

ESSAYS ON TECHNOLOGY ENTREPRENEURSHIP

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*To Gung Kak, Ajung, Mama,
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TABLE OF CONTENTS

DEDICATION	iii
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
SUMMARY	x
I OVERALL RESEARCH GOAL AND IMPLICATIONS	1
1.1 Scientific system and its interaction with commercial system	3
1.2 New ventures as mechanisms that transform scientific investment into commercial outcomes	9
II TECHNOLOGY TRANSFER AND THE SOURCES OF RESEARCH FUNDING: IMPLICATIONS FOR THE NATURE OF RESEARCH 15	
2.1 Introduction	15
2.2 Environment and Payoffs	17
2.3 Stage Two Equilibrium	21
2.4 Stage One Equilibrium	30
2.5 The University's Shares of Research Funding	42
2.6 Direct Benefits of Research Funding	44
2.7 Concluding Remarks	46
III ACADEMIC SCIENTISTS: THE NATURE OF RESEARCH AND ENTREPRENEURIAL ACTIONS	48
3.1 Introduction	48
3.2 The Model	49
3.2.1 The Academic Scientist	50
3.2.2 The University	52
3.3 Methodology	57
3.3.1 Research Setting	57

3.3.2	Data and Sample	57
3.3.3	Variables and Measures	58
3.4	Results	62
3.5	Concluding Remarks	66
IV	TEAM FORMATIONS IN TECHNOLOGY VENTURES	71
4.1	Introduction	71
4.2	The Base Model	72
4.3	Team of n-people	79
4.4	Asymmetric Importance between Issues	81
4.5	Specialization and Diversity	84
4.6	Concluding Remarks	87
APPENDIX A	— PROOFS	89
REFERENCES	96

LIST OF TABLES

1	Descriptive statistics and correlation matrix	69
2	Results of Logit regression analysis predicting academic scientists transition to entrepreneurship	70

LIST OF FIGURES

1	Overarching research framework	2
2	Best-response functions of research sponsors	24
3	Best-choice functions of an academic scientist	33
4	Academic entrepreneurship: Extensive form of the game	50
5	Probability of starting new ventures by the nature of research for academic scientists in non-life science	63
6	Probability of starting new ventures by the nature of research for academic scientists in non-life science whose average numbers of publications are below the median	64
7	Probability of starting new ventures by the nature of research for academic scientists in non-life science whose average numbers of publications are above the median	66
8	Probability of starting new ventures by the nature of research for academic scientists in the life science	67
9	Decision tree of team formations	74
10	The timing of team formations	76

SUMMARY

This dissertation attempts to contribute to extant discussions on how one utilizes knowledge for economic gain. In order to understand how one can benefit from exploiting knowledge, scholars have examined the innovation process. The mainstream view of innovation is that it is a process of knowledge recombination. Consistent with this view, two related issues are whether there is sufficient stock of knowledge to recombine, and what mechanisms there are for knowledge recombination. This dissertation addresses these issues in three essays. The first essay, titled ‘Technology Transfer and the Sources of Research Funding: Implications for the Nature of Research’, addresses the former issue. The second essay, titled ‘Academic Scientists: Their Nature of Research and Entrepreneurial Actions’, and the third essay, titled ‘Team Formations in Technology Ventures’ undertake the latter issue.

The first essay is a response to the controversies in the growing interaction between the realm of science and the realm of commercialization. One of the controversies is whether the interactions divert academic scientists research agenda toward industry interests at the expense of fundamental science. This essay considers how an academic scientist chooses the level of difficulty of a research project and its level of relevance to industry interests. The direct cost of doing science is incorporated into the scientists decision. A simple game-theoretic model between research sponsors, a government agency and a firm, and an academic scientist is constructed. The model shows that the funding decisions of research sponsors are strategic substitutes. It also shows that the academic scientists choices of project characteristics are strategic complements. The model proposes situations in which an academic scientist pursues challenging projects that are relevant to the firms interests. It also proposes situations in which

an academic scientist decides on projects that are less challenging and less relevant to the firms interests.

The second essay provides insights on scientific entrepreneurs. While science-based entrepreneurship has become an increasingly important source of innovation, understanding of who these scientific entrepreneurs are is limited. Therefore, this essay examines which academic scientists will be more likely to create new technology ventures. It is argued that the nature of scientists research, specifically the level of its commercial applicability, is an important predictor of entrepreneurial actions of academic scientists. Using data from 395 academic scientists at five top US research universities, it is observed that there is a non-linear relationship between the nature of research and entrepreneurial actions. An inverted-u shape relationship between the level of commercial applicability and the likelihood that academic scientists will create new ventures is found in the field of non-life science. In the field of life science, a decreasing relationship between the level of commercial applicability and the likelihood that academic scientist will create new ventures is observed. These results support the view that scientific human capital is heterogeneous in converting scientific result into commercial outcomes.

The third essay offers insights on entrepreneurial teams. Despite the prevalence of entrepreneurial teams, insights on individual entrepreneurs are more available than understanding on entrepreneurial teams. This essay investigates mechanisms that give rise to entrepreneurial teams. A simple model is constructed. The model shows that an entrepreneur obtains less expected value from a project if the entrepreneur chooses to work solo at latter stage than working in a team. The effects of economic value, probability of failure, and cooperation cost on the timing of team formation are presented. It is also explained how asymmetry of importance between tasks in a commercialization project influences the decision of team formation and its optimal size. An extended model is constructed to analyze two benefits of team work:

specialization and diversity. This model proposes that greater probability of failure does not necessarily increase propensity to form entrepreneurial teams. The situations in which the likelihood of team formations increases with probability failure are discussed.

CHAPTER I

OVERALL RESEARCH GOAL AND IMPLICATIONS

It is widely recognized that utilization of knowledge enables economic gain (Dasgupta and David, 1994; Mokyr, 2004). It is also acknowledged that utilizing knowledge remains an intricate issue. The intricate issues that persist are the incentive to create knowledge and to apply existing knowledge into commercial applications. It is argued that, if knowledge creation activities were entrusted to the market mechanism, a society will be deprived of knowledge, particularly fundamental knowledge (Nelson, 1959), and underinvest in innovation activities (Arrow, 1962).

In order to understand how one can benefit from exploiting knowledge, scholars have examined the innovation process. Schumpeter (1934) explained that innovation is a process of recombination of existing knowledge. Therefore, availability of knowledge pool that provides building blocks for new knowledge and the ability to combine available knowledge are essential. Consistent with this view, extant literature addresses two issues. First, studies investigate whether there is sufficient stock of knowledge to exploit (e.g., Nelson, 1959; Hargadon and Sutton, 1997; Mokyr, 2004; Murray and O'Mahoney, 2007; Thursby, Thursby, and Gupta-Mukherjee, 2007). Second, given the nature of knowledge, researchers seek to understand mechanisms that allow utilization of available knowledge for economic gain (e.g., Kline and Rosenberg, 1986; Von Hippel, 1994; Zander and Kogut, 1995; Zucker, Darby, and Brewer, 1998; Jensen and Thursby, 2001; Gans, Hsu, and Stern, 2002).

This dissertation attempts to contribute to extant discussions on how one can utilize knowledge for economic gain. Its second chapter aims to contribute to the issue of whether there is sufficient knowledge stock to exploit. Scientific system has been

an important provider of knowledge stock. However, different type of research has distinct influence on the knowledge pool. Fundamental research is deemed to have larger impact to the knowledge pool than applied research (Nelson, 1959). That is, fundamental research results in knowledge that is building blocks for larger number of potential new knowledge than applied research does. Hence, chapter two investigates how academic scientists choose their research agenda (i.e., the type of research). The third and fourth chapters aim to add to discussions on mechanisms of utilizing knowledge for economic advancement. The chapters specifically focus on new technology ventures as the mechanism of exploitation. The third chapter investigates conditions under which academic scientists decide on founding new technology ventures to commercialize scientific research. The fourth chapter analyzes conditions under which entrepreneurs create teams in their attempt to commercialize inventions.

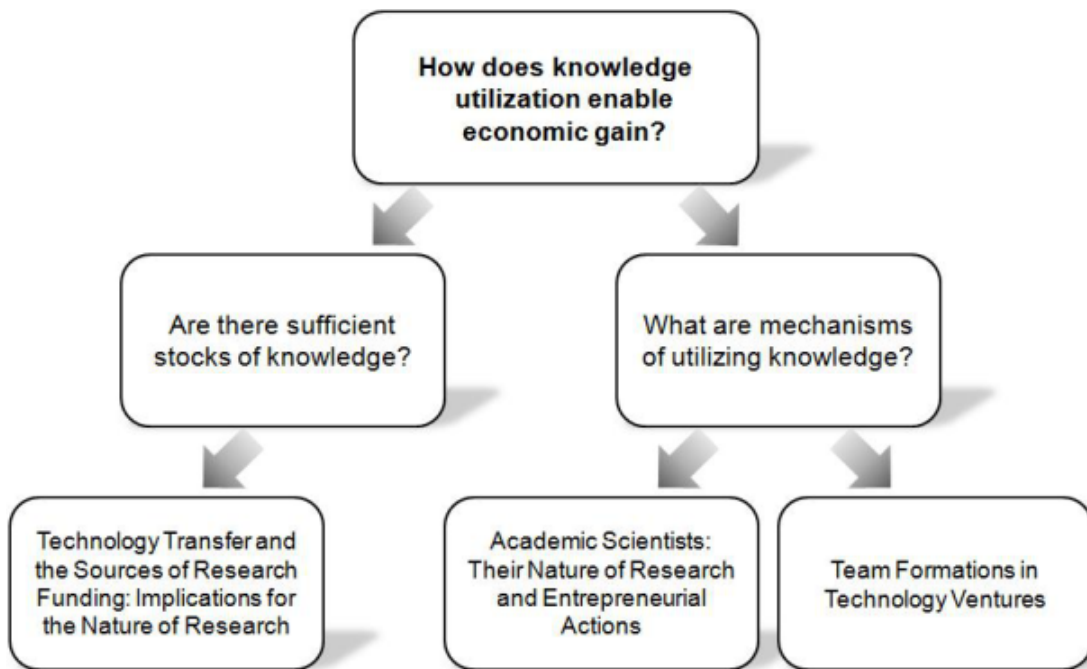


Figure 1: Overarching research framework

1.1 Scientific system and its interaction with commercial system

While it is accepted that science plays an important role in technological progress and economic growth, the implications of the growing interaction between the realm of science and commercialization remain controversial (Nelson, 2004). The heart of the controversy is as follows. The workings of scientific system involve distinctive norms that are essential to the production of knowledge, such as the rule for priority and communalism¹. Interaction with the commercial realm exposes the scientific system to the norms associated with commercialization, including the primacy of private knowledge and to pecuniary rewards. Because these norms are contradictory to those of the scientific system (Dasgupta and David, 1994), the issue arises of whether such interaction is detrimental to the scientific system, especially in its function as the knowledge producer for society (Dasgupta and David, 1994; Siegel, Wright, and Lockett, 2007).

Scholars have examined this issue from several angles. The first angle is that because economic rents depend on one's capacity to keep information private, the growing involvement of academic scientists in commercial activity will hamper the process of generating knowledge and, hence, long-term economic growth. The argument is that exclusion delays or prevents scientist access to, or use of, existing knowledge, which is an important component of potential new knowledge (e.g., Blumenthal et al, 1996; Heller and Eisenberg, 1998; Murray and Stern, 2007; Walsh, Cohen, and Cho, 2007; Thursby and Thursby, 2008; Hong and Walsh, 2009). The second angle is that commercialization activities may divert academic scientists' attention from their main mission of teaching and research. Two outcomes of diversion

¹Stephan (1996) and Dasgupta and David (1994) provide insightful details regarding how the reward system in science, the priority of discovery and the winner-takes all, encourages knowledge creation and disclosure.

that have emerged as major concerns are effects on research output and research orientation. However, previous studies have not found evidence that commercialization activities result in a decline in research output. Agrawal and Henderson (2002) find no relationship between patenting activities and publication output among academic scientists in the Mechanical Engineering and Electrical Engineering departments at MIT. Moreover, empirical studies have shown that a complementary relationship exists between commercialization and research output² (e.g., Fabrizio and Di Minin, 2008; Buenstorf, 2009). Related evidence based on patenting and disclosure activities indicates that the greater involvement of academic scientists in commercialization is driven by higher research output (e.g., Azoulay, Ding, and Stuart, 2007; Thursby and Thursby, 2009a). Regarding the effects of commercialization on research orientation, it is concerned that academic scientists pursue research projects that have commercial applications at the expense of basic research (Vavakova, 1998; Pogayo-Theotoky, Beath, and Siegel, 2002; Campbell et al., 2005; Geuna and Nesta, 2006).

Chapter 2 shares with existing studies examining the diversion of academic scientists' attention. The focus of the discussion will be on research orientation rather than research output. The search for evidence of whether basic research is neglected in favor of applied research and of why this might occur is especially complicated because it is possible to pursue research problems that are both basic and applied (Stokes, 1997). Stokes argues that in such situations, known as Pasteur's Quadrant, applied research is also fundamental in nature. Empirical studies intended to detect changes in research orientation present mixed results (Cohen et al., 1998). However, these studies have not indicated that basic research is being neglected. Some empirical studies demonstrate that academic scientists adapt their research to applied

²Fabrizio and Di Minin (2008) find that academic patenting correlates positively with the publication output. Using licensing and spin-off activities as measures of commercial activities, Buenstorf (2009) observes a similar pattern between commercialization and research output.

science and to commercially useful problems³ (e.g., Rahm, 1994; Van Looy et al., 2004; Gulbrandsen and Smeby, 2005; Azoulay, Ding, and Stuart, 2009). Other studies find no evidence of such a change⁴ (e.g., Ranga, Debackere, and Von Tunzelmann, 2003; Van Looy, Callaert, and Debackere, 2006; Thursby and Thursby, 2007; Thursby and Thursby, 2009b).

In general, empirical and theoretical studies of research orientation involve five positions. The first position is that the prospect of commercial profit encourages academic scientists to pursue research projects that have commercial applications regardless of the projects' contribution to fundamental knowledge (Krimsky et al., 1996; Hane, 1999; Campbell et al., 2005). The second position is that academic

³In a survey to the top 100 US research universities, Rahm (1994) uncovers that 41% of academic scientists express the fear of negative impact of technology transfer activities on the basic research orientation of their universities. The 59% of academic scientists in their sample do not perceive such interference. Their survey also reveals that 24% of university administrators fear the interference while 76% of the university administrators do not. Van Looy et al. (2004) use division memberships as the measures of entrepreneurial involvement. Comparing academic scientists who are members of divisions and those who do not, they find that the former group published more papers in applied-oriented journals than the later. However, both groups' publications in basic-oriented journals are comparable. In a survey on academic scientists at Norway universities, Gulbrandsen and Smeby (2005) observe that about 50% academic scientists funded by industry characterize their research as applied. About 40% of the academic scientists funded by industry characterize their research as basic. In comparison, they find that approximately 62% of academic scientists funded by non-industry (other external fund) characterize their research as basic and approximately 25% of them identify their research as applied. Azoulay, Ding, and Stuart (2009) constructed a sample of 3,862 academic scientists in life science. On these academic scientists, they find patenting activities positively correlate with commercial content of research publications. Their result is robust on three measures of commercial content: the "patentability" of research publications, the co-authorship with industry affiliated researchers and the Journal Commercial Score (i.e., the proportion of industry affiliated authors publishing in a journal).

⁴Observing publications from year 1985 to 2000 of academic scientists in KU Leuven, Ranga, Debackere, and Von Tunzelmann (2003) find a small dominance of publications in basic-oriented journals to publications in applied-oriented journals. Comparing academic scientists who involved in patenting and those who did not, Van Looy, Callaert, and Debackere (2006) show that the former group published more papers in basic oriented-journals than the later. Using a dataset of academic scientists in six major US universities over a seventeen-year period, Thursby and Thursby (2007) find that there has been no change in the proportion of research published in basic-oriented journals to research published in applied-oriented journals. Based on a sample from 11 major universities in the US, Thursby and Thursby (2009b) use disclosures as the measures of academic scientists' involvement in licensing. They observe that academic scientists who disclosed have a higher number of publications in basic-oriented journals than academic scientists who never disclose. Their findings also show that both the number of publications in basic-oriented journals and in applied-oriented journals increase with disclosure activities. The increase of the number of publications is greater for academic scientists who disclosed than those who did not.

scientists spend more time on basic research and applied research because both types of research contribute to the stock of knowledge from which they produce licensable output (Thursby, Thursby, and Gupta-Mukherjee, 2007). In the presence of licensing, Thursby, Thursby and Gupta-Mukherjee show that academic scientists are able to increase the time that they spend on basic research and applied research because they reduce their leisure time regardless of the Pasteur Quadrant. The third position is that when academic scientists consider undertaking commercializable research projects, there exists a trade-off between the ease of commercialization by the reduction in commercialization costs and the ease of performing research by avoiding disutility from performing applicable research (Lacetera, 2009). It is argued that academic scientists select applied research over basic research if the former is larger than the latter.

The fourth position is that the decisions of academic scientists regarding the type of research arise from their aspirations to undertake research projects (Goldfarb, 2008). Because applied sponsors constitute an alternative source of research funding, it is argued that academic scientists favor applied research over basic research if such a decision allows them to actualize the aspirations. A related line of argument is that industry funding is not impartial (Eisenberg, 1988; Benner and Sandstorm, 2000; Geuna, 2001; Gulbrandsen and Smeby, 2005) although it enables academic scientists to recruit additional researchers, graduate students and post-doctoral scientists, access the equipment in industrial laboratories or access research materials (Campbell et al., 2005; Azoulay, Ding, and Stuart, 2009). The fifth position is rooted in the awareness that the benefits that academic scientists can derive from applied research include both financial rewards and the satisfaction of having a wider impact on society (Sauermann, Cohen, and Stephan, 2010). It is argued that financial incentives may not be the main reason why scientists choose to engage in applied research. It is possible that academic scientists choose applied research over basic research in spite

of limited financial incentives if their desire to have a broad impact on society is sufficiently high.

Investigating the impact of commercialization on academic scientists' research orientation, extant studies consider the opportunity cost of forgoing research. Opportunity cost is usually depicted as involving non-pecuniary benefits such as the satisfaction of working on research puzzle, scientific reputation, or social impact (Levin and Stephan, 1991; Sauermann, Cohen, and Stephan, 2010). After one acknowledges the relevant opportunity cost, the existing studies on research orientation, excepting those that employ the fourth approach, have assumed that actualizing scientific freedom in academia is free. The non-pecuniary benefits of research are indeed essential building blocks of the scientific system (Levin and Stephan, 1991; Dasgupta and David, 1994). However, such abstraction away from the direct cost of doing science calls for comments as Stephan (1996) explains that funding is necessary for academic scientists to conduct their chosen research projects. Consistent with Stephan's explanation, Walsh, Cohen, and Cho (2007) find that access to funding is the fourth most popular reason why biomedical scientists in academia select particular research projects, ranking below only to scientific importance, interest, and feasibility. The survey also reveals that the main reason why these scientists do not pursue certain research projects is a lack of funding.

When funding is available from applied sponsors, their influence on academic scientists' research projects is worthy of attention (Eisenberg, 1988; Geuna, 2001; Gulbrandsen and Smeby, 2005). For example, in a survey of medical literature, Bhandri et al. (2004) find that research funded by industry sponsors is more likely to produce results that are favorable to the industry. Another example is the controversial agreement between University of California at Berkeley and Novartis in 1998. Based on a five-year research agreement, the Department of Plant and Microbial Biology at University of California at Berkeley received \$25 million of funding from Novartis

(Rosset and Moore, 1998). The benefits that Novartis received in return included two out of the five seats on the department's research committee, which gave the firm the authority to decide how the research budget would be disbursed (Press and Washburn, 2000). Nevertheless, academic scientists are not passive victims of applied research sponsors. That academic scientists exploit funding from applied sponsors is suggested in a survey of 62 major US universities conducted by Thursby, Jensen, and Thursby (2001). When asked how they measured the success of the technology transfer offices at their universities, 75% of academic scientists responded that sponsored research is an extremely important measure of success (Thursby, Jensen, and Thursby, 2001; Jensen, Thursby, and Thursby, 2003).

