1	F2
U0	(0, 0)	(0, -12.24)	NA
U1	**(3.04, 0)**	(3.10, -1.62)	(3.40, -13.28)

The table presents the firm and university strategies as well as the expected profits under each strategy. The strategy (U_1_F_0) is the only equilibrium for this game, as the firm will never find it viable to undertake this type of research line given that the expected profit under all three strategies is negative. The university will find it optimal to initiate this project as tuition revenues cover the cost and yield a profit although the value of commercializable product is minimal. The firm cannot carry a research line unless the commercializable product is of value. For the firm does not realize any profit from initiating a research line with dim prospects of commercialization, contrary to the university whose research helps attract tuition paying students. This is true not only for engineering and science departments where research yields patents and royalties for the university but also for research carried in other faculties such political science, criminology, and education where the value of research is not monetized. This example provides an answer to the second research question. Universities have an incentive to publish their research because it signals knowledge and attracts tuition paying students. The firm is unable to do the same since its research cannot be translated into any kind of revenues unless it turns into a commercializable product.

Table 2: Summary of expected profit by strategy (V= 80 and w= 12)

Firm / University	**F0**	**F1**	**F2**
U0	(0, 0)	(0, 0.96)	NA
U1	(0.43, 0)	(3.30, 4.98)	**(5.34, 6.35)**

In this example, a firm can find it viable to start this project on its own; however, the university will find this research line optimal as well. Given that the firm cannot preclude a university from initiating this research line, the strategy (F_2_U_1) is the equilibrium as the expected profit is slightly higher than that of the third strategy. For the university, the revenues generated from the research line and students' tuition still cover the wages and yield a positive profit for the university. As for the firm, it is more optimal to wait until the university publishes a practical result because the firm saves on the cost of starting the research line and is better poised to reach a commercializable product once the university publishes an applicable result. This example provides a clear explanation as to the reason behind the prevalence of the university-to-firm research development path. In the absence of a strong regime of intellectual property rights, firms free ride on the research published by the university. Once a practical result is published, the firm is better positioned to reach a commercializable product given that the scientist is totally invested in that research line, unlike the professor at the university who might very well choose to pursue the basic project.

Table 3: Summary of expected profit by strategy (V= 400 and w= 45)

Firm / University	F0	F1	F2
U0	(0, 0)	**(0, 25.20)**	NA
U1	(-31.43, 0)	(-34.55, 43.42)	(-32.08, 34.45)

In this example, the strategy ($F_1\_U_0$) is the equilibrium given that the expected profit for the university is negative. A research line with significant (V) and high wages would be viable for the firm to undertake. However, the university will refrain from undertaking this project given that the promising value of the commercializable product along with tuition revenues would not be enough to cover the cost of initiating this research line. In addition, the chances of reaching a commercializable product are low given the professor shares her time between teaching and research. This example answers the last research question and highlights the case where it is optimal for a research to start and end at the firm. Since the firm has the necessary means and organizational structure that would allow it to direct her scientist to this research line, relying on the university is not optimal because the latter will not find it viable to initiate this research line. Because the professor at the university enjoys creative freedom and cannot be forced to pursue a specific project, the firm optimally directs her scientist toward this project, which increases the probability of reaching a commercializable product and capturing the expected profit.

Table 4: Summary of expected profit by strategy (V= 950 and w= 10)

Firm / University	F0	F1	F2
U0	(0, 0)	(0, 191.60)	NA
U1	(7.20, 0)	**(5.82, 254.57)**	(5.60, 99.26)

This example illustrates how the increase in revenue while wages remain low make the firm better off adapting strategy $F_1\_U_1$. The university will be able to initiate this research because tuition revenues and the value of the commercialization will be able to cover the wages and yield a positive profit. While the firm's three strategies promise a positive payoff, the third strategy achieves the highest expected profit. Under this scenario, the firm will either rely on its basic research to produce a practical application or use a university's practical result.

6. Discussion

This model's results demonstrate that the prevalence of university-to-firm research development path happens not because wages in academia are lower than the private sector as explained by Aghion, Dewatripont and Stein (2008), but because universities release early stage research, to signal knowledge, which helps, attract tuition-paying students. Once released to the public, a firm can freely access academic research and direct her scientist to that research line. Firms on the other hand, are unable to reveal their early stage research because it cannot be translated into any kind of revenues. In addition, a firm's monopoly over that research line would be compromised as incumbents may free ride on its research.