The approach taken in Chapter 2 builds on the literature that points out the relationship between research funding and academic scientists' decision regarding research problems (i.e., fourth approach). The essay in Chapter 2 contributes to the literature in four ways. First, it complements Thursby, Thursby, and Gupta-Mukherjee (2007) and Gans and Murray (2010) in providing theoretical foundation of academic scientist's choice of research agenda when commercial profit is plausible. The difference between the essay and Thursby, Thursby, Gupta-Mukherjee (2007) is that the chapter considers the influence of funding agency on academic scientist's decision. The chapter differs from Gans and Murray (2010) in which this essay models an academic scientist as an active player in creating a research agenda while the Gans and Murray (2010) models an academic scientist as a selector of research projects. The propositions in the essay contribute to the discussion in the literature on whether academic scientists' involvement in commercialization shifts academic research agenda from objective issues toward issues of industry's interest.

Second, this essay extends our understanding on the nature of scientific work as described in Stokes' quadrants. The essay confirms to the accepted notion that fundamental research does not necessarily imply separation with application (Stokes, 1997).

Toward Stoke's framework which depicts combinations of varying degree of fundamental research and applied research, the essay suggests that the relationship between the two dimensions is complementary. Third, this essay brings industry characteristics into the discussion of whether there is a shift academic research agenda. These characteristics are incorporated in the level of difficulty of firm's research problem and the equality of firm's scientists. Inclusion of these factors is important because the quality of firm's scientists affect the ability of the firm to solve its research problem, thus its interest to fund academic scientists. The magnitude of scientists who work in the industry is not trivial. In the US, 40% of 2006 science and engineering PhD graduates in the US took employment in the industry (Sauermann, Cohen, and Stephan, 2008). Moreover, some industries are aggressive in recruiting competent scientists from academia (Washburn, 2005).

1.2 New ventures as mechanisms that transform scientific investment into commercial outcomes

Chapter 3 and Chapter 4 investigate the transformation of scientific investment into commercial outcomes through new technology ventures. Chapter 3 focuses on new technology ventures founded on university research. In particular, Chapter 3 seeks to explain which academic scientists are more likely to create new technology ventures. Besides the magnitude of scientific investment, this question is important for two additional reasons. First, the role of scientific human capital in transforming scientific results into commercial outcomes cannot be underestimated. For instance, the tendency in the biotechnology industry for locations of new technology ventures to follow the location of prominent scientists illustrates the fact that knowledge is embedded in individuals (Zucker, Darby, and Brewer, 1998). In addition, reliance on scientists for successful technological development is intensified when inventions are in an embryonic stage (Jensen and Thursby, 2001). Furthermore, Agarwal (2006)

has shown that engaging inventors increases the probability of commercialization success. Second, the role of scientific human capital in transforming scientific results into commercial outcomes is not a simple input-and-output function. For example, the contribution of academic scientists to new technology ventures' performance does not increase proportionally with their scientific productivity. Rather, their contribution to patenting productivity of the new ventures decreases as their scientific productivity increases (Toole and Czarnitzki, 2009). In a related study, Gittelman and Kogut (2003) argued that research that highly impacts scientific knowledge does not necessarily lead to valuable inventions because different selection logic operates in science and in commercialization. This emerging literature indicates that the mechanism through which scientific human capital contributes to commercial outcomes is not homogenous, but rather heterogeneous. More importantly, the quality of science is only one part of the heterogeneity. Hence, examining which academic scientists are more likely to create new technology ventures offers a step in examining alternative sources of heterogeneity.

While determinants of new ventures have been at the heart of entrepreneurship literature (e.g., Gartner, 1990; Shane and Venkataraman, 2000), extant studies have treated scientists-entrepreneurs as different from general entrepreneurs. For example, scientists engaging in commercialization activities face conflicting institutional norms in scientific and industrial community (Dasgupta and David, 1994). In addition, scientists' reservation cost for leaving their laboratory bench is high because they derive utility from doing science (e.g., Stephan, 1996; Stern, 2004). Furthermore, academic scientists and industry scientists differ in their choices of the timing of commercializing an invention (Lacetera, 2009). The extant literature explaining academic scientists' entrepreneurship has provided valuable insights, yet the majority of studies examine macro level explanations. Thus, a systematic study at the individual level is required to answer the research question.

At macro level, literature has identified the influence of environment, university, and social influence on the creation of new ventures. Environmental factors of interest have included venture capital funding as enactment of opportunity mechanism (e.g., Steffensen, Rogers, and Speakman, 2000; Di Gregorio and Shane, 2003; Wright et al., 2006) and intellectual property protection (Shane, 2002). Furthermore, studies have shown that the number of new venture creations is not a direct function of the amount of a university's research expenditure (i.e. research resource), but that it is also a function of the university's specific type of resources. These specific resources include the university's expenditure on technology transfer activities, industry funding on research expenditure, and the quality of scientific human capital (e.g., Di Gregorio and Shane, 2003; Lockett and Wright, 2005; O'Shea et al., 2005). Finally, studies show that social influence reduces the cost of being an academic entrepreneur by providing resources such as advice on whom to contact and how to work with Technology Transfer Offices. Such studies also show that an entrepreneurial social environment can change a scientist's perception of the benefits of being an academic entrepreneur (e.g., Louis et al., 1989; Nicolau and Birley, 2003; Kenney and Goe, 2004; Krabel and Mueller, 2009). For instance, Stuart and Ding (2006) showed that proximity to other academic entrepreneurs increases the likelihood that a focal scientist will engage in entrepreneurship.

At the individual level, extant studies have emphasized the role of scientific productivity in creating new ventures (e.g., Zucker, Darby, and Brewer, 1998). Stuart and Ding (2006) showed that the effect of social proximity to an academic entrepreneur increases when the focal scientist is in the proximity of an academic entrepreneur who is also a markedly productive scientist. In a conceptual paper, Lacetera (2009) showed that academic scientists are selective in commercializing inventions, especially when they are dealing with particularly promising inventions. Jain, George, and Maltarich (2009) proposed that academic scientists who found new ventures are those who

can cope with conflicting roles by protecting their scientific identity and asking help from Technology Transfer Offices. Studies also consider the influence of scientists' prior experiences with entrepreneurship (e.g., Krabel and Mueller, 2009; Ding and Choi, 2008). Furthermore, scientists that have been identified as productive of new venture creation have been associated with the following characteristics: a greater exposure to the technological source, a personal ability to perceive, understand, and apply advanced technology, a younger age, and a sense of challenge and satisfaction with sources (Roberts, 1991). These studies, however, provide limited explanation on human scientific capital's characteristics related to their role in commercialization outcomes. In addition, while an academic scientist's decision to create new ventures depends upon alternative commercialization routes, such as licensing to existing firms, extant studies rarely incorporate this alternative option⁵.

In Chapter 3, we seek to understand the following question: which academic scientists are more likely to engage in founding new ventures? Our proposed answer is that academic scientists' decision to create new ventures is influenced by the nature of research, specifically its level of commercial applicability. The essay in Chapter 3 contributes to the literature in three ways. First, it complements a stream of studies that examines the role of university based ventures in technology transfer. In this literature, the study that is closest to this essay is Lowe (2006). This essay differs from Lowe (2006) in that Lowe focuses on the role of contract design in predicting university based ventures. Second, this essay adds to the limited studies on the choice of commercialization routes (e.g., licensing to established firm vs. establishing new technology ventures). A study by Jensen and Showalter (2009) is closest to this essay. The difference between the essay and their study is that Jensen and Showalter (2009) concentrates on contract design and offers empirical evidence at university level whereas this essay emphasizes scientists' research characteristic and

⁵Exception includes Ding and Choi (2008) and Jensen and Showalter (2009).

provides empirical evidence at individual level. Third, the essay contributes to the discussion on the role of scientific human capital in bridging the realm of science and commercialization. Consistent with extant studies (e.g., Gittleman and Kogut, 2003; Toole and Czarnitzki, 2009), the essay show that heterogeneity of human capital explains differential outcomes of commercializing scientific results. The essay extends this literature by proposing that the nature of scientist's research is another dimension of heterogeneity of human capital.

While Chapter 3 discusses the origin of new technology ventures, Chapter 4 focuses on commercialization process once the technology ventures are founded. Specifically, Chapter 4 discusses team formation in new technology ventures, and attempts to answer the following questions: why does an entrepreneur forms a team at a particular stage of a commercialization project? What are the factors that encourage or inhibit the formation of entrepreneurial teams? These questions are important for, at least, three reasons. First, there is an increasing occurrence of teamwork. In all fields of science, more research is done in teams (Wutchy, Jones, and Uzzi, 2007). In addition, the average number of inventors per patent has been steadily increasing (Jones, 2009). In the field of entrepreneurship, 40 to 50 percent of new businesses are formed by teams (Shane, 2008). Yet, most studies on entrepreneurship focus on individual entrepreneur (Forbes et al., 2006), such as entrepreneur trait and entrepreneur optimism.

Second, entrepreneurial teams have been linked to the performance of new ventures. For instance, working in a team allows the accumulation of experience of the team members, which have been found to increase the survival and sales of the new ventures (Delmar and Shane, 2003). In addition, founding team size and its heterogeneity are positively associated with the growth of the new ventures (Eishenhardt and Schoonhoven, 1990). Third, because new ventures are plagued with resource constraint (Stinchcombe, 1965; Rothaermel and Thursby, 2005a; Rothaermel and

Thursby, 2005b), it is important to carefully allocate its resource. The optimal decision of team formation influences resource allocation by avoiding two types of risks. One is the risk of an early team formation is carrying unnecessary cooperation cost, hence depleting the scarce resource of the new ventures. In addition, an entrepreneur experiences the risk from a late team formation is missing higher outcome which comes from specialization in a team-project. It is found that an entrepreneur obtains less expected value from a project if the entrepreneur chooses to work solo at latter stage than working in a team. The effects of economic value, probability of failure, and cost of cooperation on the timing of team formation are presented. We also explain how asymmetry of importance between tasks in a commercialization project influences the decision of team formation.

The essay in Chapter 4 contributes to the literature in four ways. First, it adds to the dearth of literature in on entrepreneurial teams. Second, the essay broadens the literature on team structure by elaborating the relation between the specialization and diversity. Third, the essay extends the existing studies on the impact of uncertainty on the propensity of working in team. It confirms to extant studies that uncertainty increases the likelihood of team formations. The essay also suggests that the likelihood of team formations declines when the uncertainty is sufficiently high. The conditions in which this pattern is reversed is analyzed. Fourth, the essay complements existing literature by evaluating how asymmetry of importance between tasks influences the propensity of team formation.

CHAPTER II

TECHNOLOGY TRANSFER AND THE SOURCES OF RESEARCH FUNDING: IMPLICATIONS FOR THE NATURE OF RESEARCH

2.1 Introduction

As mentioned in the first chapter, the approach taken in Chapter 2 builds on the literature that points out the relationship between research funding and academic scientists' decisions regarding research problems. This paper also builds on the work done by Jensen, Thursby, and Thursby (2010), who detail the interaction between research sponsors and academic scientists that occurs when the potential for commercial profit exists. By including research funding as one of the factors that academic scientists consider in choosing a research problem, this approach results in a model that identifies mechanisms that link academic scientists and the nature of research projects. Because the focus is on the type of research project undertaken, the model abstracts from the issue of hazard in commercialization. In-depth theoretical investigations of the hazard, including considerations such as disclosure, shirking and shelving, are discussed elsewhere (e.g., Jensen and Thursby, 2001; Jensen, Thursby, and Thursby, 2003; and Dechenaux, Thursby, and Thursby; 2009).

The first section of the model specifies its elements. The second section addresses the funding decisions of two research sponsors, a government agency and a firm. Both research sponsors move simultaneously. It is shown that their decisions are strategic substitutes. This result differs from Jensen, Thursby, Thursby (2010) that shows sponsors' decisions are strategic complement. The strategic substitute in this essay arises because of the concavity of effect on productivity while the strategic

complement in Jensen, Thursby, and Thursby (2010) arises because different type of funding influences one another. It is also shown that the government agency provides more funding and the firm reduces its funding when the academic scientist chooses a more difficult problem. As expected, the firm allocates larger amount of funding to the academic scientist if the scientist selects a research problem that is better related to the firm's interests. In such situations, the government agency reduces its contribution to the academic scientist's project. The total funding from both research sponsors is larger for an academic scientist who has higher research-competence.

The academic scientist's share of licensing does not influence the amount of funding from research sponsors. Meanwhile, the firm lessens its funding and the government agency enlarges its funding when the licensing paid to the university increases. In situations in which the firm confronts a more challenging problem in its own research, the firm provides a larger amount of support to the academic scientists. Despite the lower funding from the government agency, the total funding of the academic scientist is larger when the firm's research problem increases in difficulty. In contrast, the firm decreases its amount of funding to the academic scientist when the firm employs higher-quality scientists. Under these circumstances, the total funding of the academic scientist declines in spite of the additional funding from the government agency.

The third section of the model elaborates on the academic scientist's decision with specific reference to two characteristics of a research problem: the relevance of the scientist's problem to the firm's field of interest and the difficulty of the problem. The model shows that the scientist's benefits from working on a challenging problem is greater when the problem is more relevant to the firm's interest. Consistent with Lach and Shankerman (2008), the model indicates that academic scientists do respond to financial incentives associated with commercializing the outcome of university research. It is demonstrated that if problem difficulty and relevance are highly

complementary, an academic scientists select less challenging and more commercially relevant problems when the licensing paid to the university or the academic scientists' share of the licensing revenue increases.

When the scientists at a firm have higher research-competence, an academic scientist decides on research problems that are less challenging and less commercially relevant. Reverse pattern is obtained when the difficulty of the firm's research problems increases. Under such circumstances, an academic scientist chooses more challenging and more commercially relevant problems. The reason is that the firm that funds academic scientist's project incurs greater opportunity cost when it employs competent scientists. In contrast, the firm that supports academic scientist incurs less opportunity cost when its own project is difficult to solve. Moreover, the higher-quality academic scientists favor more challenging and more relevant research problems. The fourth section incorporate the academic scientist's and the university's shares of research funding. The fifth section of the model includes the direct benefit of research grants on academic scientist's utility. The results remain when we include shares of research funding or the direct benefit of grants.

2.2 Environment and Payoffs

We built the environment of the model using a game with three players¹: an academic scientist, a government agency, and a firm. The academic scientist decides two characteristics of a research project: the level of difficulty, $x_a \in [0, X]$, and the relevance of the research problem to the firm's field of interest, $\beta \in [0, 1]$. To carry out her research project, the academic scientist requires funding, $e_a \geq 0$, and uses her research-competence, $q_a \in [0, Q]$. Thus, the probability of success of her research project, $p_a(e_a, q_a, x_a) \in [0, 1]$, depends upon the level of difficulty of the research problem, the amount of research funding, and her research-competence. Because a

¹The environment is an adaptation of one presented in Jensen, Thursby, and Thursby (2010).

more difficult problem is harder to solve, the probability of success decreases as the level of problem difficulty increases at an increasing rate, $\frac{\partial p_a}{\partial x_a} < 0$ and $\frac{\partial^2 p_a}{\partial x_a^2} > 0$. On the other hand, the probability of success increases with the quality of the scientist at a decreasing rate because a more capable scientist has a greater chance of solving the research problem than a less capable one, $\frac{\partial p_a}{\partial q_a} > 0$ and $\frac{\partial^2 p_a}{\partial q_a^2} < 0$. In addition, research funding assists the academic scientist in searching for the solution to her chosen research problem. The more generous the research funding, the greater the chance of solving the problem, $\frac{\partial p_a}{\partial e_a} > 0$ and $\frac{\partial^2 p_a}{\partial e_a^2} < 0$. It is natural to assume that research funding and research-competence are complements, $\frac{\partial^2 p_s}{\partial e_a \partial q_a} > 0$. However, an increase in level of difficulty of a research problem decreases the marginal contribution of research funding and research-competence to the probability of success, $\frac{\partial^2 p_s}{\partial e_s \partial x_s} < 0$ and $\frac{\partial^2 p}{\partial q_s \partial x_s} < 0$.

In conducting a research project, the academic scientist earns wages, W_i , and improves her reputation, R_i , where $i \in \{s, f\}$. Naturally, a successful project enhances a scientist's reputation more than a failed project, $R_s > R_f$. A more difficult research problem has a similar effect on reputation, $\frac{dR}{dx_a} > 0$. If a project is successful, it has the potential to be commercialized. The chance that a successful project will entice a firm to license the academic scientist's research output depends on the relevance of her project to the firm's interests, $l(\beta) \in [0, 1)$. The less relevant the academic scientist's project is, the less likely it is that the firm will license the research output, $\frac{dl}{d\beta} > 0$. The firm allocates part of the profit from commercializing academic research to the university in the form of licensing revenue, $L \geq 0$. That is, the academic scientist secures additional income to supplement her university salary, $A \geq 0$, when a research project is successful, $W_s = A + \gamma L$ and $W_f = A$. The additional income depends on her share of the licensing fee paid to the university, $\gamma \in (0, 1)$.

An academic scientist's utility from the research project is defined as the value that she enjoys from wages and reputation, $U(R, W)$. She enjoys greater utility from

more generous wages or a better reputation, $\frac{\partial U}{\partial R} > 0$ and $\frac{\partial U}{\partial W} > 0$, at a decreasing rate, $\frac{\partial^2 U}{\partial R^2} < 0$ and $\frac{\partial^2 U}{\partial W^2} < 0$. Without loss of generality, we assume that her utility is additively separable², $U(R, W) = f(R) + g(W)$. We assume that, although the marginal effect of reputation on utility when the project is successful is less than the marginal effect of reputation on utility when the project fails, a more challenging problem enhances greater additional reputation to a successful project than to a failed project such that the difference in the reputational enhancement offset the difference in utility gained between successful project and fail project, $\frac{R'_s(x_a)}{R'_f(x_a)} > \frac{U'(R_f)}{U'(R_s)}$. Given additional research funding, the academic scientist earns greater additional utility if the additional funding is allocated to the more challenging problem than if it is allocated to an easier problem³, $\frac{\partial^2 p_a}{\partial e_a \partial x_a} \Delta U + \frac{\partial p_a}{\partial e_a} \Delta \frac{\partial U}{\partial x_a}$. In other words, the additional expected utility from solving the more challenging problem is larger than the opportunity cost of giving up the less challenging problem.

At the same time, an academic scientist experiences disutility from the level of relevance of the project to the firm's interests, $V(\beta) \geq 0$. Problems that are relevant to firms usually encompass broader disciplines, requiring more effort to solve (Lacetera, 2009). Such disutility also arises because problems are not always equally of interest to firms and the scientific community, nor are they always equally of interest to firms and the particular scientist (Goldfarb, 2008). Her disutility is increasing in its argument and convex. The academic scientist's expected utility is

$$EU_a(G, F_a, x_a, \beta) = p_a(e_a, q_a, x_a)U(R_s, W_s) + [1 - p_a(e_a, q_a, x_a)]U(R_f, W_f) - V(\beta) \quad (2.2.1)$$

By sponsoring a research project, $G \geq 0$, the government agency obtains a better reputation. That is, $R_g > 0$ only if $G > 0$. The government agency's utility

²This approach is similar to the one in Jensen, Thursby, and Thursby (2010).

³where $\Delta U = U(R_s, W_s) - U(R_f, W_f)$ and $\Delta \frac{\partial U}{\partial x_a} = \frac{\partial U(R_s, W_s)}{\partial x_a} - \frac{\partial U(R_f, W_f)}{\partial x_a}$.

from the academic scientist's project is denoted as $U_g(R_{gi})$ where $i \in \{s, f\}$. Like the academic scientist, the government agency has more to gain in this regard from a successful project than from a failed one, $R_{gs} > R_{gf}$. The government agency's utility is increasing and concave in the reputational stock. In funding the academic scientist's project, the government agency forgoes the opportunity to fund other research projects. The opportunity cost of forgoing other research projects is denoted as $V(G)$ where $V(G) \geq 0$. The government agency disutility increases in its argument and convex because spending more units of funding on the academic scientist's project means spending fewer units on other research projects. The government agency's expected utility is

$$EU_g(G, F_a, x_a, \beta) = p_a(e_a, q_a, x_a) U_g(R_{gs}) + [1 - p_a(e_a, q_a, x_a)] U_g(R_{gf}) - V(G) \quad (2.2.2)$$

The firm decides the level of funding to the academic scientist, $F_a \in (0, F)$, based on its own research projects. It distributes a certain amount of the research budget, $F > 0$, to its own research projects and an additional amount to the academic scientist's project. As with the academic scientist's project, the probability of success of the firm's research project, $p_c(e_c, q_c, x_c) \in [0, 1)$, is contingent on the level of difficulty of the research problem, the amount of research funding, and the quality of the firm's scientists. These two research projects also have differing consequences to the firm. First, the firm naturally chooses a problem that is commercially relevant to its business when conducting its own research. Unlike the results of the academic scientist's project, the results of the firm's own project will absolutely be relevant for commercialization. Secondly, the firm retains all profits when commercializing its own research but shares some of the profits with the university when commercializing academic research. Thirdly, the firm's project only receives funding from its own research budget, while the academic scientist's project can have up to two sources of

funding. We use Π_u and Π_c to represent the firm's profit from the academic scientist's research project and the firm's own research project. The firm's expected profit is

$$E\Pi(G, F_a, x_a, \beta) = p_a(e_a, q_a, x_a)l(\beta)(\Pi_u - L) + p_c(e_c, q_c, x_c)\Pi_c - F \quad (2.2.3)$$

where the level of funding on the academic scientist's project is

$$e_a = G + F_a \quad (2.2.4)$$

and the level of funding on the firm's research project is

$$e_o = F - F_a \quad (2.2.5)$$

The timing of the game is as follows. In the first stage, the academic scientist decides on the characteristics of the research project. In the second stage, the academic scientist seeks funding from the government agency and the firm. The firm and the government agency simultaneously chooses the level of funding for the academic scientist. At the end of the second stage, the success or failure of the academic scientist's project is observed.

2.3 Stage Two Equilibrium

In the second stage, the government agency and the firm choose their units of funding, G and F_a , for the academic scientist's research project. The interior Nash equilibrium must satisfy

$$\frac{\partial EU_g(G^*, F_a^*, x_a, \beta)}{\partial G} = 0, \quad (2.3.1)$$

and

$$\frac{\partial E\Pi(G^*, F_a^*, x_a, \beta)}{\partial F_a} = 0 \quad (2.3.2)$$

where

$$\frac{\partial EU_g(G, F_a, x_a, \beta)}{\partial G} = \frac{\partial p_a}{\partial e_a} [U_g(R_{gs}) - U_g(R_{gf})] - V'(G) \quad (2.3.3)$$

and

$$\frac{\partial E\Pi(G, F_a, x_a, \beta)}{\partial F_a} = \frac{\partial p_a}{\partial e_a} l(\beta) (\Pi_u - L) - \frac{\partial p_c}{\partial e_c} \Pi_c - 1 \quad (2.3.4)$$

A unit increase in the government funding for the academic scientist's project increases her total funding, thus also increasing the chances of solving the research problem. The government agency's expected utility then increases with the increase in the chance of solving the problem. However, a unit increase in government funding to the academic scientist's project increases opportunity cost and thus is actually associated with disutility. If the losses from diverting resources to the academic scientist's project are too high, the government agency will not provide the scientist with funding. Otherwise, the government agency will increase the amount of the grant to the academic scientist until a one-unit increase in funding results in additional unit of expected utility equal to the amount of the added disutility. In other words, the government agency increases the level of funding until the marginal effect of government funding on its expected utility is offset by the marginal loss.

The firm is subjected to two conflicting forces when it increases research funding for an academic scientist. On the one hand, it adds to the total funding for the academic scientist, increasing the chance that the academic scientist will solve the problem. Consequently, the firm's expected profit from the academic scientist's research also rises. On the other hand, greater funding for an academic scientist reduces the funding allocated to its own research project, decreasing the chance that the firm's scientist will find a solution. Accordingly, the firm's expected profit from its research also declines. If the expected loss of profit from its own research is too high, the firm will not allocate its research budget to the academic scientist. Otherwise, the firm

will increase the amount of funding to the academic scientist until a one-unit increase of funding results in additional expected profit from the academic scientist's research that is equal to the additional loss of expected profit from the firm's research. That is, the firm will increase the level of funding to the academic scientist until the marginal effect of its funding on the expected profit from the academic research is offset by the marginal expected loss of profit from the firm's research.

As mentioned earlier, it is possible for the academic scientist to obtain funding from both research sponsors. Considering this likely dual source of funding, the firm decides the amount of research funds for the academic scientist, F_a , which maximizes $E\Pi(G, F_a, x_a, \beta)$. The firm's decision differs for different levels of government agency funding. Thus, the firm's best response function, $\hat{F}_a(G)$, is the level of firm funding to the academic scientist that maximizes its expected profit for any level of funding from the government agency. The government agency also chooses the amount of the grant, G , for the academic scientist, which maximizes $EU_g(G, F_a, x_a, \beta)$. The agency's decision depends on the firm's contribution to the academic scientist's research. The government agency's best response function, $\hat{G}(F_a)$, is the level of government-provided funding for the academic scientist that maximizes the agency's expected utility for any given level of firm funding. An example of research sponsors' best response functions and the equilibrium level of funding is illustrated in Figure 1 below.

Proposition 2.3.1 *When the government agency's and the firm's best response are interior, $\hat{G}(F_a) \in (0, B_g)$ and $\hat{F}_a(G) \in (0, F)$, their best responses are negatively sloped.*

Proof. Available at the appendix ■

Depicted in Figure 1, the firm's best response is a declining function of the government agency's funding. At the same time, the government agency's best response is a declining function of the firm's funding. The government agency gives the academic

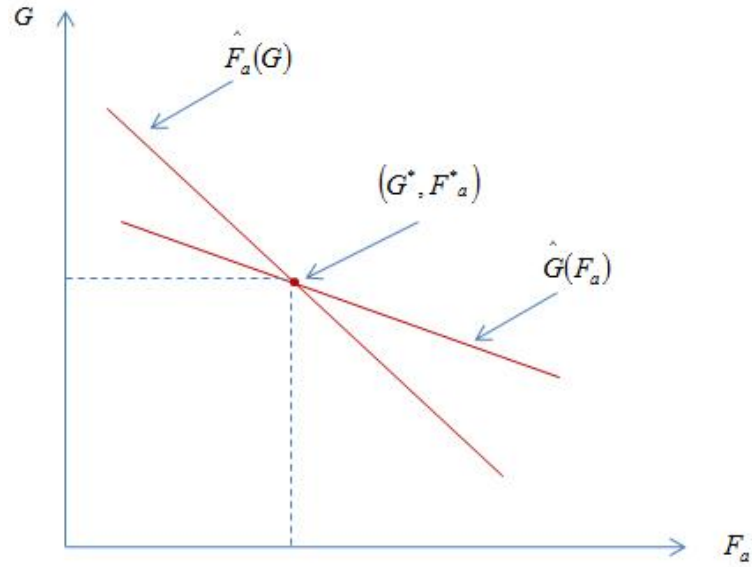


Figure 2: Best-response functions of research sponsors

scientist a smaller amount of funding when the firm provides substantial funding. The more substantial the government’s grant, the less funding the firm allocates to the academic scientist. That the government agency’s best reply is a declining function of the firm’s funding implies that the firm funding decreases the marginal effect of government funding on the its expected utility. Likewise, that the firm’s best reply is a declining function of the government agency’s funding implies that the funding from the government agency decreases the marginal effect of firm funding on its expected profit. These relationships arise because the additional chance of solving the problem using a greater amount of funding declines as the total amount of funding increases. It is more difficult to increase one’s chances of success by putting in more funding when the total research funding is abundant because there is a limit on how much funding contributes to the project’s chance of success.

From the government agency’s point of view, the declining marginal chance of success generates its best response in the following way. The government agency contributes a larger marginal chance of success with each unit of its funding when

the agency is the only sponsor⁴. Consequently, the government agency receives larger marginal expected utility for each unit of its funding when it is the sole research sponsor. This does not imply that the government agency prefers to be the sole research sponsor because the probability of success and the government agency's expected utility increase along with the larger total amount of funding from the increased number of research sponsors. The government agency welcomes firm contributions and the resulting reduction in the government agency's marginal expected utility as long as the reduced marginal expected utility is greater than the marginal loss from not funding alternative research projects. Recall that the equilibrium level of government agency funding is the amount of government funding for which its marginal expected utility is equal to its marginal loss from forgoing alternative projects. When the firm contributes to the academic scientist's project, the equilibrium level of government agency funding is the amount of government funding for which its reduced marginal expected utility is equal to its marginal loss from not funding other projects. At the equilibrium level, additional firm funding results in a greater reduction in the marginal expected utility such that it does not compensate for the marginal loss associated with forgoing alternative research projects. Hence, the government agency will adjust its contribution by decreasing the amount of funding so that its marginal expected utility is equal to the marginal expected loss.

A similar explanation can be used to account for the process through which the

⁴To see this, we can imagine two situations. In both situations, the probability of success increases by 0.2 for the first unit of funding. The second unit of funding adds to the probability of success by 0.1. In the first situation, the government agency is the sole research sponsor. By granting one unit of funding, the government agency receives greater net-expected utility based on an increase of twenty percent in the chance of success. In the second situation, the academic scientist obtains funding from a government agency and the firm. Let us suppose that each sponsor provides one unit of funding. When the government agency grants one unit of funding, the academic scientist obtains two units of funding because the firm provides another unit of funding. Because there are two units of funding in total, the probability of success increases by 0.3. This indicates that the additional chance of success is 0.15 per unit of funding. Unlike in the first situation, in which the one unit of funding from the government agency increases the chance of success by twenty percent, the government agency receives greater net-expected utility from an increase of fifteen percent in the chance of success.

declining marginal chance of success generates the firm's best response. Like the government agency, the firm contributes a larger marginal chance of success for each unit of its funding when it is the sole sponsor. Accordingly, the firm gains a larger marginal expected profit from academic research for each unit of its funding when it is the only sponsor. In other words, the firm's marginal expected profit from academic research is reduced along with the government contribution to the academic scientist's project. The equilibrium level of firm funding is the amount of funding for which its reduced marginal expected profit from academic research is equal to its marginal expected loss of profit by diverting the fund from its own research. At the equilibrium, further increases in government funding provide a greater reduction in the marginal expected profit from academic research such that it does not offset the marginal expected loss of profit from diversion. To accommodate this change, the firm will decrease the amount of its funding for the academic scientist so that its marginal expected profit from academic research is the same as the marginal expected loss of profit associated with diverting funding away from the firm's research.

Proposition 2.3.2 *In the equilibrium of the second stage funding subgame:*

1. *An increase in the level of problem difficulty of the academic scientist's project, x_a , increases the level of government funding and decreases the level of firm funding.*
2. *An increase in the level of alignment to the firm's interest, β , decreases the level of government funding and increases the level of firm funding.*
3. *An increase in the research-competence of an academic scientist, q_a , decreases the level of government funding and increases the level of firm funding.*
4. *An increase in the level of problem difficulty of the firm's project, x_c , decreases the level of government funding and increases the level of firm funding.*

5. *An increase in the research-competence of firm's scientists, q_c , increases the level of government funding and decreases the level of firm funding.*
6. *An increase in the licensing payment to the university, L , increases the level of government funding and decreases the level of firm funding.*
7. *An increase in the share of the licensing payment to the academic scientist, γ does not have effects on the level of government funding or the level of firm funding.*

Proof. Available at the appendix ■

An increase in the difficulty of the academic scientist's problem results in increasing funding from the government agency and decreasing funding from the firm. The mechanism that generates the effects of an increase in the difficulty of the academic scientist's problem can be explained as follows. Because a more challenging problem reduces the chance of finding a solution, a unit of funding allocated to a difficult problem contributes less to the probability of success than the same unit of funding will when allocated to an easy problem. Therefore, the government agency receives less additional utility from a unit of funding as the difficulty of the problem increases. Consequently, an increase in problem difficulty reduces the marginal expected utility of the government agency. Thus, the government agency will be less willing to contribute to the scientist's project for any given level of firm funding. This indicates that the government agency's best response, as depicted in Figure 1, shifts to the left. For a similar reason, an increase in the difficulty of the academic scientist's problem reduces the firm's marginal expected profit from academic research. Hence, the firm is willing to contribute less to the academic scientist's project for any given level of government agency funding. This lowered willingness indicates that the firm's best response shifts down. In response, the government agency becomes willing to contribute more to the academic scientist's project because its best response is declining

in the level of firm's funding.

In summary, the government agency is exposed to two conflicting forces when the academic scientist's problem becomes more challenging. One is a decrease in agency willingness based on its lower marginal expected utility. The other is an increase in agency willingness based on its lowered contribution. Like the government agency, the firm experiences two conflicting forces when the academic scientist chooses a more challenging problem. On one hand, the firm's willingness to fund the academic scientist declines because of the lowered marginal expected profit from the academic research. On the other hand, the firm's willingness to contribute to the academic research increases because the government agency is less willing to fund the academic research. The government agency will experience an increase in willingness based on its lowered contribution that is larger than the decrease in willingness based on its lower marginal expected utility. Hence, the government agency provides a larger amount of funding and the firm reduces its funding.

An increase in the relevance of her research problem to the firm's field of interest decreases the level of funding from the government agency and increases the level of funding from the firm. This adjustment occurs because the firm's best response shifts upward. Meanwhile, the government agency's best response remains unaffected. The firm's best response shifts upward because the more relevant the academic scientist's problem is to the firm's interest, the more likely it is that successful academic research will be beneficial to the firm's business. Accordingly, the firm's marginal expected profit from academic research increases.

When the research-competence of the academic scientist increases, the government will reduce its level of funding and the firm will increase its level of funding. These adjustments take place because a unit of funding in the hands of a high-quality scientist contributes more to the chances of solving the research problem than does the same unit of funding in the hands of a lower-quality scientist because the more

competent scientist is more capable of finding a solution to the problem. Accordingly, an increase in the quality of the academic scientist will result in a greater marginal expected utility of the government agency. The government agency is willing to contribute more to the scientist's project for any given level of firm funding. Thus, the government agency's best response shifts to the right.

An increase in the quality of the academic scientist also enhances the firm's marginal expected profit from academic research. The firm is willing to allocate more of its research budget to the academic scientist for any given level of government agency funding. Thus, the firm best response shifts upward. Because the government agency's best response is declining in the level of firm funding, the government is less willing to provide funding. In short, an increase in the quality of the academic scientist creates two opposing forces that influence the government agency. The government agency's increased willingness to contribute because of the greater marginal expected utility is less than the government agency's decreased willingness to contribute because of the firm's greater interest in the academic project. Therefore, the government agency reduces its funding and the firm provides larger amount of funding.

When the firm's research problem becomes more challenging, the government agency reduces its funding, whereas the firm provides the academic scientist with a larger amount of funding. The reason is that the firm's best reply shifts upward and the government agency's best reply is unchanged. The firm is willing to allocate a greater proportion of its research budget to the academic scientist because the more challenging its research problem is, the lower the chance that the firm's scientist will solve the problem and the lower the firm's opportunity cost as associated with diverting its research funds to the academic project. In contrast, the firm reduces its funding to the academic scientist and the government grants a larger amount of funding to her when the firm's scientist is more competent. This adjustment is

attributed to the downward shift in the firm's best reply. Meanwhile, the government's best reply is not affected. With a higher quality scientist, the firm gains larger marginal expected profit from its research. Thus, the firm's loss of marginal expected profit as associated with diverting the research budget away from its own research increases, and the firm is less willing to fund the academic scientist given any level of government agency funding.

Any changes in the academic scientist's share of the licensing paid to the university have no effect on the level of funding from both sponsors. However, an increase in the licensing paid to the university results in a larger amount of funding from the government agency and a smaller amount of funding from the firm. This adjustment occurs because the firm's best reply shifts downward and the government agency's best reply does not change. A larger licensing payment to the university reduces the firm's profit from commercializing academic research and the associated expected profit. Therefore, the firm is willing to provide less funding to the academic scientist. Consequently, the government agency gives more funding because the government agency's best reply is decreasing in the level of firm funding.

2.4 Stage One Equilibrium

In the first stage, the academic scientist decides on the level of difficulty of her project, x_a , and its level of relevance, β . We assume that the academic scientists chooses these two characteristics based on the equilibrium decisions of research sponsors in the stage two equilibrium, $G^*(x_a, \beta)$ and $F_a^*(x_a, \beta)$. Thus, the academic scientist's objective function is

$$\max_{\{x_a, \beta\}} EU_a(G^*(x_a, \beta), F_a^*(x_a, \beta), x_a, \beta) \quad (2.4.1)$$

The first-order conditions are

$$\frac{\partial EU_a}{\partial x_a} = 0, \quad (2.4.2)$$

and

$$\frac{\partial EU_a}{\partial \beta} = 0 \quad (2.4.3)$$

where

$$\frac{\partial EU_a}{\partial x_a} = \left(\frac{\partial p_a}{\partial e_a} \frac{\partial G^*}{\partial x_a} + \frac{\partial p_a}{\partial e_a} \frac{\partial F_a^*}{\partial x_a} + \frac{\partial p_a}{\partial x_a} \right) (U(R_s, W_s) - U(R_f, W_f)) + \left(p_a \frac{\partial U(R_s, W_s)}{\partial x_a} + (1 - p_a) \frac{\partial U(R_f, W_f)}{\partial x_a} \right) \quad (2.4.4)$$

and

$$\frac{\partial EU_a}{\partial \beta} = \left(\frac{\partial p_a}{\partial e_a} \frac{\partial G^*}{\partial \beta} + \frac{\partial p_a}{\partial e_a} \frac{\partial F_a^*}{\partial \beta} \right) (U(R_s, W_s) - U(R_f, W_f)) - V'(\beta) \quad (2.4.5)$$

When the academic scientist chooses a more challenging problem, this decision has two opposite effects on expected utility. First, a more difficult problem lessens the scientist's probability of success for two reasons. First of all, a more difficult problem is harder to solve. It also decreases the total funding from research sponsors⁵, meaning that the scientist has fewer resources and a lesser chance of finding the solution. Consequently, the expected utility also declines. Secondly, a more challenging problem provides greater reputational enhancement and, thus, greater utility. The academic scientist will increase the difficulty of her research problem until the marginal increase in her expected utility because of the greater improvement in her reputation is offset by the marginal decrease in her expected utility because of her reduced chance of success.

⁵As noted in the previous section, the government agency increases the level funding and the firm decreases the level of funding when there is an increase in the difficulty of the academic scientist's research problem. The resulting total funding for the academic scientist decreases. This implies that despite the higher-level funding from the government agency, the additional amount does not compensate for the reduction in funding from the firm.

By increasing the relevance of her research project to the firm's interests, the academic scientist receives higher expected utility. The reason is that she has greater total funding because the firm provides more funding⁶. With more resources, the academic scientist has a greater chance of solving the problem. However, the academic scientist experiences greater disutility based on the relevance of the problem. As described earlier, the disutility appears because problems that are relevant to the firm's field of interest require more effort to solve and because these problems may not be as relevant to the interests of the scientific community or the academic scientist. Therefore, the academic scientist increases the relevance of her research problem to the firm's field of interest until the marginal gain in her expected utility is equalized by a marginal increase in disutility.

The academic scientist chooses the level of difficulty of her project, x_a , and its level of relevance, β , which maximize $EU_a(G^*(x_a, \beta), F_a^*(x_a, \beta), x_a, \beta)$. The level of difficulty, which maximizes her expected utility at one level of relevance, does not necessarily maximize her expected utility at another level of relevance. Therefore, a difficulty best-choice function, $\hat{x}_a(\beta)$, is the level of difficulty that maximizes the academic scientist's expected utility for any level of relevance. In the same way, the level of relevance that maximizes the expected utility at one level of difficulty does not always maximize the expected utility at a different level of difficulty. The relevance best-choice function, $\hat{\beta}(x_a)$, is the level of relevance that maximizes the academic scientist's expected utility for a research problem at any level of difficulty.

Proposition 2.4.1 *The difficulty best-choice function and the relevance best-choice function are positively sloped.*

Proof. Available at the appendix ■

⁶In the previous section, we also describe how the firm's equilibrium level of funding increases with the relevance of the academic scientist's project. At the same time, the government agency reduces its equilibrium level of funding. The reduction in funding from the government agency is lower than the additional funding from the firm. Thus, the total funding increases.

An academic scientist chooses a more challenging problem when her chosen problem is more relevant to the firm's interests. She selects a problem that is less relevant to the firm's interests if the problem is less challenging. In other words, the difficulty best-choice function is an increasing function of the level of relevance, and the relevance best-choice function is an increasing function of the level of difficulty. An example of difficulty and relevance best-choices is illustrated in the figures below.