In the absence of a strong regime of intellectual property rights, the university-to-firm research development path largely emboldens firms' stance, as they are able to circumvent the uncertainty of initiating a basic research line and its related costs. Simply put, starting a basic research project is embroiled in uncertainty, which is compounded by the fact that a firm's basic result has no monetary value. A firm will find it optimal and profitable to adopt a wait and see strategy, use a practical result from academia's research and then direct her scientists to that research line in order to maximize the chances of commercialization. As the scientist in the firm spends most of her time on that research line, the chances of commercialization are maximized. Firms are also pressured to only invest in research lines that promise high returns.

The case of how Gilead, a US based pharmaceutical company, achieved phenomenal profits from drugs conceived from publicly funded research clearly reveals why firms would prefer to have access to publicly funded applicable results. The company collaborated with the center of disease and control (CDC) to come up with a drug dubbed Truvada that aims to block HIV from infecting otherwise healthy people who engaged in unprotected sex. Eventually, the drug was developed with both taxpayers' money and from grants. Efforts by the CDC to enforce their patenting rights were futile as the company enjoys monopolistic privileges and charges a substantial amount for the drug.

The sales from Truvada alone amounted to $3 billion in 2018 as the company charges between "$1600 and $2000 for a month's supply of a pill that can be manufactured for a fraction of that amount" (Rowland, 2019). While the drug is covered mostly by private and government insurance, taxpayers end up paying twice for the drug, which affects the budget for other important programs. Activists are imploring the government to take a tough stance against such corporations by enforcing their patents' rights. Naturally, firms like Gilead would strongly oppose any measures that aim to curtail this free access not because innovation will be stifled or hurt but mainly because their bottom line, which is profitability, will be adversely affected.

On a different note, the model proves that firms might still find it optimal to invest in a research line when a university cannot. Specifically, projects with significantly promising returns and high wages are still viable for the firm to undertake from the start until the commercialization. This is largely due to the private sector's ability to direct their scientists toward a specific project and then spending the entirety of their time on a specific research line thus maximizing the chances of bringing the product to market. The veiled pressure for a practical result is deeply rooted in the private sector's economics and the promise to maximize stakeholders' wealth.

The analysis also reveals that it is never optimal for a firm to invest in a research line when the expected profit is nil. In the absence of a commercializable product, a firm basic or applicable research cannot be translated into revenues. A different story transpires for universities whose expected profit does not depend entirely on the expected profit from the research line but also from generating tuition revenues. This is true for faculties whose research does not yield marketable products or royalties but whose impact helps attract tuition paying students. Research in academia regardless of its practical application signals knowledge and increasingly international and domestic students are using that as a key factor when selecting their academic institutions. For some research lines, however, the significant prospect of revenues is not enough to make the university committed as both the revenues generated from commercialization as well as tuition revenues will not cover the cost of engaging in this project when intellectual property rights are weak.

Assuming that academia's mission to invest only in research activities regardless of the prospects of practical application as it advances human knowledge and that early privatization of ideas would stifle innovation ignores the fact that investments are made when they maximize social welfare. Professors in academia have always been inclined to conduct research and disseminate it because it signals knowledge regardless of the status of intellectual copyrights. In foregoing their rights and publishing their results, these professors "signal their competence and attract resources to fund their activities" (Antonelli, 2008, p. 6). The tuition revenues, alone, explain why universities still find it feasible and profitable to initiate research lines in different fields where commercialization never happens. Competition among peers and universities fuel and ignite innovation and serve as an incentive to knowledge generation not the contrary.

For the university professor, it is not always the probability of success or failure that guides their choice between the applicable and basic project. The creative freedom extended to academics simply means that the university can in no way interfere with their choices. The professor can choose to pursue the basic research project even though the prospects of achieving a commercializable product are high. This is clearly illustrated in the case of Tom Johnson, a professor at the university of Colorado, whose research launched and revolutionized the science of aging. As soon as his paper was published in 1988, several firms, seeking to commercialize his discovery prematurely, approached him to access his breakthrough research. His statement "I sought independence over money" clearly captures the essence of research in academia and how a stronger intellectual property rights regime would not necessarily stifle innovation (McKracken, 2020).