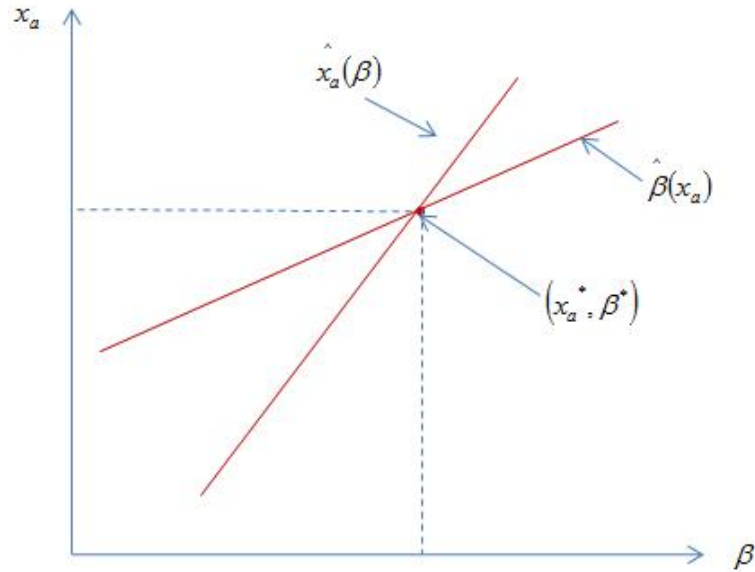


Figure 3: Best-choice functions of an academic scientist

The mechanism underlying these best-choice functions is the following. As previously mentioned, the academic scientist increases the level of problem difficulty until the marginal gain in her expected utility because of the greater increase in her reputation is offset by the marginal decrease in the expected utility because of her lowered chance of success. The extra funding that the problem relevance inspires increases both the scientist's marginal gain in expected utility from the more challenging problem and her marginal loss in expected utility from the easier problem. This implies that an academic scientist earns a larger marginal expected utility from problem difficulty when she aligns her research project with the firm's interests. The scientist also

receives a larger marginal expected utility from relevance when the scientist works on a more challenging problem.

The scientist experiences an increase in the marginal gain that is greater than the increase in the marginal loss because of two reasons. Receiving more generous funding based on increased relevance, the academic scientist has a greater chance of achieving the additional utility from the more challenging problem if she allocates the extra funding to the difficult project. The extra funding also attenuates the impact of the reduction in funding that occurs when the academic scientist increases the level of difficulty of the problem. Because she will suffer fewer consequences from increasing the level of difficulty, the academic scientist will be willing to take on a more challenging problem.

We can obtain comparative statics under the following reasonable assumptions:

$$\text{A1. } \frac{\partial^2 p_a^*}{\partial x_a \partial i} < 0 \text{ for } i = q_a, x_c, L \text{ and } \frac{\partial^2 p_a^*}{\partial x_a \partial i} > 0 \text{ for } i = q_c$$

$$\text{A2. } \frac{\partial^2 p_a^*}{\partial x_a \partial i} \Delta U + \frac{\partial p_a^*}{\partial x_a \partial i} \Delta \frac{\partial U}{\partial x_a} < 0 \text{ for } i = q_c \text{ and}$$

$$\frac{\partial^2 p_a^*}{\partial x_a \partial i} \Delta U + \frac{\partial p_a^*}{\partial x_a \partial i} \Delta \frac{\partial U}{\partial x_a} > 0 \text{ for } i = q_a, x_c$$

$$\text{A3. } \frac{\partial^2 p_a(e_a(G^*(x_a, \beta), F_a^*(x_a, \beta)), q_a, x_a)}{\partial \beta \partial q_a} > 0$$

$$\text{where } \frac{\partial^2 p_a^*}{\partial x_a \partial i} = \frac{\partial^2 p_a(e_a(G^*(x_a, \beta), F_a^*(x_a, \beta)), q_a, x_a)}{\partial x_a \partial i} \text{ and}$$

$$\frac{\partial p_a^*}{\partial x_a \partial i} = \frac{\partial p_a(e_a(G^*(x_a, \beta), F_a^*(x_a, \beta)), q_a, x_a)}{\partial i}$$

These conditions state that an increase in the quality of the academic scientist, in difficulty of the firm's own project, or in the licensing payment to the university decreases the marginal effect of the level of difficulty on the stage-two equilibrium probability of success of the academic scientist's project. An increase in the quality of firm's scientist increases the marginal effect of the level of difficulty on the stage-two equilibrium probability of success. Furthermore, an academic scientist who works on a difficult project enjoys a higher marginal expected utility when she has more

than less funding. This situation occurs when the firm has low opportunity cost associated with low research-competence of its scientists. The situation also happens when the firm has to work on a difficult problem. In addition, an academic scientist who has higher research-competence enjoys larger additional expected utility from a more challenging problem than a less competent scientist. Meanwhile, an increase in the research-competence of an academic scientist increases the marginal effect of relevance, thus the additional funding brought into the project, in the stage-two equilibrium probability of success.

Proposition 2.4.2 *Assume that second-order effects on the equilibrium funding from government agency and from the firm are negligible, $\frac{\partial^2 G^*}{\partial i \partial j} \approx 0$ and $\frac{\partial^2 F_a^*}{\partial i \partial j} \approx 0$, for all parameters i and j . Then:*

1. *An increase in the research-competence of academic scientist, q_a , increase the level of problem difficulty and the level of alignment to the firm's interest.*
2. *An increase in the research-competence of firm's scientist, q_c , decreases the level of problem difficulty and the level of alignment to the firm's interest*
3. *An increase in the level of difficulty of the firm's research problem, x_c , increases the level of problem difficulty and the alignment to the firm's interest*
4. *If $\frac{\partial^2 EU_a / \partial \beta^2}{\partial^2 EU_a / \partial x_a^2} > \delta_\gamma$, an increase in the academic scientist's share of licensing paid to the university, γ , decreases the level of problem difficulty and the level of alignment to the firm's interest when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} < M_\gamma$, but it increases the level of problem difficulty while decreasing the level of alignment when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} > M_\gamma$. If $\frac{\partial^2 EU_a / \partial \beta^2}{\partial^2 EU_a / \partial x_a^2} < \delta_\gamma$, an increase in the academic scientist's share of licensing paid to the university, γ , increases the level of problem difficulty and the level of alignment when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} < \bar{M}_\gamma$, but it increases the level of problem difficulty while increasing the level of alignment when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} > \bar{M}_\gamma$.*

5. If $\frac{\partial^2 EU_a/\partial\beta^2}{\partial^2 EU_a/\partial x_a^2} > \delta_L$, an increase in the licensing paid to the university, L , decreases the level of problem difficulty and the level of alignment to the firm's interest when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} < M_L$, but it increases the level of problem difficulty while decreasing the level of alignment when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} > M_L$. If $\frac{\partial^2 EU_a/\partial\beta^2}{\partial^2 EU_a/\partial x_a^2} < \delta_L$, an increase in the licensing paid to the university, L , increases the level of problem difficulty and the level of alignment when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} < \bar{M}_L$, but it increases the level of problem difficulty while increasing the level of alignment when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} > \bar{M}_L$.

$$\text{where } \delta_j = \frac{(\partial^2 EU_a/\partial\beta\partial j)^2}{(\partial^2 EU_a/\partial x_a \partial j)^2}, \quad M_j = \frac{(\partial^2 EU_a/\partial x_a \partial j)(\partial^2 EU_a/\partial\beta^2)}{(\partial^2 EU_a/\partial\beta\partial j)},$$

$$\bar{M}_i = \frac{(\partial^2 EU_a/\partial\beta\partial j)(\partial^2 EU_a/\partial x_a^2)}{(\partial^2 EU_a/\partial x_a \partial j)}, \quad \text{and } j \in \{\gamma, L\}$$

Proof. Available at the appendix ■

A more competent academic scientist increases the challenge and the relevance of the research project. Her decision will stem from the following process. A more competent academic scientist obtains a larger marginal expected utility from relevance because a higher-quality scientist can better utilize the extra funding from relevance. Hence, the more capable scientist has a greater chance of finding a solution. Thus, the academic scientist is willing to make her research project better aligned with the firm's interests, and the best-choice function for relevance, as in Figure 2, shifts upward. The consequence of this upward shift is a greater willingness to undertake a more challenging problem because the scientist's best-choice function for difficulty is upward sloping.

An academic scientist who has higher research-competence also receives a larger marginal expected utility from problem difficulty because a higher-quality scientist not only is superior in finding a solution but also attracts a larger amount of research funding. Hence, the academic scientist is willing to increase the level of problem difficulty. This implies that the best-choice function for difficulty shifts to the right. Consequently, the academic scientist further increases the level of difficulty and the level of relevance of the research problem.

When the research-competence of the firm's scientist increases, the academic scientist chooses a less challenging and less relevant problem. These adjustments originate from the following mechanism. Having hired a more competent scientist, the firm incurs a larger opportunity cost in diverting its research budget away from the firm's own research. As a result, the firm cuts down its funding to the academic scientist⁷. Having received less funding, the academic scientist then obtains lower marginal expected utility if she selects a more challenging problem. First, the academic scientist endures a larger decline in funding because she bears not only the reduction in funding caused by the increased difficulty of the problem but also a reduction in funding caused by the larger opportunity cost to the firm. Secondly, the academic scientist has a smaller chance to achieve the additional utility that can result from choosing a more challenging problem because there is less funding available to her as a result of the better quality of the firm's scientist. Because an increase in the research-competence of the firm's scientist reduces the effect of problem difficulty on the marginal expected utility, an academic scientist will prefer a less challenging problem at any level of relevance. Thus, the best-choice function for difficulty shifts to the left.

When the firm employs a more competent scientist, an academic scientist whose research project is more closely aligned with the firm's interests will enjoy greater marginal expected utility. The reason is that the academic scientist will receive extra funding. As a result, she suffers less from the reduction in funding as the firm's opportunity cost increases. Under these circumstances, the academic scientist obtains a greater additional chance of success by aligning her project with the firm's interests. Consequently, the academic scientist prefers a higher level of relevance for any level

⁷In the previous section, we describe how the firm reduces its equilibrium level of funding with an increase in the quality of the firm's scientist. At the same time, the government agency increases its equilibrium level of funding. However, the reduction in funding from the firm is larger than the additional funding from the government agency. Thus, the total funding becomes smaller.

of difficulty. Thus, the best-choice function for relevance shifts upward. The implication of this upward shift is that the academic scientist is more willing to undertake a difficult problem because the scientist's best-choice function for difficulty is upward sloping. The academic scientist will select a less challenging and less relevant problem because the encouragement caused by the increasing relevance of the problem is smaller than the disincentive caused by the decline in firm funding.

An academic scientist will select a more challenging and more relevant problem when the firm's research problem becomes more difficult. These adjustments arise from the following process. As its own research problem becomes more difficult, the chance that the firm will develop a solution to that problem declines. This means that the firm will incur lower opportunity costs if it allocates less funding to the problem. Thus, the firm is more willing to provide research funding to the academic scientist⁸. In receiving more funding, an academic scientist obtains larger marginal expected utility if she works on a more difficult problem. As previously explained, extra funding attenuates the impact of reductions in funding when the academic scientist increases the level of difficulty. In addition, the academic scientist has a better chance of achieving the additional utility, a result of the increased difficulty level, because the project has more funding, a result of the decline in the firm's opportunity cost. Thus, an academic scientist will favor a more difficult problem for any level of relevance. It indicates that the best-choice function for difficulty shifts to the right.

Another implication of the increased difficulty of the firm's problem is that it reduces the marginal gains of the expected utility that result from increasing the level of relevance. As previously mentioned, the firm provides a larger amount of funding to

⁸In the previous section, we note that the firm provides a higher equilibrium level of funding when the difficulty of its own research increases. In response, the government agency then decreases its equilibrium level of funding. The additional funding from the firm is greater than the reduction in funding by the government agency. Therefore, the total funding increases.

the academic scientist. The academic scientist experiences a lower additional chance of success because, as the total funding increases, it is harder for the extra funding associated with the greater relevance of the problem to increase the scientist's chances of success. Thus, the academic scientist prefers a lower level of relevance for any level of difficulty, and the best-choice function for relevance shifts downward. In the light of this downward shift, an academic scientist will prefer a less challenging problem because the scientist's best-choice function is upward sloping. The academic scientist will decide on a more difficult and more relevant problem because the inducement caused by additional funding is larger than the disincentive caused by decreasing relevance.

The implications of an increase in the licensing paid to the university are not straightforward, but rather contingent upon the extent of complementarity between problem difficulty and its relevance. When the licensing paid to the university increases, the firm retains a smaller profit from commercializing a successful academic research project. Consequently, the firm will have less interest in the academic scientist's research and will reduce its support⁹. However, the academic scientist will obtain more additional income if her research project is successful. If the academic scientist increases the difficulty of the research problem, she will receive a smaller marginal expected utility. First, an academic scientist has less of a chance of achieving additional income both because the problem is harder to solve and because the research sponsors react by reducing the amount of funding. Secondly, the academic scientist suffers more from a reduction in funding based on increasing problem difficulty because she already receives less funding because of the increased licensing

⁹As explained in the earlier section, the firm cuts down the amount of equilibrium level of funding when the licensing paid to the university increases. In response, the government agency provides a larger amount of equilibrium level of funding. The reduction of funding from the firm is larger than the additional funding from the government agency. Hence, the total funding declines.

revenue. This implies that in increasing difficulty of her research problem, the academic scientist experiences a larger decline in her probability of success when the licensing revenue increases. Thirdly, the academic scientist has less of a chance to obtain the additional reputation by working a more challenging problem because of her lowered funding (which, again, results from the increase in licensing revenue). Thus, the academic scientist prefers a less challenging problem for any level of relevance. That is, the best-choice for difficulty level shifts to the left.

In addition to its influence on the effect of difficulty, an increase in the licensing paid to the university changes the effect of problem relevance. An academic scientist gains larger net-marginal expected utility if she chooses a problem that is more relevant to the firm's interests. As previously discussed, the firm will allocate a larger amount of funding to an academic scientist whose problem is more relevant. This extra funding attenuates the decline in the academic scientist's total funding when the firm cuts down its contribution because of the increase in licensing revenue. Furthermore, the extra funding gives the scientist a better chance of solving the problem. Accordingly, the scientist will be more likely to earn additional income from increased licensing revenue. Hence, the academic scientist will select a problem with greater relevance at any level of difficulty, and the best-choice function for relevance shifts upward. When the best-choice function for relevance shifts upward, a more challenging problem becomes more attractive because the academic scientist's best-choice function for difficulty is upward sloping.

The steepness of the slopes of best-choice functions indicates the extent of complementarity between the level of difficulty and the level of relevance. When licensing paid to the university increases, the academic scientist will choose a more challenging but less relevant problem if the level of difficulty and the level of relevance are highly complementary as shown by steep slopes. If the level of difficulty and level of relevance are low to moderate in complementarity, the academic scientist prefers

a less difficult and less relevant problem when the marginal effect of relevance on academic scientist expected utility declines rapidly. However, the academic scientist favors a more difficult and more relevant problem when the amount of licensing revenue paid to the university substantially enhances the marginal effect of relevance on her expected utility.

When her share of the licensing revenue increases, an academic scientist receives more additional income if her research project is successful. However, the academic scientist obtains a smaller marginal expected utility by increasing difficulty level because the academic scientist has a smaller chance of achieving the additional utility based the larger income. The possibility for such achievement is smaller because her chance of success declines as research sponsors reduces their funding and the problem becomes harder to solve. Consequently, the academic scientist prefers a less challenging problem at any level of relevance, and the best-choice function for difficulty shifts to the left.

Unlike its negative implication to the effect of difficulty on the marginal expected utility, an increase in the academic scientist's share of licensing revenue enables an academic scientist to receive a larger marginal expected utility if she chooses a research problem that is more relevant to the firm's interests. The explanation is as follows. Recall that the firm provides a larger amount of funding to a more relevant project. Because the academic scientist who has access to a larger amount of funding has a greater chance of finding a solution to her research problem, she is more likely to achieve the additional utility resulting from the larger income. Thus, the academic scientist favors a research project that is more relevant to the firm's interests for any level of difficulty. This indicates that the best-choice function for relevance shifts upward. Hence, a more challenging problem becomes favorable because the academic scientist's best-choice function for difficulty is upward sloping.

If the slopes of best-choice functions are not too steep, the level of difficulty and

level of relevance are low to moderate complementarity. In these situations, an academic scientist will choose a less difficult and less relevant problem when the marginal effect of relevance on academic scientist expected utility declines rapidly. Experiencing similar levels of complementarity, an academic scientist will prefer a more difficult and more relevant problem when her share of licensing revenue substantially enhances the marginal effect of relevance on her expected utility. If the slopes of best-choice functions are steep, the level of difficulty and the level of relevance are highly complementary. In these circumstances, academic scientist will choose a more difficult problem but less relevant problem when her share of licensing revenue increases.

2.5 *The University's Shares of Research Funding*

In this section we consider the situation that universities are institutions that must generate income (Slaughter and Leslie, 1997; Bok, 2003). For example, universities in the US receive shares from research funding regardless the outcome of the project. We use $(1 - \delta_G)$ and $(1 - \delta_F)$ to denote the university's share of research funding from the government agency and from the firm respectively, where $\delta_G \in (0, 1)$. Consequently, the academic scientist receives $\delta_G G$ of the agency's funding, G , and she receives $\delta_F F_a$ of the firm's funding, F_a . Meanwhile, the university obtains $(1 - \delta_G) G$ and $(1 - \delta_F) F_a$ ¹⁰. Thus, the level of funding on the academic scientist's project is

¹⁰The specification that $G = \delta_G G + (1 - \delta_G) G$ captures the effect of university mark-up and academic scientist's share from it. In order to see this, suppose that the academic scientist submits a proposal requesting an amount of G_s . We denote the university's mark-up on the government agency funding by μ_G where $\mu_G \in (0, 1)$. Thus, $G = \mu_G G_s + G_s$. The university gives some of its revenue, $\mu_G G_s$, to the academic scientist. Let θ be the fraction that academic scientist receives from university's revenue from government research funding, where $\theta \in (0, 1)$. We can rewrite $G = (1 - \theta) \mu_G G_s + \theta \mu_G G_s + G_s = (1 - \theta) \mu_G G_s + (\theta \mu_G + 1) G_s$, where $(1 - \theta) \mu_G G_s$ goes to the university and $(\theta \mu_G + 1) G_s$ goes to the academic scientist. Let K_u be the amount received by the university from the government agency's funding, G , and let K_s be the amount received by the academic scientist from the government agency's funding, G . Then, $K_u = (1 - \delta_G) G = (1 - \theta) \mu_G G_s$, and $K_s = \delta_G G = (\theta \mu_G + 1) G_s$. Notice that $\frac{\partial K_s}{\partial \theta} > 0$, $\frac{\partial K_s}{\partial \mu_G} > 0$, and $\frac{\partial K_s}{\partial \delta_G} > 0$. In addition, $\frac{\partial K_u}{\partial \theta} < 0$, $\frac{\partial K_u}{\partial \mu_G} < 0$, and $\frac{\partial K_u}{\partial \delta_G} < 0$. In order to see that the specification that $F_a = \delta_F F_a + (1 - \delta_F) F_a$ captures the effect of university mark-up and academic scientist's share from it, a similar explanation is applied.

$$e_a = \delta_G G + \delta_F F_a \quad (2.5.1)$$

The first-order conditions in the second stage are

$$\frac{\partial EU_g(G, F_a, x_a, \beta)}{\partial G} = \frac{\partial p_a}{\partial e_a} \delta_G [U_g(R_{gs}) - U_g(R_{gf})] - V'(G) = 0 \quad (2.5.2)$$

and

$$\frac{\partial E\Pi(G, F_a, x_a, \beta)}{\partial F_a} = \frac{\partial p_a}{\partial e_a} \delta_F l(\beta) (\Pi_u - L) - \frac{\partial p_c}{\partial e_c} \Pi_c - 1 = 0 \quad (2.5.3)$$

In the first stage, the first-order conditions are

$$\frac{\partial EU_a}{\partial x_a} = \left(\frac{\partial p_a}{\partial e_a} \frac{\partial G^*}{\partial x_a} \delta_G + \frac{\partial p_a}{\partial e_a} \frac{\partial F_a^*}{\partial x_a} \delta_F + \frac{\partial p_a}{\partial x_a} \right) (U(R_s, W_s) - U(R_f, W_f)) + \left(p_a \frac{\partial U(R_s, W_s)}{\partial x_a} + (1 - p_a) \frac{\partial U(R_f, W_f)}{\partial x_a} \right) = 0 \quad (2.5.4)$$

and

$$\frac{\partial EU_a}{\partial \beta} = \left(\frac{\partial p_a}{\partial e_a} \frac{\partial G^*}{\partial \beta} \delta_G + \frac{\partial p_a}{\partial e_a} \frac{\partial F_a^*}{\partial \beta} \delta_F \right) (U(R_s, W_s) - U(R_f, W_f)) - V'(\beta) = 0 \quad (2.5.5)$$

As before, the government agency increases the level of funding until the marginal effect of government funding on its expected utility is offset by the marginal loss; and the firm will increase the level of funding to the academic scientist until the marginal effect of its funding on the expected profit from the academic research is offset by the marginal expected loss of profit from the firm's research. In the first stage, the process of decision making remains. That is, the academic scientist will increase the difficulty of her research problem until the marginal increase in her expected utility because of the greater improvement in her reputation is offset by the marginal decrease in her expected utility because of her reduced chance of success; and she increases the

relevance of her research problem to the firm's field of interest until the marginal gain in her expected utility is equalized by a marginal increase in disutility.

Stage-two equilibrium and extant comparative statics do not change by the inclusion of the academic scientist's and the university's shares of research funding. In the same way, the equilibrium and extant comparative statics in stage-one equilibrium remains despite the presence of academic scientist's and the university's shares of research funding. However, the effects of these shares on the level of government funding, the level of firm funding, and the academic scientist's choice of research project are ambiguous.

2.6 Direct Benefits of Research Funding

In the earlier sections, we consider indirect effects of research funding on the utility of an academic scientist. Research funding indirectly influence the utility of an academic scientist through the effect of resource on the probability of solving a research problem. Besides indirect effects, research funding directly influence the utility of an academic scientist. The direct effect is positive and independent of research output. For example, research funding enhances the power of an academic scientist in the department or university (Pfeffer and Salancik, 1974). The academic scientist may use this power to obtain a bigger office, to obtain nicer equipments, to provide fellowships for students, and to avoid doing committee work. Research funding also allows the faculty to buy out teaching, and it relieves any possible disutility associated with teaching. For simplicity, we abstract from academic scientist's and the university's share of research funding. We define $U_d(e_a)$ that is the direct benefit of research funding on academic scientist's utility. It is increasing in its argument and concave. The academic scientist's expected utility, $EU_a(G, F_a, x_a, \beta)$, is

$$p_a(e_a, q_a, x_a) U(R_s, W_s) + [1 - p_a(e_a, q_a, x_a)] U(R_f, W_f) + U_d(e_a) - V(\beta) \quad (2.6.1)$$

Stage-two equilibrium and its related comparative statics do not change by the inclusion of the direct benefit, $U_d(e_a)$. In stage-one equilibrium, the first-order conditions are

$$\begin{aligned} \frac{\partial EU_a}{\partial x_a} &= \left(\frac{\partial p_a}{\partial e_a} \frac{\partial G^*}{\partial x_a} + \frac{\partial p_a}{\partial e_a} \frac{\partial F_a^*}{\partial x_a} + \frac{\partial p_a}{\partial x_a} \right) (U(R_s, W_s) - U(R_f, W_f)) \\ &+ \left(p_a \frac{\partial U(R_s, W_s)}{\partial x_a} + (1 - p_a) \frac{\partial U(R_f, W_f)}{\partial x_a} \right) + \frac{\partial U_d}{\partial e_a} \left(\frac{\partial G^*}{\partial x_a} + \frac{\partial F_a^*}{\partial x_a} \right) \quad (2.6.2) \\ &= 0 \end{aligned}$$

and

$$\begin{aligned} \frac{\partial EU_a}{\partial \beta} &= \left(\frac{\partial p_a}{\partial e_a} \frac{\partial G^*}{\partial \beta} + \frac{\partial p_a}{\partial e_a} \frac{\partial F_a^*}{\partial \beta} \right) (U(R_s, W_s) - U(R_f, W_f)) \\ &+ \frac{\partial U_d}{\partial e_a} \left(\frac{\partial G^*}{\partial \beta} + \frac{\partial F_a^*}{\partial \beta} \right) - V'(\beta) \quad (2.6.3) \\ &= 0 \end{aligned}$$

When deciding the level of difficulty, the academic scientist will increase the difficulty of her research problem until the marginal increase in her expected utility because of the greater improvement in her reputation is offset by the marginal decrease in her expected utility because of her reduced chance of success and because of lower direct benefits. When choosing the level of relevance, the academic scientist increases the relevance of her research problem to the firm's field of interest until the marginal gain in her expected utility is equalized by a marginal increase in disutility. The marginal gain in her expected utility arises because additional funding from the firm improve the chance of solving the problem and because of the larger utility from direct benefits.

Similar to the section where only indirect effect of research funding is considered, the difficulty best-choice function and the relevance best-choice function are positively sloped. Moreover, inclusion of direct benefits does not affect the comparative statics involving the level of difficulty of firm's research problem, the amount of licensing paid to the university, and the academic scientist's share of licensing paid to the university. It is reasonable to assume that, in an academic community, the utility related with

research output, such as the utility from scientific reputation and wage, dominates the utility unrelated to research output, such as the utility from direct benefits of research funding. By this assumption, the comparative statics involving research-competence of academic scientist and research-competence of firm's scientists are the same as those in the earlier section.

2.7 Concluding Remarks

The custom that we use to comprehend the linkages between scientific systems and economic systems is non-linear relationships (Kline and Rosenberg, 1986). While the idea that science is not completely exogenous is well accepted, the challenge is to identify the linkage between the scientific system and the economic system so that the idea has practical implications (Rosenberg, 1982). Rosenberg argues that the economic system influences the scientific system for two reasons. One is that doing science is costly. The other fact is that scientific research can be directed toward economically profitable areas of inquiry. The majority of the extant studies that investigate the impact of commercialization activities on academic scientists' research orientation have concentrated on the second reason. This paper adds to the body of research that has brought both factors into play in examining academic scientists' choice of research projects. We have shown how two types of linkages between scientific system and economic system, licensing and funding, shape academic scientists' selections of research problems.

There are several limitations to the approach taken in this paper. First, it does not explore how competition among scientists (e.g., Walsh and Hong, 2009), the career life cycle of academic scientists (e.g., Levin and Stephan, 1991; Thursby, Thursby, and Gupta-Mukherjee, 2007), their previous accomplishments (e.g., Lazear, 1997) or prior disclosure activities (Thursby and Thursby, 2009b) may affect decisions regarding research problems. Furthermore, this paper only takes into account academic

scientists who stay in academia and abstracts from the scenarios in which academic scientists have the option to leave academia (Jensen and Thursby, 2004). In addition, analyzing the type of commercialization link created by licensing academic research to an established firm excludes circumstances in which university research is commercialized by founding new firms, including those begun by academic scientists (Jensen and Showalter, 2008; Di Gregorio and Shane, 2003). Moreover, the model is limited to situations in which an principal investigator may obtain funding from multiple agencies. Despite these caveats, the question of how academic scientists actualize their scientific freedom should not be overlooked. Academic scientists select research problems with the aim of having their findings published even in instances in which commercial profit is possible (Agrawal and Henderson, 2002). In line with this view, the results of a survey by Walsh, Cohen, and Cho (2007) reveal that for 97% of respondents, scientific importance is one of the main reasons for choosing a research project, whereas only 8% of respondents reported that commercial potential is one of the main reasons for selecting research projects.

CHAPTER III

ACADEMIC SCIENTISTS: THE NATURE OF RESEARCH AND ENTREPRENEURIAL ACTIONS

3.1 Introduction

This chapter discusses how academic scientists' decision to create new ventures is influenced by the nature of research, specifically the level of commercial applicability. The approach taken builds on extant studies that argue that the opportunity cost of engaging in non-research activities is less time spent on scientists' laboratory work (e.g., Levin and Stephan, 1991; Thursby, Thursby and Gupta-Mukherjee, 2007; Jensen, Thursby and Thursby, 2010). The model shows that the opportunity cost is attenuated because knowledge is transferred from successful entrepreneurial actions to scientists' research agenda. The attenuation is larger for some academic scientists than for others, depending on the nature of their respective research. The model explains academic scientist's nature of research in one dimension: the level of commercial applicability. This dimension spans a continuum from low to high.

Within the continuum of commercial applicability, there is a point after which a scientist is willing to create a new venture. Before reaching that point on the continuum, the scientist will not create a new venture. Within this continuum, there is another point starting from which an established firm is willing to license the scientist's invention. If the point after which a scientist deems an invention commercially applicable, and is thus willing to create a new venture, is less than the point at which an established firm believes it is commercially applicable, and is thus willing to license the invention, we will observe that scientists who have the highest probability of creating new ventures are those whose level of commercial applicability is medium.

Scientists whose nature of research is low and high in the dimension of level of commercial applicability will have lower probability than scientists with medium level of commercial applicability. In this case, there is an inverted-u shape relationship between the level of commercial applicability and the likelihood that an academic scientist creates a new venture. When the level of commercial applicability which an academic scientist decides to create a new venture is higher than the level of commercial applicability which an established firm is interested to license the invention, we predict a decreasing relationship between level of commercial applicability and the likelihood that an academic scientist creates a new venture. Empirical estimation of the model is performed on a sample of 395 academic scientists at five top U.S. research universities.

3.2 The Model

This section presents a theoretical analysis of an academic scientist's decision to create a new venture. As the starting point of the game, an academic scientist has disclosed his invention to the university. At this first stage, the university evaluates the invention and has two choices: to shelve (i.e. give the invention to the academic scientist) or not to shelve the invention. If the university shelves the invention, the academic scientist can choose either to create a new venture based on the shelved invention or to work on another research project instead. If the university decides not to shelve the invention, at the second stage, the university can either search for a licensee or offer the academic scientist the option to create a new venture based on the invention licensed by the university. Facing such an offer at this stage, the academic scientist chooses whether or not to create a new venture. Figure 4 depicts the extensive form of the game.

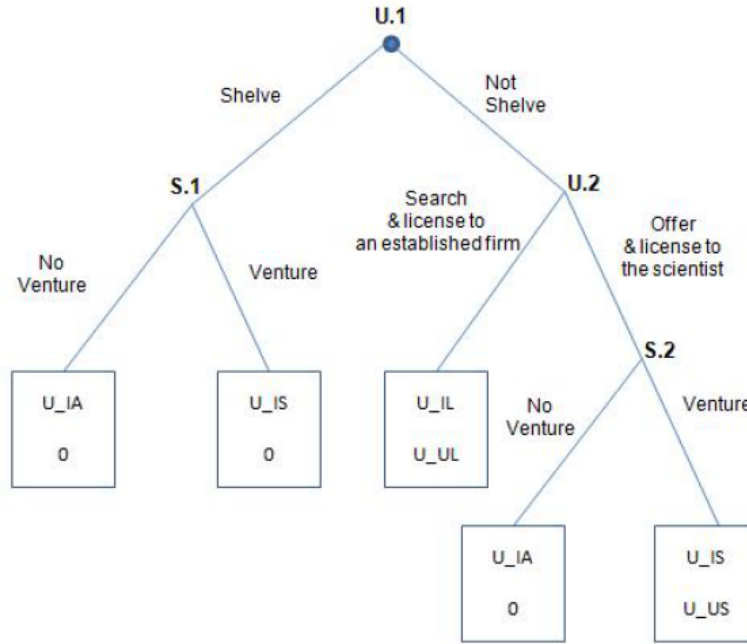


Figure 4: Academic entrepreneurship: Extensive form of the game

3.2.1 The Academic Scientist

An academic scientist is associated with his level of scientific prominence, q . His scientific prominence determines his probability of success should he found a new venture, $p(q)$. The probability of success, a function of q , is both increasing and concave because more prominent scientists are more likely to get resources. For instance, prominent scientists are better able to attract partners or signal to investors that they perform exceptional assessment of the technology (Higgins, Stephan, and Thursby, 2008). For simplicity, we assume risk neutrality. In the case of successful commercialization, the academic scientist gains utility from non-scientific return, B , such as money and satisfaction from having a practical impact (e.g., reaching people). He also obtains utility from scientific return (i.e. knowledge), K . The extent to which his scientific return from commercialization activity is valuable for his research at the university depends on a , which is the level of commercialization applicability of the academic scientist's research orientation. Where $a > 0$, this transferability

of knowledge from the commercialization activity to university research is known in the literature as the Mansfield effect (e.g., Mansfield, 1995; Jensen, Thursby, and Thursby, 2010). For the amount of time which the scientist allocates to creating a new venture, he could have allocated it to his research at the university. We denote such opportunity cost as $r(q)K$ where K is knowledge (i.e. scientific benefit) generated at the university if the scientist does not found a new ventures. Furthermore, $r(q)$ is an academic parameter where $r(q) > 0$, $r' > 0$, and $r'' > 0$, showing that the opportunity cost of doing science at the university is higher for prominent scientists than for average scientists because prominent scientists produce scientific results of higher quality or volume.

The academic scientist's expected return from creating a new venture is $EU_{Is} = p(q)(B + aK)$. The scientist creates a new venture if and only if

$$p(q)(B + aK) \geq r(q)K \quad (3.2.1)$$

Equation (1) can be rewritten as $p(q)B + K(ap(q) - r(q)) \geq 0$. This leads to

Proposition 3.2.1 *The scientist creates a new venture if $B \geq \bar{B} = K \left(\frac{r(q)}{p(q)} - a \right)$. \bar{B} is decreasing a. \bar{B} is decreasing in q when $\frac{r'(q)}{r(q)} < \frac{p'(q)}{p(q)}$. \bar{B} is increasing in q when $\frac{r'(q)}{r(q)} > \frac{p'(q)}{p(q)}$.*

Proof. Available at the appendix ■

For a scientist to be willing to create a new venture, the expected return from founding the venture must be greater than the scientific return from concentrating on university research. Since the outcome of successful commercialization comprises two types, namely scientific and non-scientific, the scientific benefit from successful commercialization attenuates the opportunity cost of spending less time at the university research. Hence, the minimum level of non-scientific benefit, such that creating a new venture is an attractive option, is reduced. Compared to average scientists, prominent

scientists expect both greater non-scientific and scientific benefit from creating new ventures. In other words, prominent scientists have not only greater expected non-scientific benefit, but also greater reduction of their opportunity cost. At the same time, their opportunity cost from spending less time at the university research is also greater than that of average scientists. Prominent scientists are more likely to create new ventures than average scientists when the elasticity of probability of success due to scientific prominence is greater than the elasticity of academic parameter.

3.2.2 The University

The university payoff is zero if the academic scientist decides not to create a new venture based on a university-licensed invention. If the academic scientist accepts the offer, the university obtains returns from two sources, B_U and L . B_U is the university's return from successful commercialization (e.g., income). L is the university's return from simply licensing an invention, regardless of whether or not the commercialization is successful (Jensen, Thursby, and Thursby, 2003). The university also incurs disutility, V_{U_s} that comes both from supporting the academic scientist and from the cost of forgoing the opportunity of promoting other disclosed inventions that might have a higher probability of successful commercialization. Although the university gets utility simply from executing a license to the academic scientist, the disutility from supporting the scientist does not payoff unless the new venture is successful, $EU_{U_s} = L - V_{U_s} < 0$. Thus, the university's expected utility from supporting the academic entrepreneur is

$$EU_{U_s} = p(q) B_U + L - V_{U_s} \quad (3.2.2)$$

To solve the university's problem at information set U.2, first consider a subgame between the university and a potential firm licensee. The university cannot even give a license away unless the probability of commercial success is high enough (Jensen,

Thursby, and Thursby, 2003). Since the extent of the firm's effort (including investment in capital and human resources) depends on the level of commercial applicability of the invention, the university will not search for a licensee unless $p_F(a) \geq V_F(a)/R$ where $p_F(a)$ is the probability of commercialization success if the invention is further developed by the firm. The probability of success by the firm licensee is increasing in its argument and concave. We denote $V_F(a)$ as the firm's disutility from the commercialization effort. It is increasing in its argument and convex. We denote R as the return to the firm licensee if the commercialization is successful. We also assume that $p(q) > p_F(a)$ when $\min(a); \frac{dp(q)}{dq} < \frac{dp_F(a)}{da}$ such that $p(q) < p_F(a)$ when $\max(a)$ for all q . These specifications show that the probability of commercialization success by an academic scientist is larger than that of commercialization success by licensee firms when the research orientation of academic scientist, hence his invention, is low in the level of commercial applicability; this is true since the academic scientist has the tacit knowledge to further develop the embryonic invention (Jensen and Thursby, 2001). The specifications also indicate that the probability of success by a firm licensee is larger than the probability of success by the academic scientist when the research orientation of the academic scientist, hence his invention, is high in the level of commercial applicability. This illustrates the fact that the higher an invention's level of commercial applicability, the better a firm licensee can utilize its existing assets to successfully commercialize it. In other words, the higher the invention's level of commercial applicability, the greater is a firm licensee's advantage from possessing complementary assets. If the university searches for a licensee, it incurs disutility from searching, V_{Ul} . The university's expected utility from licensing is thus:

$$EU_{Ul} = p_F(a) B_U + L - V_{Ul} \quad (3.2.3)$$

While the university's payoff from supporting an academic scientist's venture is

positive only when the commercialization is successful, it is possible that the university searches for a licensee even if the commercialization will not be successful, $EU_{Ul} = L - V_{Ul} > 0$. These two conditions reflect higher disutility from supporting academic scientists. Unlike licensing to an established firm, the university responsibility does not end by the signing of licensing contracts, but rather it entails providing the academic scientist supports such as preparing business plans and connecting academic entrepreneurs to potential partners (e.g., surrogate entrepreneurs or VCs). If the university licenses the invention to a firm licensee, the academic scientist is involved in the further development, and thus the non-academic benefit from successful commercialization to established firm is normalized to zero. The former is in line with the fact that university invention is embryonic such that the involvement of an academic scientist is needed for successful commercialization (Jensen and Thursby, 2001). The latter is justified by the magnitude of difference between the satisfaction that comes from creating a successful new venture and that which comes from consulting, respectively. Thus, the academic scientist's expected utility when the invention is licensed to a firm is

$$EU_{Il} = p_F(a)(aK) + (1 - p_F(a))(0) \quad (3.2.4)$$

Proposition 3.2.2 *In the equilibrium, there are $a_s = \frac{r(q)}{p(q)} - \frac{B}{K}$ and $p_F(a_f) = \frac{V_F(a_f)}{R}$*

1. *When $a_f > a_s$, the likelihood that the academic scientist engages in creating a new venture increases until a cut-off point, \bar{a} , after which the likelihood of creating a new venture decreases.*
2. *When $a_f > a_s$, an increase in the academic scientist's prominence, q , increases the cutoff point, \bar{a} .*

3. When $a_f \leq a_s$, the likelihood that the academic scientist engages in creating a new venture decreases as variable a increases.

Proof. Available at the appendix ■

First consider the situation in which the scientist's willingness to create a new venture occurs earlier in the continuum of level of commercial applicability than the point on the continuum where the established firm becomes interested in licensing the invention. Academic scientists whose research orientation entails a low level of commercial applicability do not find it worthwhile to found new ventures because the expected return does not compensate for the opportunity cost of ceasing to focus on university research. Increasing commercial applicability increases the incentive for academic scientists to engage in entrepreneurship because of the greater expected entrepreneurial return, which comes from the greater scientific benefit of the activity. As long as there is no established firm interested in licensing the invention and its net expected return from supporting the scientist entrepreneur is positive, the university does not shelve the invention and, instead, will support the scientist's venture.