Irrespective of what the professor in academia chooses, greater appropriability has truly been empowering as it enabled the professor to profit from research with practical applications. Increasingly, scientists are relying on royalties to fund and expand their laboratories in the face of declining government subsidies. This new trend finds its root in the move from research to entrepreneurial university where "academia has become entrepreneurial in its inner dynamic as well as through external connections made to business firms for research contracts and transfer of knowledge and technology" in order to raise more funds to support research activities (Etzkowitz, 2003, p. 109).

The passing of the Bayh-Dole Act in the US, for instance, has opened many opportunities for academic research as it empowered professors by allowing them to claim ownership of research done with government funding. More patents mean that universities' profits are soaring and serve as an incentive for innovation not the contrary. Top research universities like MIT and Stanford benefit greatly from the current system and are set to collect billions of dollars from granting patents rights (Cohan, 2017). These revenues would certainly alleviate the need for public funding and address a market failure that persisted for so many years and justified using taxpayers' money to fund research in academia.

For many years, firms have made it clear that strengthening intellectual property rights is key to their existence as it stimulates innovation eventually leading to economic growth and to greater social welfare. As for academic research, it has long been debated that implementing stronger intellectual property rights would only stifle innovation and firms should have access to this publicly funded research in order to increase the chances of commercialization and thus benefiting society as a whole. The results indicate that firms rely on publicly funded research to maximize their profits. Having free access to research does not necessarily lead to lots of innovative products, as firms would prefer to undertake projects with better the prospects of commercialization. By imposing a strong regime of intellectual property rights, firms would no longer freely access academic research. They will instead have to pay to get patents' rights and thus shifting a big portion of their profits to the university.

The implications of stronger intellectual property rights seem to be more detrimental to the firm rather than the process of innovation itself or the social welfare. A government's budget will be spared from publicly funding academic research and thus redirecting these funds to other underfunded projects in other key sectors. Government labs would certainly benefit as well from stronger intellectual property rights regimes, as the royalties collected will help fund and initiate other projects that would have been impossible to undertake in an environment of declining funding for research.

This work could be further expanded by studying the impact of stronger intellectual property on research and development in academia vs. the private sector. A quantitative analysis could be used to derive whether greater appropriability hurt or promotes the process of innovation in academia. Adding high-powered incentives to the university and firm's scientists could be studied as well to see how it affects the process of innovation, feasibility and profitability of a research line.

7. Conclusion

The importance of research and development activities stems from how subsequent innovations positively transform people's way of life and leads to better knowledge, processes, and systems. However, scientific activities are often mired in uncertainty and several studies demonstrated how practical applications of basic research often come unexpected. Because of the uncertainty that embodies research, it has been thought that academia should provide the perfect setup where initial stages of research activities could be carried out, whereas the private sector is better positioned for later stages. It has been believed that government funding for academia would solve the underinvestment problem which explains why the private sector has, for decades, relied on research published from government labs and universities to bring about high yielding innovative products that maximize firms' revenues and profits.

The findings of this thesis shed a different light on the dynamics of the university to firm research development path. Universities are able to derive tuition revenues from publication of basic research without any practical application because a professor's research signals knowledge and students value this wealth of wisdom. For many projects in the social science and humanities that have no monetary value, tuition revenues help cover for the cost as well as leave a profit for university. As for firms, publishing basic research or even applicable results would hurt their competitive position and above all lead to no revenues. For this reason, firms have always been reluctant to divulge their research and development activities to potential or existing competitors.

The university-to-firm research development path is predominant because a firm bypasses the uncertainty related to basic research and maximizes the chances of bringing a product to market when entering during the second stage. Investing in a project with dim prospects of commercialization would jeopardize a firm's financial health, which explains why it is more optimal for firms to have free access to research conducted in universities and selecting research lines with better prospects of reaching a commercializable product.

Limiting a firm's free access to university's research will have financial implications. This thesis reveals that such measures would affect firms' profitability, as a considerable part of their profit would move to the university. Firms maximize their profit in an environment of weak intellectual property rights and would undoubtedly see stronger copyrights laws as threatening to their survival. Given that innovation is hailed as the key to survive and thrive in today's evolving market, firms' are more than ever pressured to have access to academic research.