However, as commercial applicability increases, the established firm's expected return from licensing the scientist's invention also increases. At an equal expected return from either licensing to an established firm or supporting a scientist entrepreneur, the university incurs higher cost from the latter, which makes supporting a scientist entrepreneur the less attractive option. That is, although the scientist's willingness to create new ventures increases in the level of commercial applicability, the university's willingness to support the scientist's venture decreases in the level of commercial applicability. Hence, once the established firms are interested in licensing the scientist's invention, there is a decline in the likelihood that the scientist will create a new venture. The point of decline, however, depends on the scientific prominence of the scientist. That is, it is easier for scientists of higher prominence to attract the resources required for a successful venture. Their prominence both lures talented team

members and can tacitly indicate to an investor the high quality of their assessment of the scientific potential of their invention (Higgins, Stephan, and Thursby, 2008). To elaborate on the latter point, it must be understood that scientists of higher prominence can assess the scientific potential of inventions better than average scientists can. If the scientist who pursues the commercialization (i.e. creates the new venture) has high prominence, the investor takes it as an indication that the scientific potential of the technology is better assessed. Since the good quality of the assessment is part of an investors' consideration in allocating investments, highly prominent scientists are more likely to get this resource than are average scientists. Thus, increasing scientific prominence delays the point of declines in the likelihood of a scientist's creation of a new venture.

Next, consider the situation in which the established firm's interest to license the invention occurs earlier than the scientist's willingness to create a new venture on the continuum of the level of commercial applicability. In this situation, the scientist who is willing to create a new venture is always faced with the university that as two alternative commercialization options (i.e. support the scientist's venture or license the invention to an established firm). In other words, the scientist interested in creating a new venture is always in the area where the university's willingness to support the scientist's venture decreases in the level of commercial applicability. Hence, there is no area on the continuum of level of commercial applicability where the scientist's likelihood of creating a new venture increases. There is a decline in the scientist's likelihood of creating a new venture as the level of commercial applicability increases.

Note that the model does not necessitate that the university's objective contradicts that of the academic scientist. To see this, consider the situation when an academic scientist prefers licensing the invention to an established firm. This preference occurs when $EU_{Il} > EU_{Is}$. That is, $p_F(a)(aK) > p(q)(B + aK) \Leftrightarrow [p_F(a) - p(q)] aK -$

$p(q)B > 0$. The equation shows that as a increases, the right hand side of the equation increases, indicating that an academic scientist would rather license to an established firm than to found a new venture. The reason is that the academic scientist can gain knowledge benefit by riding on the established firm, which increases the probability of success. Academic scientists who would likely find this option less appealing are those with high scientific prominence because these high profile scientists have a higher expected return of non-academic benefit.

3.3 Methodology

3.3.1 Research Setting

The academic scientists in our study are faculty members who are listed in bimolecular, electrical engineering, and computer science departments at five top U.S. research universities. The sample is not random, and the characteristic of universities is chosen because top U.S. research universities drive new technology ventures based on university research (O'Shea and Allen, 2008). In addition, the three departments, especially life sciences (e.g., biomolecular), have been used in previous studies as settings of university technology transfer (e.g., Zucker, Darby, and Brewer, 1998; Agrawal and Henderson, 2002).

3.3.2 Data and Sample

The database comprises academic scientists at MIT, The University of Minnesota at Twin Cities, The University of California at Berkeley, Stanford University, and The University of Wisconsin at Madison. In a first step toward creating an academic-entrepreneur database, we identified the names of faculty members who are listed in bimolecular, electrical engineering, and computer science departments in the National Research Council (1995). Based on this initial list, we collected their curriculum vitas (CVs) from university websites, their publication lists from ISI Web of Science, and their patent list from USPTO and Delphion. In the second step, we identified

whether the academic scientists started new ventures. We identified academic entrepreneurs from CVs and web searches (i.e. google search). In the first part of the third step, we matched academic scientists' publication lists from ISI Web of Science with information in their CVs, such as their statements of research interests, prior affiliations, and selected publication lists. The second part of this third step entailed a similar procedure performed on academic scientists' patent lists from USPTO and Delphion. In the fourth step, we matched the resulting publication list from the second step with the National Science Foundation-IpiQ 2007 journal classification system (i.e. NSF/IpiQ classification). IpiQ classification categorizes journals into four categories: 1 indicates applied technology, 2 indicate engineering and technological science, 3 indicates applied research, targeted basic research, and 4 indicate basic scientific research. For ease of interpretation of econometric analysis, we recoded the categories such that 1 indicates basic scientific research, 2 indicates applied research, targeted basic research, 3 indicates engineering and technological science, targeted basic research, and 4 indicates applied technology.

The four steps result in 395 academic scientists whose CVs are available on-line and for whom the matching process (i.e. the third step) was possible. Out of 395 academic scientists, 101 scientists created new ventures. These scientists published a total of 35,840 publications. In addition, they are listed as inventors in a total of 6,558 patents.

3.3.3 Variables and Measures

Dependent variable: Startup

Our dependent variable, *startup*, was binary, with 1 indicating academic scientists who founded new technology ventures. As our dependent was binary, we applied a logistic regression model estimating how the nature of research and scientific prominence affect the probability of an academic scientist engaging in entrepreneurship.

Independent variables

In order to capture the nature of research, an independent variable *research orientation* was constructed based on NSF/iPiQ classification. We calculated the research orientation variable as follow:

$$\text{research orientation} = 1 - \frac{\text{number of publication rated by NSF/IpiQ as basic scientific research}}{\text{Total number of publication rated by NSF/IpiQ}}$$

Academic scientists whose research is low in the level of commercial applicability are associated with a low value of research orientation variable. In order to capture the non-linear relationship between the nature of research and the creation of new technology ventures, we constructed an independent variable *research orientation square*.

The independent variable for scientific prominence is measured by an average number of publications per year. We calculated the average number of publications is calculated as follow:

$$\text{average number of publication per year} = \frac{\text{Total number of publications}}{\text{Number of active year}}$$

We define 'number of active years' as the number of years from PhD completion until retirement. We consider the length of an academic career to be approximately 35 years. The calculation of 'number of active years' is as follows: if the sum of year of PhD completion and thirty five is less than 2008, 'number of active years' is 35; if the sum of year of PhD completion and thirty five is greater than 2008, 'number of active years' is 2008 minus the year of PhD completion.

In order to test proposition 2.3, we construct a variable *bio x research orientation*. The variable bio is 1 for academic scientists in the life sciences discipline. Since the research of the life sciences is characteristically basic in nature yet also relevant to practical problems (i.e. Pasteur Quadrant's, Stokes (1997)), the research output of scientists in the life sciences is close to the interest of existing firms in the industry.

Control variables

Since literature in entrepreneurship indicates that women are less likely than men to start new businesses (Shane, 2004) and that woman scientists are less likely to be involved in the commercialization of their research (Ding, Murray, and Stuart, 2006), we included the control variable *gender* with 1 indicating women. In addition, recent studies argue that an academic scientist's choice of research project may be influenced by the commercial potential of that project (e.g., Lacetera, 2009). To address this possibility, we include patenting variables which portray academic scientists' inclination towards commercialization. These variables are *commercial patent*, which indicates the average number of patents assigned to non-research institutions and *university patent* which indicates the average number of patents assigned to research institutions. Its calculation is:

$$\begin{aligned} \text{average number of commercial patents per year} &= \frac{\text{Cumulative number of commercial patents}}{\text{Cumulative years since PhD completion}} \\ \text{average number of university patents per year} &= \frac{\text{Cumulative number of university patents}}{\text{Cumulative years since PhD completion}} \end{aligned}$$

We define 'cumulative number of patents' in two ways. If the academic scientist was involved in founding a new technology venture, the cumulative number of patents is the number of patents accumulated until the year prior to the founding of the new technology venture. If the academic scientist does not found a new venture, the cumulative number of patents is the number of patents accumulated until the year 2008. 'Cumulative years since PhD completion' is computed in a similar way. It is the number of years elapsed from PhD completion to the year of founding the first new venture if the academic scientist was also an entrepreneur. It is the number of years elapsed from PhD completion to the year 2008 if the academic scientist member is not an entrepreneur. If then the academic scientist has retired and did not found a new venture, we use 35 years as the cumulative years since PhD completion. Moreover, we control for the possibility of social influence on the academic scientist's choice of research orientation. To take into account such a possibility, we create a variable *dep_fresor*, which is the average research orientation in the scientist's department.

While we concur that scientific prominence reflects a scientist’s scientific ability, we expect that commercial ability does not necessarily reflect scientific prominence. This is in line with existing studies arguing that there are different logics to science and commercialization, respectively (e.g., Gittelman and Kogut, 2003; Toole and Czarnitzki, 2009). Thus, we create the variable *commercial ability*, which is the average number of forward citations received by the academic scientist’s patent. The variable is calculated as follows:

$$\text{average number of forward citation per year} = \frac{\text{Total number of forward patent citations}}{\text{Number of active years}}$$

Since research has shown that more recent graduates are more likely to create new ventures, due to a trend in universities to become more supportive toward commercialization (e.g., Stuart and Ding, 2006), we also controlled for the year of PhD completion by including variable *PhD year*. Moreover, to capture a possible imprinting effect, we indicated whether the academic scientist earned his/her doctorate degree from a university that embraces technology transfer. Specifically, variable *imprint_MIT* is 1 if the scientist graduated from MIT and *imprint_Stanf* is 1 if the scientist graduated from Stanford. We also differentiate between public and private PhD granting universities. The variable *imprint_pub* is 1 if the scientist graduated from a public university. In addition, a dummy variable *phd_non US* is 1 if the scientist graduated from non-US universities.

As extant studies emphasize the influence of social context on a scientist’s decision in entrepreneurship actions, we include a control variable *dep_start*, which is the proportion of academic entrepreneurs in the department. In addition, studies point out that academic scientists respond to incentive (e.g., Lach and Schankerman, 2008). Accordingly, we collected information on university policy regarding the royalty rate received by the inventor and include variable *royalty*. We also include the percentage of university research funded by industry to capture the possibility that a university with higher percentage of industry funding may be involved in research projects that

are closer to practical problems. We collected university funding information from WEBCASPAR website of the NSF and created the variable *ind_fund*. As university commitment to technology transfer has been found to influence academic scientists' involvement in technology transfer, we include variable *tto*, which is the average number of technology transfer personnel at the university. This information is based on AUTM reports.

Since environment resource munificence may influence an academic scientist's decision to create new technology ventures, we control for venture capitalist activities. Based on the National Venture Capital Association Yearbook 2009, we collected information on venture capital investments in the states of the five universities in our sample from 1980 to 2007. We adjusted the investment using yearly the consumer price index and created variable *vc*, which represents the average annual venture capital investment in the university's state.

3.4 Results

Of the 395 academic scientists in our sample, 26 percent created new ventures, and their average research orientation leans toward applied or targeted basic research. Table 1 depicts the descriptive statistics, while Table 2 shows the regression analysis results¹.

Model 1, serving as the base model, contains the control variables only. Model 2 shows that variable scientific prominence is positive and significant ($p < 0.001$). This is consistent with proposition 3.2.1, in which academic scientists possessing higher scientific prominence can be more interested in creating new ventures because they have a higher expected return of non-academic and knowledge benefits associated with successful new technology ventures.

¹† $p < 0.01$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In proposition 3.2.2.1, we predicted that the relationship between academic scientists' nature of research and the creation of new technology venture is non-linear such that the likelihood of creating new ventures increases as the research orientation increases in its commercial applicability until a cut-off point; after this cut-off point, the likelihood of creating new ventures decreases as the level commercial applicability further increases. Model 2 shows that the research orientation variable is positive and significant ($p < 0.01$)². In addition, the research orientation square variable is negative and significant ($p < 0.05$), confirming the non-linear relationship. Plotting the result, as shown in figure 5, we observe that the cut-off point is approximately at a research orientation of 0.9. Figure 5 depicts the effect of research orientation on the probability of creating new technology ventures while holding other variables at their mean values.

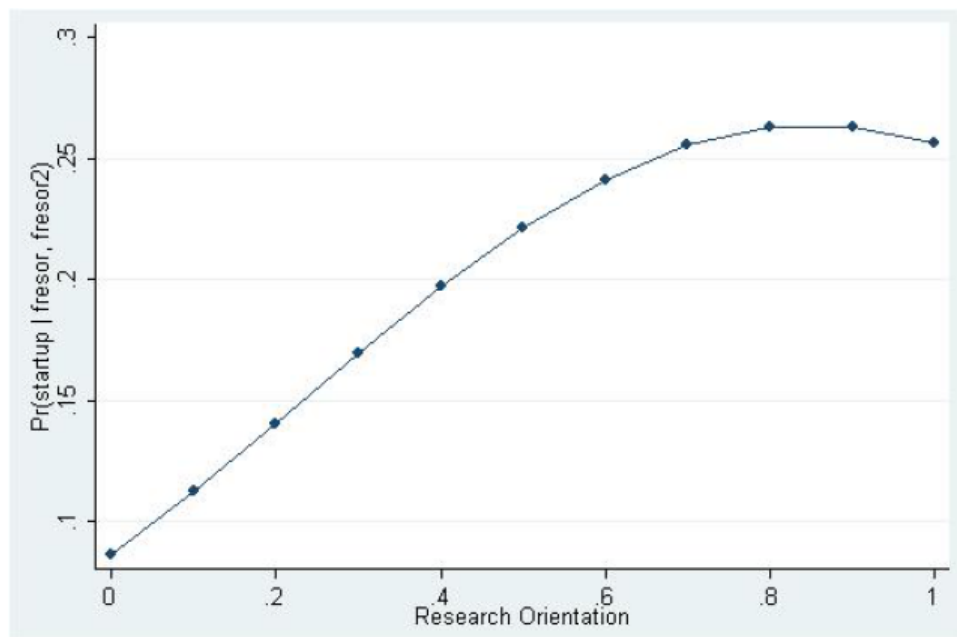


Figure 5: Probability of starting new ventures by the nature of research for academic scientists in non-life science

²The author is working on the interpretation of interaction terms in non-linear models as suggested by Hoetker (2007) and Wiersema and Bowen (2009). In addition, Linear Probability Model of the specification does not change the significance and signs.

We split the sample into academic scientists who have an average number of publications below the median (i.e. in the lower 50% of the average number of publications) and academic scientists who have an average number of publications above the median (i.e. in the upper 50% of the average number of publications). The resulting logit regression is depicted in model 3 and model 4, respectively. As shown in model 3, the research orientation variable is positive and significant ($p < 0.1$) while the research orientation square variable is negative and significant ($p < 0.05$), confirming the non-linear relation between the research orientation and creation of new technology ventures. Figure 6 depicts the effect of the research orientation on the probability of creating new technology ventures while holding other variables at their mean values for academic scientists whose average publication number is below the median. It shows that the cut-off point is approximately at a research orientation of 0.6.

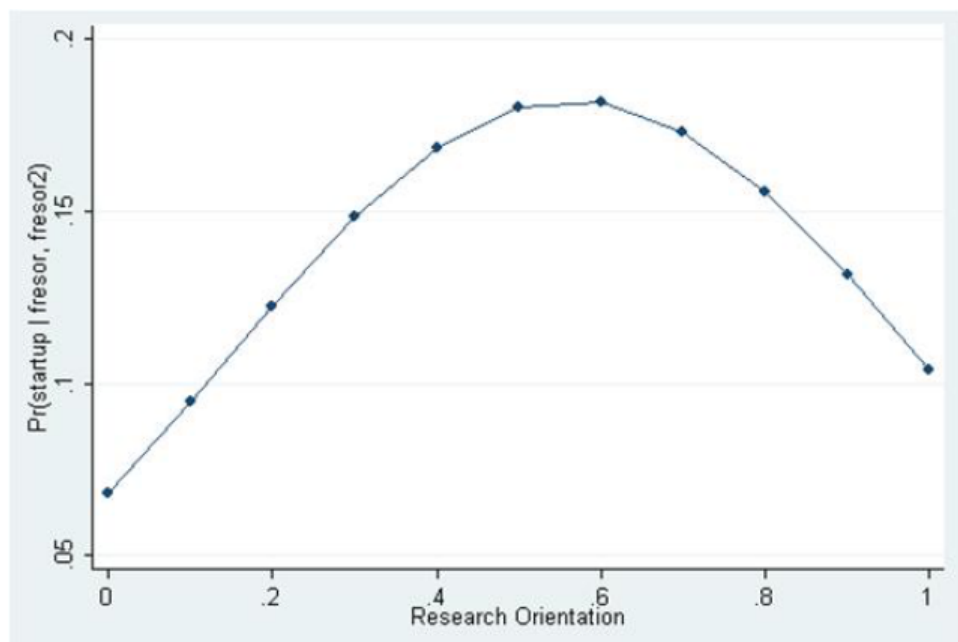


Figure 6: Probability of starting new ventures by the nature of research for academic scientists in non-life science whose average numbers of publications are below the median

Model 4 shows that the research orientation variable is positive and significant

($p < 0.05$). The research orientation square is negative but not significant. Figure 7 depicts the effect of research orientation on the probability of creating new technology ventures while holding other variables at their means for scientists whose average publication number is above the median. Taken together, results of model 3 and model 4 indicate a weak support of proposition 3.2.2.2.

In proposition 3.2.2.3, we predict a decreasing relationship between the level of commercial applicability and the likelihood that an academic scientist creates a new venture when the point on the continuum after which a scientist deems an invention commercially applicable (i.e. is willing to create a new venture) is higher than the point at which an established firm believes it is commercially applicable (i.e. is willing to license the invention). Model 2 shows that the coefficient of bio x research orientation is negative and significant ($p < 0.05$). Figure 8 depicts the effect the research orientation on the probability of creating new technology ventures while holding other variables at their mean values for academic scientists in the life sciences, confirming proposition 3.2.2.3.

Our findings also show that a number of control variables were significant predictors of academic scientists' entrepreneurial activity. Model 2 shows that the more recently an academic scientist graduated from his doctoral program, the more likely that scientist is to engage in new venture formation. This is depicted by the positive and significant coefficient of PhD year variable ($p < 0.001$). In addition, women academic scientists are less likely to create new ventures ($p < 0.05$). We also found that academic scientists who graduated from MIT and Stanford are less likely to create new ventures ($p < 0.05$). This may indicate that these scientists are more selective in deciding whether to create new ventures, given their exposure to entrepreneurial activities during their graduate studies.

Furthermore, those who graduated from public universities are less likely to engage in entrepreneurship than graduates from private universities ($p < 0.05$). This

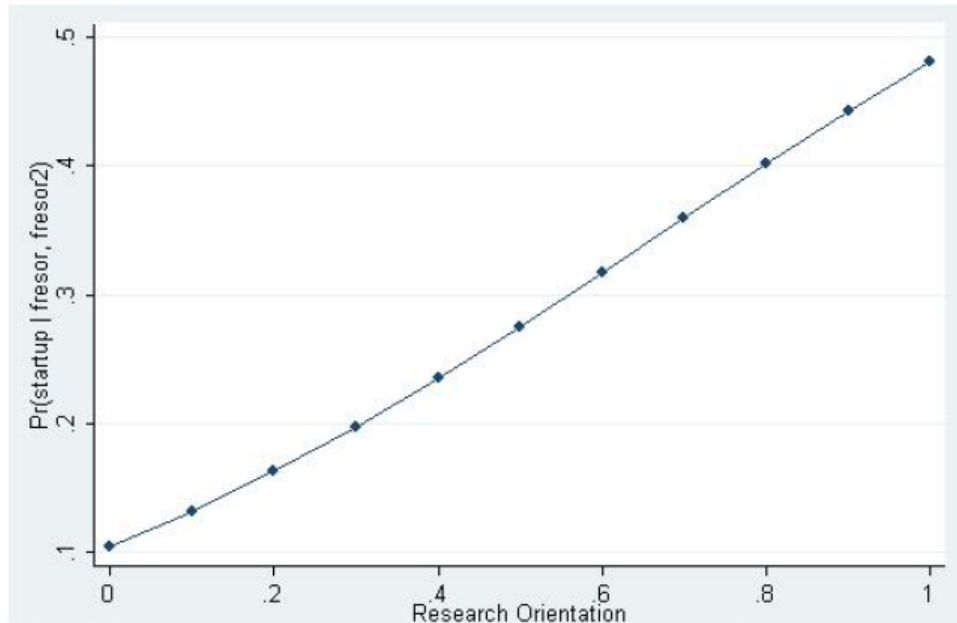


Figure 7: Probability of starting new ventures by the nature of research for academic scientists in non-life science whose average numbers of publications are above the median

finding is consistent with our interview, which suggested that private universities are more engaged than public universities in startup activities. Consistent with prior literature, which emphasized the social effect of entrepreneurial activities, the variable department startup is positive and significant ($p < 0.05$). In addition, the variable commercial patent and university patent are significant and negative ($p < 0.05$). Moreover, the variable commercial ability is positive and significant ($p < 0.001$).

3.5 Concluding Remarks

Using an analytical model and empirical evidence, we add to extant understanding on how academic scientists decide to create new ventures. While focusing on the creation of new technology ventures, our model considers alternative routes by which the invention can be commercialized through licensing agreements with established firms. Our empirical analysis shows that the relationship between academic scientists' research orientation and their entrepreneurial decision exhibits two types of patterns.

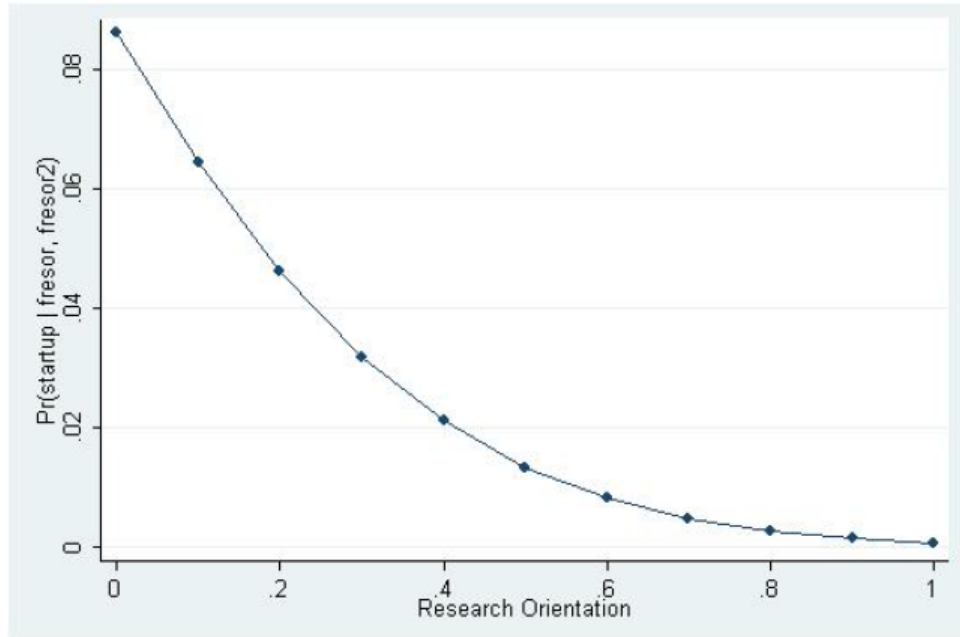


Figure 8: Probability of starting new ventures by the nature of research for academic scientists in the life science

When the point on the continuum after which a scientist deems an invention commercially applicable (i.e. is willing to create a new venture) is lower than the point at which an established firm believes it is commercially applicable (i.e. is willing to license the invention), we observed an inverted-u shape relationship between the level of commercial applicability and the likelihood that an academic scientist will create a new venture. When the point on the continuum after which a scientist deems an invention commercially applicable is higher than the point at which an established firm believes it is commercially applicable, we found a decreasing relationship between level of commercial applicability and the likelihood that an academic scientist will create a new venture.

Our results also show that scientific prominence positively explains academic scientists' decision to create new ventures. This finding is consistent with the literature of university entrepreneurship (e.g., Stuart and Ding, 2006). This study adds to

the literature of science-driven entrepreneurship by concluding that academic scientists' nature of research matters in predicting new venture creation. This resonates with entrepreneurship literature which emphasizes a 'knowledge corridor' to recognize entrepreneurial opportunities (Shane, 2000). However, these results are not without limitations. For example, entrepreneurship literature has illuminated varying individual characteristics that explain entrepreneurial entry, such as risk-taking propensities and a taste for variety. But all of these characteristics are difficult to obtain from publicly available data. Future research that captures these characteristics in the context of university entrepreneurship will provides valuable insights.

Table 1: Descriptive statistics and correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Mean	0.256	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
s.d.	0.437	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134
Startup	0.413	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100
Research orientation	0.491	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100
Bio	2.665	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151
Scientific prominence	8.955	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241
Commercial ability	2.954	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Commercial Patent	0.047	0.126	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
University Patent	0.086	0.178	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
Gender	0.091	0.288	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105
PhD-Stanf	0.111	0.315	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
PhD-MIT	0.170	0.376	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
PhD_Public	0.441	0.497	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123	-0.123
PhD-Non US	0.081	0.273	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Year PhD	1974.630	10.129	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
VC	3059.155	3411.100	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172
Dep Res orientation	0.588	0.379	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
Dep Startup	0.256	0.153	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
Dep Royalty	0.273	0.055	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
Industry Fund	0.059	0.037	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195	0.195
TTO	17.354	3.398	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265	-0.265

Table 2: Results of Logit regression analysis predicting academic scientists transition to entrepreneurship

	Model 1		Model 2		Model 3		Model 4	
	beta	s.e.	beta	s.e.	beta	s.e.	beta	s.e.
Constant	2.0150	(3.3388)	-0.0284	(3.3639)	-0.7183	(4.6484)	23.1772	(11.1590)
Research orientation			3.1251	(1.3061)	3.9518	(2.4870)	2.6552	(1.3528)
Research orientation 2			-1.8269	(1.0139)	-3.4866	(1.9930)	-0.5826	(0.7453)
Scientific prominence			0.5223	(0.1666)	1.7206	(1.5606)	0.4263	(0.2017)
Commercial impact	0.8915	(0.3042)	1.0120	(0.2969)	2.4872	(0.8730)	0.8276	(0.2619)
Commercial Patent	-0.2710	(0.1929)	-0.3265	(0.1885)	-0.6028	(0.3057)	-0.2354	(0.2358)
University Patent	-0.1595	(0.2488)	-0.3550	(0.1828)	-0.8234	(0.6159)	-0.2966	(0.1635)
Gender	-1.4930	(0.6215)	-1.2808	(0.6265)	-0.9600	(0.9114)	-1.1497	(0.1635)
PhD_Stanf	-1.0690	(0.5253)	-1.0089	(0.5907)	-0.3968	(0.8309)	-1.6271	(0.8063)
PhD_MIT	-0.8887	(0.4556)	-0.7277	(0.4649)	-1.1370	(0.7633)	-0.5659	(0.6668)
PhD_Public	-0.7042	(0.3475)	-0.7875	(0.3546)	-1.1480	(0.6526)	-0.7331	(0.4886)
PhD_Non US	0.3052	(0.5223)	0.3148	(0.5318)	0.9494	(1.0343)	0.0921	(0.7454)
Year PhD	0.4691	(0.1477)	0.5538	(0.1512)	0.5993	(0.2930)	0.4269	(0.2007)
Bio	-6.6863	(8.3430)	-4.1512	(8.2114)	-0.1811	(11.7772)	-63.3765	(28.2224)
Research orientation			-6.0847	(2.8851)	-9.2188	(5.5668)	-3.5075	(2.0719)
VC	0.0880	(0.4703)	0.1366	(0.4517)	0.5053	(0.7203)	-3.2679	(1.5518)
Dep Res orientation	-3.2895	(4.0650)	-1.9720	(4.0084)	0.7726	(5.8125)	-31.9311	(13.7917)
Dep Startup	1.4123	(0.5941)	1.2047	(0.5902)	0.3511	(0.7979)	5.7560	(2.2640)
Royalty	0.1607	(0.3457)	0.0468	(0.3348)	-0.6460	(0.5083)	2.0436	(0.9769)
Industry Fund	0.0356	(0.4148)	0.0850	(0.4041)	0.1146	(0.6309)	-3.0876	(1.4680)
TTO	0.6689	(0.6147)	0.5693	(0.6492)	-0.3278	(1.1489)	2.3945	(1.2546)
Log likelihood	-178.255		-168.231		-65.074		-90.894	
Pseudo R ²	0.2062		0.251		0.321		0.264	
Chi Square (χ^2)	0.0000	***	0.0000	***	0.0036	**	0.0094	**

CHAPTER IV

TEAM FORMATIONS IN TECHNOLOGY VENTURES

4.1 Introduction

Extant studies that investigate established organizations show that greater uncertainty or complexity in the environment has made difficult for accomplishing one's goal alone and has increased the propensity to work in teams (Cannella, Park, and Lee, 2008). Another apparent situation that encompasses considerable uncertainty is entrepreneurship. However, scholars who examine entrepreneurship have raised concerns pertaining to the focus of extant studies (Blatt, 2009; Harper, 2008). Their concern is that existing studies have emphasized individual entrepreneurs despite the prevalence of team works in entrepreneurship (Foo, Wong and Ong, 2005; Biais and Perotti, 2008). The concern is exacerbated by studies that show entrepreneurial teams often perform better than solo entrepreneurs (Roberts, 1991; Chandler and Hanks, 1998). Thus, in this essay, the question of what factors that influence the creation of entrepreneurial teams is investigated.

There are two major explanations for the formation of entrepreneurial teams. One explanation is that entrepreneurial teams are created because of resource needs. According to this explanation, there is a gap between resources required for entrepreneurial success and existing resources. This explanation includes social capital, financial resources, and complementary skills (e.g., Kamm and Nurick, 1993; Ruef, Aldrich, and Carter, 2003; Stuart and Sorenson, 2007; Astebro and Serrano, 2008; Foss et al., 2008). Another explanation is that entrepreneurial teams are created because an individual has inherent desire for social connections. Therefore, people decide to work in teams with those whom they like, admire, trust, or feel connected

(i.e., "chemistry"). This explanation draws considerably from attraction/ similarity theory (e.g., Francis and Sandberg, 2000; Forbes et al., 2006; Ruef, Aldrich, and Carter, 2003). In relation to these explanations, this essay focuses on complementary skill of the resource needs.

Studies that are closest to this essay are Ruef, Aldrich, and Carter (2003) and Astebro and Serrano (2008). Ruef, Aldrich, and Carter (2003) empirically tested social mechanisms, such as homophily and status, that explain formations of entrepreneurial teams. Astebro and Serrano (2008) model the formation of entrepreneurial teams as a problem of financial constraint. Their model takes into account productivity effects of an entrepreneurial team that originate from social network and complementary skills. The decisions of the entrepreneur are whether to create a team and the amount of investment. While explanations of complementary skills are considered in Ruef, Aldrich, and Carter (2003) as well as in Astebro and Serrano (2008), this essay differs by including a combination of working solo and working in a team and by introducing asymmetry of importance between issues in commercialization process.

The next section specifies the basic model of the formation of an entrepreneurial team. The basic model abstracts from team size. In the third section, the decision of team size is considered. The fourth section of this chapter discusses the effect of asymmetry of importance between issues on the creation of entrepreneurial teams. In the fifth section, the gain from diversity is captured in the model. That is, an entrepreneurial team is benefited not only from specialization but also from diversity.

4.2 The Base Model

We draw the model from Aghion, Dewatripont and Stein (2008) and Arditti and Levy (1980). The model depicts the problem of team formation as a trade-off between increasing probability of success and cooperation cost. An entrepreneur seeks to solve

the problem in a project that comprises of two stages: Stage 1 and Stage 2¹. At the end of Stage 2, an economic value, V , is generated, where $V > 0$. At each stage, the project involves two issues: Issue 1, I_1 , and Issue 2, I_2 . For example, we can think of Issue 1 as technology related issues and Issue 2 as market related issues. In this section, both issues are equally important in every stage of the project. The entrepreneur obtains an outcome at the end of a stage only if both issues are successful. Otherwise, the entrepreneur obtains nothing.

At the beginning of each stage, the entrepreneur decides whether to work alone (i.e., solo-project) or work in a team (i.e., team-project). When a team is employed, the project entails cooperation cost², c , where $c > 0$. For simplicity, we start with a team of two-people. In other words, if the entrepreneur decides to work in a team, she adds only one other person into the project. If the entrepreneur works on both issues, the individual probability of failure on each issue increases because the person's attention is divided. We denote q as the probability of failure on an issue when the person works on both issues, where $q \in [0, 1)$. By specializing in one issue, the individual probability of failure on each issue decreases (Sine, Mitsuhashi, and Kirsch, 2006). We denote α as the coefficient of reduction in the probability of failure, where $\alpha \in (0, 1)$. We assume that, in a team-project, individuals specialize. We also assume that an individual's chance of success is independent of each other. The decision of the entrepreneur is depicted in the figure 9.

Consider Stage 2, the expected return of a solo-project, $E(\Pi_2^S)$, is the probability that both issues are successful multiplied by the final economic value plus the probability that one of the issues is successful multiplied by zero plus the probability that both issues are unsuccessful multiplied by zero. The probability of success of an issue

¹For simplicity, we define that a project contains two stages. By induction, it is shown the results do not change if the project comprises of any number of stages.

²We can interpret cooperation cost to include coordination cost, cost of conflict, or the cost of maintaining a team, such as compensating partners for the opportunity cost of joining the team.

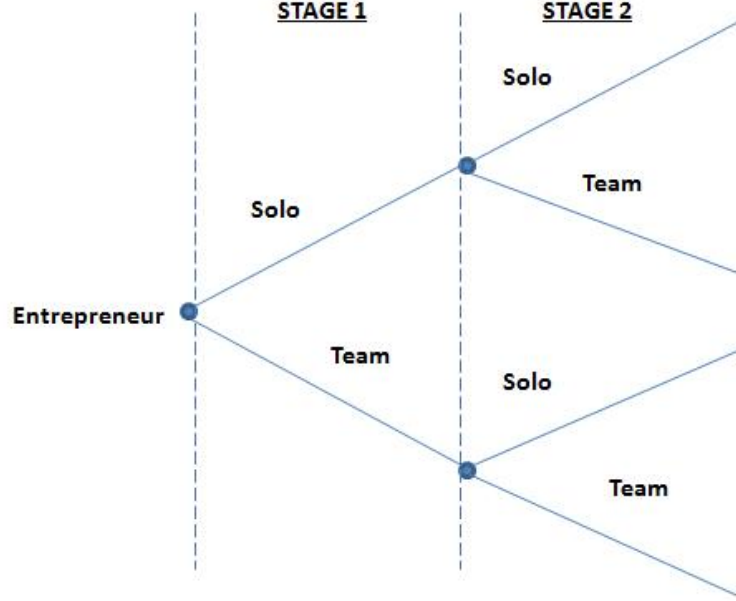


Figure 9: Decision tree of team formations

in a solo-project is $(1 - q)$. Thus,

$$E(\Pi_2^S) = (1 - q)^2 V \quad (4.2.1)$$

The expected return of a team-project, $E(\Pi_2^T)$, is the probability that both issues are successful multiplied by the final economic value plus the probability that one of the issues is successful multiplied by zero plus the probability that both issues are unsuccessful multiplied by zero minus the cooperation cost. Because individuals specialize when working in a team, the probability of success of an issue in a team-project is higher than the probability of success in a solo-project. The probability of success of an issue in a team-project is $(1 - \alpha q)$. Thus,

$$E(\Pi_2^T) = (1 - \alpha q)^2 V - c \quad (4.2.2)$$

Let the highest expected return be Π_2 , where $\Pi_2 = \max \{E(\Pi_2^S), E(\Pi_2^T)\}$. Naturally, the entrepreneur will choose the mode of work that delivers the higher expected return. Folding back to Stage 1, the expected return of a solo-project, $E(\Pi_1^S)$ is

$$E(\Pi_1^S) = (1 - q)^2 \Pi_2 \quad (4.2.3)$$

and the expected return of a team-project is

$$E(\Pi_1^T) = (1 - \alpha q)^2 \Pi_2 - c \quad (4.2.4)$$

For Stage 2 to be a team-project, it must be that $E(\Pi_2^T) > E(\Pi_2^S)$

$$(1 - \alpha q)^2 V - c > (1 - q)^2 V \Leftrightarrow [(1 - \alpha q)^2 - (1 - q)^2] V > c$$

$$(1 - \alpha) q (2 - (1 + \alpha) q) V > c \quad (4.2.5)$$

For Stage 1 to be a team-project, it must be that $E(\Pi_1^T) > E(\Pi_1^S)$

$$(1 - \alpha q)^2 \Pi_2 - c > (1 - q)^2 \Pi_2 \Leftrightarrow [(1 - \alpha q)^2 - (1 - q)^2] \Pi_2 > c$$

$$(1 - \alpha) q (2 - (1 + \alpha) q) \Pi_2 > c \quad (4.2.6)$$

The advantage of the team-project over a solo-project is contingent upon the specialization effect on each issue as well as the complementarity between the two issues. The entrepreneur favors a team-project if the cooperation cost is less than the expected return when only one of the issues has higher probability of success or when both issues have higher probability of success because of specialization.

Proposition 4.2.1 *It cannot be value maximizing to have a solo-project operates at a latter stage than a team-project.*

Proof. Available at the appendix ■

It is possible that the entrepreneur chooses a solo-project at both stages (i.e., SS), or a team-project at both stages (i.e., TT). She may choose a solo-project at Stage 1 and a team-project at Stage 2. However, she will not choose a team-project at Stage 1 and a solo-project at Stage 2 (i.e., TS). The reason is as follows. The outcome of

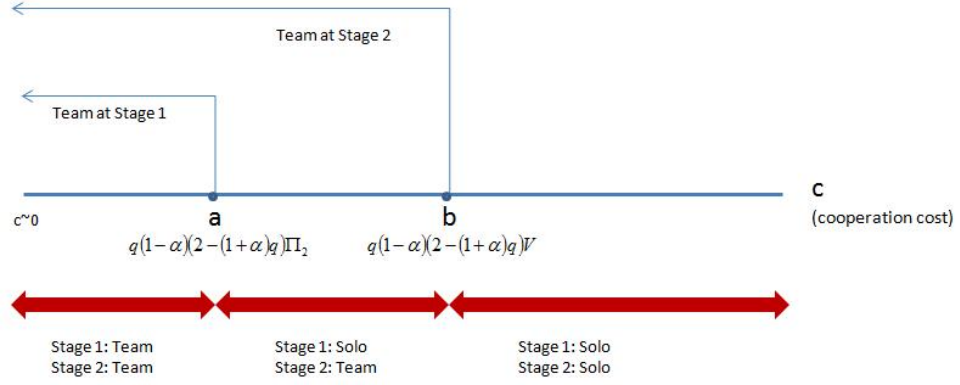


Figure 10: The timing of team formations

Stage 1 is the value of a work in progress while the outcome of Stage 2 is the value of a completed work. The value of a work in progress is less than the value of a completed work because the latter contains uncertainty of successful completion while the former is successfully completed with certainty. Therefore, it is unlikely for a team-project, which entails cooperation cost, to generate higher pay-off than a solo-project at Stage 1 if, at Stage 2, the marginal benefit of including additional person into the project does not outweigh the cooperation cost. The result remains even when the probability of failure, q , is not constant across stages. The underlying intuition is that the value function is always rising high enough such that it compensates the possible higher advantage of a team-project to a solo-project at Stage 1 over the advantage of a solo-project to a team-project in Stage 2³.

Proposition 4.2.2

1. *Increasing economic value, V , increases the payoff of a team-project to a solo-project at each stage of development.*

³Let q_1 and q_2 be the individual probability of failure at Stage 1 and at Stage 2, respectively. Suppose the optimal decision is a team-project at Stage 1 and a solo-project at Stage 2. In other words, $\Pi_2 = (1 - q_2)^2 V$, and it must be that $(1 - \alpha) q_2 (2 - (1 + \alpha) q_2) V < c$. For a team-project to be optimal at Stage 1, it requires $(1 - \alpha) q_1 (2 - (1 + \alpha) q_1) \Pi_2 > c$ which is impossible because $(1 - \alpha) q_2 (2 - (1 + \alpha) q_2) V > (1 - \alpha) q_1 (2 - (1 + \alpha) q_1) \Pi_2$. To see this, notice that $\frac{q_1(2-(1+\alpha)q_1)}{q_2(2-(1+\alpha)q_2)} (1 - q_2)^2 < 1$.

2. *Decreasing cooperation cost, c , increases the payoff of a team-project to a solo-project at each stage of development.*
3. *Increasing probability of failure, q , decreases the payoff of a team-project to a solo-project at Stage k if $q > q_k$ but increases the payoff of a team-project to a solo-project if $q < q_k$, where $q_1 = \frac{1}{(1+\alpha)} - \frac{\Pi_2}{\Pi_2^2} - \left(\frac{1}{(1+\alpha)^2} + \frac{\Pi_2^2}{\Pi_2^2} \right)^{\frac{1}{2}}$ ⁴ and $q_2 = \frac{1}{(1+\alpha)}$.*
4. *Increasing coefficient of specialization, α , decreases the payoff of a team-project to a solo-project in each stage of development. It also decreases the cut-off point of the probability of failure, q_k .*

Proof. Available at the appendix ■

The intuitions that underlie the influence of increasing economic value and decreasing cooperation on the advantage of a team-project over a solo-project are straightforward. An increase in the cooperation cost makes it harder for a team-project to outperform a solo-project. In contrast, greater economic value is associated with higher expected return in each stage. Hence, it is less difficult for a team-project to outperform a solo-project.