As empirical evidence points to a de-commitment of governments to research and development activities in academia, the implications of imposing stronger intellectual property laws are substantial (Grove, 2017). Universities will become more independent and rely less on government funding. Royalties will incentivize scientists in academia and provide a good stream of revenues for the university. Public projects that have long been underfunded could benefit greatly from this shift and governments would be able to direct more funds to much-needed initiatives that benefit society as a whole.

Bibliography

Aghion, P., Dewatripont, M., & Stein, J. C. (2008). Academic freedom, private-sector focus, and the process of innovation. *The RAND Journal of Economics*, *39*(3), 617-635.

Antonelli, C. (2008). The new economics of the university: A knowledge governance approach. *The Journal of Technology Transfer*, *33*(1), 1-22.

Auranen, O., & Nieminen, M. (2010). University research funding and publication performance—An international comparison. *Research Policy*, *39*(6), 822-834.

Cater, B., Lew, B., & Pivato, M. (2017). The efficiency of tenure contracts in academic employment. *Journal of Public Economic Theory*, *19*(2), 331-361.

Cohan, 2017. MIT's 19 trillion money machine. Retrieved from https://www.inc.com/peter-cohan/mits-19-trillion-money-machine.html

Dill, D. D., & Soo, M. (2005). Academic quality, league tables, and public policy: A cross-national analysis of university ranking systems. *Higher Education*, *49*(4), 495-533.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy*, *29*(2), 109-123.

Etzkowitz, H. (2003). Research groups as 'quasi-firms': the invention of the entrepreneurial university. *Research Policy*, *32*(1), 109-121.

Grove, Lynda. *The effects of funding policies on academic research*. Diss. University College London, 2017.

Huang, C., Arundel, A. V., & Hollanders, H. J. G. M. (2010). How firms innovate: R&D, non-R&D, and technology adoption.

Kim, W. C., & Mauborgne, R. (2004). *Blue ocean strategy*. Cambridge, MA: Harvard Business School Press.

Lach, S., & Schankerman, M. (2008). Incentives and invention in universities. *The RAND Journal of Economics*, *39*(2), 403-433.

Makri, M., Lane, P. J., & Gomez-Mejia, L. R. (2006). CEO incentives, innovation, and performance in technology-intensive firms: a reconciliation of outcome and behavior-based incentive schemes. *Strategic Management Journal*, *27*(11), 1057-1080.

Mansfield, E. (1984). R&D and innovation: Some empirical findings. In *R&D, patents, and productivity* (pp. 127-154). University of Chicago Press.

Mansfield, E. (1991). Academic research and industrial innovation. *Research Policy*, *20*(1), 1-12.

McKraken, A., (2020). Researcher on aging confronts his own mortality. Retrieved from https://www.washingtonpost.com/health/researcher-on-aging-confronts-his-own-mortality/2020/03/20/81326d7e-3d55-11ea-baca-eb7ace0a3455_story.html

Mitchel, M., Leachman, M., & Maasterson, K. (2017). A lost decade in higher education funding. *Center on Budget and Policy Priorities*.

Mowery, et al,. (2001). The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh–Dole act of 1980. *Research Policy*, *30*(1), 99-119.

OECD. (2015). Frascati Manual 2015: Guidelines for collecting and reporting data on research and experimental development. OECD Publishing.

Pasour Jr, E. C. (1981). The free rider as a basis for government intervention. *The Journal of Libertarian Studies*, *5*(4), 453-464.

Rosenberg, N. (2010). Why do firms do basic research (with their own money)?. In *Studies on science and the innovation process: Selected works of Nathan Rosenberg* (pp. 225-234).

Rowland, C., 2019. An HIV treatment cost taxpayers millions. The government patented it. But a pharma giant is making billions. Retrieved from https://www.washingtonpost.com/business/economy/pharma-giant-profits-from-hiv-treatment-funded-by-taxpayers-and-patented-by-the-government/2019/03/26/cee5afb4-40fc-11e9-9361-301ffb5bd5e6_story.html?utm_term=.7425c916a37a

Shin, J. C., Toutkoushian, R. K., & Teichler, U. (Eds.). (2011). *University rankings: Theoretical basis, methodology and impacts on global higher education* (Vol. 3). Springer Science & Business Media.

Spulber, D. F. (2013). How do competitive pressures affect incentives to innovate when there is a market for inventions? *Journal of Political Economy*, *121*(6), 1007-1054.