An increase in the probability of failure of an issue does not necessarily enhance the advantage of a team-project. The reason is that an increase in the probability of failure gives rise to two counter forces. On the one hand, increasing probability of failure corresponds to a higher return from specialization. A team-project becomes more attractive because the higher return from specialization implies greater increase in the probability of success. On the other hand, increasing probability of failure implies lower probability that both issues are successful. Given the lowered probability of successful completion of a stage, a team-project becomes less appealing because a team-project involves cooperation cost while a solo-project does not.

⁴For project which consists of n issues, the two cut-off points are $q = \frac{1}{(1+\alpha+\dots+\alpha^n)}$ and $\bar{q} = \left(\frac{1}{(1+\alpha+\dots+\alpha^n)} - \frac{\Pi_2}{\Pi_2^2} - \left(\frac{1}{(1+\alpha+\dots+\alpha^n)^2} + \frac{\Pi_2^2}{\Pi_2^2} \right)^{\frac{1}{2}} \right)$.

When the probability of failure of an issue is low, the former dominates. In these situations, the advantage of a team-project to a solo-project improves as the probability of failure an issue increases. When the probability of failure of an issue is low, the latter dominate. In other words, the advantage of a team-project to a solo-project diminishes as the probability of failure of an issue increases. In Stage 1 the region where the advantage of a team-project to a solo-project is smaller than such region in Stage 2 because the outcome at the end of Stage 1, the value of a work in progress, is smaller than the outcome at the end of Stage 2, the value of a completed work.

A team-project is preferable to a solo-project when the probability of failure of an issue is not too low or not too high. When the probability of failure of an issue is too low, the probability that the entrepreneur solves each issue by herself is high. In this situation, the return from specialization is low. Given the low return from specialization, a solo-project is preferable because it does not entail cooperation cost although the attractiveness of a team-project increases as the probability of failure rises. When the probability of failure of an issue is too high, the probability that both issues are successful is too low despite specialization. Therefore, the entrepreneur favors a solo-project to a team-project.

The larger return from specialization, as indicated by the smaller coefficient of specialization, improves the advantage of a team-project to a solo-project because the probability that each issue is successful increases. In addition, the larger return from specialization enlarges the region where increasing probability of failure improves the advantage of a team-project to a solo-project. At the same time, it reduces the region where increasing probability of failure decreases the advantage of a team-project to a solo-project.

4.3 Team of n -people

In this section we relax the assumption that a team consists of two people. If the entrepreneur chooses a team-project, she adds $n-1$ people into the project and creates a team of n -people. The reduction in the probability of failure of an issue depends on the team size. Specifically, the coefficient of specialization, $\alpha(n)$, is decreasing in its argument and concave where $\alpha \in (0, 1]$. The larger the team size is the better team members specialize on an issue. The larger team size also demand greater cooperation cost. That is, the cooperation cost, $c(n)$, is increasing in its argument and convex where $c(n) \geq 0$. When the team size is one (i.e., a solo-project), the coefficient of specialization is $\alpha(1) = 1$ and the cooperation cost is $c(1) = 0$. We begin with the assumption that both issues are equally important at every stage of the project.

Consider Stage 2, the probability of success of an issue is $(1 - \alpha(n_2)q)$. The entrepreneur's objective function is

$$\max_{n_2} E(\Pi_2) = (1 - \alpha(n_2)q)^2 V - c(n_2) \quad (4.3.1)$$

The first-order condition is

$$\frac{dE(\Pi_2)}{dn_2} = -2\alpha'(n_2)qV(1 - \alpha(n_2)q) - c'(n_2) = 0 \quad (4.3.2)$$

Let Π_2^* be the highest expected return at Stage 2. Folding back to Stage 1, the entrepreneur's objective function is

$$\max_{n_1} E(\Pi_1) = (1 - \alpha(n_1)q)^2 \Pi_2^* - c(n_1) \quad (4.3.3)$$

The first-order condition is

$$\frac{dE(\Pi_1)}{dn_1} = -2\alpha'(n_1)q\Pi_2^*(1 - \alpha(n_1)q) - c'(n_1) = 0 \quad (4.3.4)$$

When the entrepreneur adds another person into the project, team members can better specialize, thus increasing the chance of solving each issue. However, a new member increases the cooperation cost. If the losses from cooperation cost is too high, the entrepreneur will choose a solo-project. Otherwise, she will increase the team size until the marginal expected return from larger chance of solving both issues are offset by the marginal increase in the cooperation cost.

As noted in Proposition 1, it cannot be value maximizing to have a solo-project operates at a later stage than a team-project. The effect of changes in the economic value on the advantage of a team-project to a solo-project remains the same. That is, a greater economic value enhances the advantage of a team-project.

Proposition 4.3.1

1. *If a team-project is optimal at both stages, it is not value maximizing to have a smaller team operate at latter stage than a larger team.*
2. *An increase in probability of failure, q , decreases the optimal team size at Stage k if $q > q_k$ but increases the optimal team size if $q < q_k$, where $q_1 = \frac{1}{2\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \frac{1}{2} \left(\frac{1}{\alpha(n_1^*)^2} + \left(\frac{2\Pi_2^*}{\Pi_2'} \right)^2 \right)^{\frac{1}{2}}$ and $q_2 = \frac{1}{2\alpha(n_2^*)}$.*

Proof. Available at the appendix ■

As explained in the earlier section, the value of a work in progress is less than the value of a completed work because the latter contains uncertainty of successful completion while the former is successfully completed with certainty. Consequently, it is harder for a team-project to generate pay-off at Stage 1 than at Stage 2. Because larger team size comes with greater cooperation cost, it is impossible for a larger team-project to outperform a smaller team-project at Stage 1 if, at Stage 2, the smaller team-project outperforms the larger team-project.

Similar to situations when an increase in the probability of failure of an issue does not necessarily enhance the advantage of a team-project to a solo-project, an increase

in the probability of failure does not always improve the advantage of a larger team-project to a smaller team-project. That is, greater probability of failure of an issue does not necessarily result in a larger team-project. As explained earlier, the reason is that an increase in the probability of failure generates two conflicting forces. On the one hand, an increase in the probability of failure of an issue suggests a higher return from specialization. The higher return from specialization makes a larger team-project attractive because team members can better specialize as the team size increases. On the other hand, increasing probability of failure suggests that it is more difficult to complete a stage because completion requires success on both issues. The lowered probability of completion of a stage reduces the appeals of a larger team size because the larger team demands greater cooperation cost.

The former dominates when the probability of failure of an issue is low, and the latter dominates when the probability of failure is high. Accordingly, an increase in the probability of failure increases the optimal team size when the probability of failure is not too high. Otherwise, an increase in the probability of failure reduces the optimal team size. Similar to the earlier section, the region of probability of failure where it increases the optimal team size is smaller at Stage 1 than at Stage 2 because its value of work in progress, at the end of Stage 1, is less than the value of a completed work, at the end of Stage 2.

4.4 Asymmetric Importance between Issues

In this section we relax the assumption that the two issues are equally important. For example, technology issue may be more important than market issue in the early stage of the project. At later stage of the project, market issue may be more important than technology issue. When one issue is more important than the other, the probability of completing the stage depends on the probability of success of the more important issue. We use w_{ki} as the coefficient of importance of an issue

where k denotes a stage, $k \in \{1, 2\}$, i denotes an issue, $i \in \{1, 2\}$, $0 < w_{ki} < 1$, and $w_{k1} + w_{k2} = 1$. The larger w_{ki} the less important an issue is relative to the other.

Incorporating the possibility of asymmetric importance between issues at Stage 2, the probability of success of Issue 1 and Issue 2 at Stage k are $(1 - qw_{k1}\alpha(n_k))$ and $(1 - qw_{k2}\alpha(n_k))$. Thus, the entrepreneur's objective function at Stage 2 is

$$\max_{n_2} E(\Pi_2) = (1 - w_{21}\alpha(n_2)q)(1 - w_{22}\alpha(n_2)q)V - c(n_2) \quad (4.4.1)$$

Consider Stage 1, the entrepreneur's objective function is⁵

$$\max_{n_1} E(\Pi_1) = (1 - w_{11}\alpha(n_1)q)(1 - w_{12}\alpha(n_1)q)\Pi_2^* - c(n_1) \quad (4.4.2)$$

Proposition 4.4.1

1. An increase in probability of failure, q , decreases the optimal team size at Stage k if $q > q_k$ but increases the optimal team size if $q < q_k$, where $q_1 = \frac{1}{4w_{11}w_{12}\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \frac{1}{4} \left(\frac{1}{(w_{11}w_{12}\alpha(n_1^*))^2} + \left(\frac{4\Pi_2}{\Pi_2'} \right)^2 \right)^{\frac{1}{2}}$ and $q_2 = \frac{1}{4w_{21}w_{22}\alpha(n_2^*)}$.
2. Increasing coefficient of importance of issue i , w_{ki} , increases the cut-off point of the probability of failure, q_k , if $w_{ki} < \frac{1}{2}$ but decreases the cut-off point if $w_{ki} > \frac{1}{2}$. The maximum cut-off point is at $w_{ki} = \frac{1}{2}$.

Proof. Available at the appendix ■

The intuition that underlies the effect of an increase in the probability of failure on the advantage of a team-project is the same as before. That is, an increase in the probability of failure results in two counter forces. On the one hand, increasing probability of failure corresponds to a higher return from specialization. On the other hand, increasing probability of failure implies lower probability that both issues are

⁵When $w_{ki} = \frac{1}{2}$, the expected return of a team-project and the expected return of a solo-project are analogous to the expected return of a team-project and expected return of a solo-project in the base model.

successful. Therefore, an increase in the probability of failure of an issue does not always improve the advantage of a team-project to a solo-project. Similar intuition applies on the optimal team size. That is, a greater probability of failure of an issue increases the optimal team size when the probability of failure is not too high. At the border between the region where greater probability of failure enhances the advantage of a team-project and the region where greater probability of failure lessens the advantage of a team-project is a cut-off point. The cut-off point is the level of probability of failure where the two counter forces are equal.

The effect of a decrease in the importance of an issue on the region where greater probability of failure enhances the advantage of a team-project to a solo-project is contingent upon whether the issue is the more important. If the issue is the more important of the two, a decrease in the importance reduces the region where greater probability of failure enhances the advantage of a team-project. If the issue is the less important of the two, a decrease in the importance expands the region where greater probability of failure enhances the advantage of a team-project.

The reason is as follows. A decrease in the importance of an issue implies an increase of importance of the other issue. Consequently, the success of the other issue becomes more crucial and the success of the focal issue becomes less crucial for the completion of the stage. If the issue is the less important of the two, an increase in the importance reduces the asymmetry of importance between issues. In contrast, the asymmetry of importance between issues is widened by an increase in the importance of an issue if the issue is the more crucial of the two. Regardless the asymmetry, completion of a stage requires that both issues are successful. When the asymmetry is large, the less important issue becomes a costly necessity in a team-project because specialization on the less critical issue nevertheless involves expense in cooperation. Therefore, an increase in asymmetry reduces the advantage of a team-project to a solo-project. The region where greater probability of failure enhances the advantage

of a team-project is at its greatest extent when the issues are equally important.

Similar intuition applies on the optimal team size. If the issue is the more important of the two, a decrease of importance reduces the asymmetry of importance between issues. In contrast, if the issue is the less crucial of the two, a decrease of importance enlarges the asymmetry of importance between issues. Because of the asymmetry, the less important issue becomes a costly necessity for completing a stage. Greater team size exacerbates the problem because it involves larger cooperation cost. Consequently, an increase in asymmetry reduces the attractiveness of a larger team-project to a smaller team-project. As in the earlier section, the implication is that the region where greater probability of failure increases the optimal team size is at its greatest extent when both issues are equally important.

4.5 Specialization and Diversity

In this section, we consider diversity as one of the benefits from working in a team. Building on literature that argues team diversity enhances the quality of solution (e.g., Milliken and Martins, 1996; Cannella, Park, and Lee, 2008), we specify the economic value of the project as a function of diversity. Because increasing team size allows greater diversity, we capture the effect of diversity on economic value through team size. That is, $V(n) = A + k(n)$ where A is the initial value without diversity and $k(n)$ is the additional economic value because diversity enhances the quality of solution. The additional economic value, $k(n)$, is increasing in its argument and concave. For simplicity, we assume that there is only one stage of development and that both issues are equally important.

The entrepreneur objective function is

$$\max_n E(\Pi) = (1 - \alpha(n)q)^2 V(n) - c(n) \quad (4.5.1)$$

The first-order condition is

$$\frac{dE(\Pi)}{dn} = -2\alpha'(n)qV(n)(1 - \alpha(n)q) + (1 - \alpha(n)q)^2 V'(n) - c'(n) = 0 \quad (4.5.2)$$

Team size influences the expected return from the project in two ways: specialization and diversity. First, increasing team size allows team members to better specialize. The greater return from specialization is reflected in the smaller probability of failure of an issue. It follows that the probability of a successful project increases. The reason is that the reduction of the probability of failure of an issue is accompanied by a reduction of the probability of failure of the other issue. Second, increasing team size allows diversity that improves the final economic value of the project. Therefore, it improves the expected return of a project. Specialization increases the chance of obtaining the larger economic value resulting from diversity. However, a new member increases the cooperation cost. If the losses from cooperation is too high, the entrepreneur will choose a solo-project. Otherwise, she will increase the team size until the marginal expected return from the larger chance of solving issues and from the larger economic value is offset by the marginal loss due to the cooperation cost.

Proposition 4.5.1

1. *An increase in the initial value of the project increases team size and team diversity.*
2. *If $\alpha'(n^*) < \bar{\alpha}$, an increase in the probability of failure decreases team size and team diversity if $q < \bar{q}$. Otherwise, an increase in the probability of failure can increase or decrease team size and team diversity. If $\alpha'(n^*) > \bar{\alpha}$, an increase in the probability of failure increases team size and team diversity if $q < \bar{q}$. Otherwise, an increase in the probability of failure can increase or decrease*

team size and team diversity, where⁶ $\bar{q} = \frac{\alpha V' + \alpha' V}{\alpha(\alpha V' + 2\alpha' V)}$ and $\bar{\alpha} = -\frac{\alpha V'}{2V}$.

Proof. Available at the appendix ■

Larger initial value of the project is associated with a greater optimal team size. The intuition is straight forward. Greater initial value is associated with a larger expected return. Therefore, it enables the entrepreneur to tolerate additional cooperation cost resulting from a larger team. At the same time, it enables the entrepreneur to benefit from more specialization and greater diversity from a larger team.

The influence of initial probability of failure (i.e., the probability of failure without specialization) on specialization is as follows. An increase in the initial probability of failure of an issue gives rise to two forces. On one hand, the return from specialization is larger. This force is in favor of increasing team size. On the other hand, the probability of a successful project declines. This force is against adding more members. The influence of initial probability of failure on diversity is as follows. An increase in the initial probability of failure gives rise to two counter forces. On one hand, at a given level of specialization, increasing initial probability of failure reduces the chance of successfully solve an issue. This force works against increasing team size. On the other hand, the probability that both issues are successful will increase. This force works in favor of increasing team size.

In order to see the mechanism of the second force, we first note that the probability that both issues are successful becomes smaller the larger the chance that one issue is successful while the other issue fails. The probability that one issue is successful but the other issue fails declines the larger the probability that both issues fail. In other words, there are two effects of the probability that both issues fail on the probability that both issues are successful. First is the negative direct effect. Second, it is the positive indirect effect though the reduction in the chance that one issue is

⁶For clarity, we suppress the notations. Hence, we wrote $\alpha(n^*)$, $\alpha'(n^*)$, $V(n^*)$, and $V'(n^*)$ as α , α' , V , and V' .

successful but the other issue fails. Because the latter always dominates the former the probability that both issues fail increases the probability that both issues are successful.

Changes in the initial probability of failure affect the optimal team size through specialization and diversity. As explained earlier, an increase in the initial probability of failure enhances the return from specialization. It was also described that, for a given level of specialization, an increase in the initial probability of failure reduces the chance to successfully solve an issue. Hence, it lowers the chance to benefit from diversity. If the former dominates, greater initial probability of failure increases the optimal team size when the probability of failure is not too high. However, it reduces the optimal team size when the probability of failure is high enough.

An opposite pattern is obtained if the latter force dominates. That is, greater initial probability of failure reduces the optimal team size when the initial probability of failure is not too high. Otherwise, it increases the optimal team size. The first pattern occurs when adding a new member into the project substantially reduces the probability of failure. Meanwhile, the second pattern occurs when the probability of failure does not decline substantially when a new member is included in the project.

4.6 Concluding Remarks

This essay explains the mechanisms that give rise to entrepreneurial team and its structure. It focuses on two dimensions of team structure: size and diversity. These dimensions have been deemed as important in explaining performance differential among entrepreneurial teams (Taylor and Greve, 2006; Beckman, Burton, and O'Reilly, 2007; Dencker, Gruber, and Shah, 2009). The model and results in this essay are limited in several ways. First, it abstracts from the possibility of turnover. While the model explains the optimal team size, it is silent on the continuation or the discontinuation of persons who join the team. Second, it is limited in capturing the uncertainty

involved in entrepreneurship. Third, it abstracts from psychological reasons of creating entrepreneurial teams.

Despite the limitations, the model advances our understanding on entrepreneurial teams in new technology ventures by contributing to the entrepreneurship literature and to the team literature. It contributes to the entrepreneurship literature in three ways. First, it complements Astebro and Serrano (2008) in adding theoretical foundations on entrepreneurial teams. Second, it extends our knowledge on the effect of uncertainty on formations of entrepreneurial teams. While consistent with the current understanding that greater uncertainty increases the propensity of team work, this essay shows that an entrepreneur is better-off by working alone than working in a team if the uncertainty is too high. Third, the essay introduces the asymmetry of importance into the discussion of entrepreneurial teams. It shows that entrepreneurial teams are more likely to be created the more balanced the issues are.

The essay contributes to the team literature by investigating the relation between specialization and diversity. Most studies on team have examined specialization and diversity as two independent choices. However, in practice, these choices are intertwined. This essay complements Hong and Page (2004) that explains the connections between teams size and team diversity. Future research opportunities include empirical estimations of the predictions in this essay. Another interesting investigation would be to understand the relation between resource needs and psychological needs in the creation of entrepreneurial teams.

APPENDIX A

PROOFS

A.1 Proofs of Propositions in Chapter 2

Proof of Proposition 2.3.1. The slope of the government agency's best reply is

$$\hat{G}'(F_a) = -\frac{\partial \hat{G}/\partial F_a}{\partial \hat{G}/\partial G} \text{ where } \partial \hat{G}/\partial F_a = \frac{\partial^2 p_a}{\partial e_a^2} \cdot \frac{\partial e_a}{\partial F_a} [U_g(R_{gs}) - U_g(R_{gf})] < 0;$$

$$\partial \hat{G}/\partial G = \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial e_a}{\partial G} [U_g(R_{gs}) - U_g(R_{gf})] - V''(G) < 0. \text{ Therefore, } -\frac{\partial \hat{G}/\partial F_a}{\partial \hat{G}/\partial G} < 0.$$

The slope of the firm's best reply is $\hat{F}'_a(G) = -\frac{\partial \hat{F}_a(G)/\partial G}{\partial \hat{F}_a(G)/\partial F_a}$ where $\partial \hat{F}_a(G)/\partial G = \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial e_a}{\partial G} l(\beta) \Pi_u < 0$; and $\partial \hat{F}_a(G)/\partial F_a = \frac{\partial^2 p_a}{\partial e_a^2} \cdot \frac{\partial e_a}{\partial F_a} l(\beta) \Pi_u - \frac{\partial^2 p_c}{\partial e_c^2} \frac{\partial e_c}{\partial F_a} \Pi_c < 0$. Therefore, $-\frac{\partial \hat{F}_a(G)/\partial G}{\partial \hat{F}_a(G)/\partial F_a} < 0$. ■

Proof of Proposition 2.3.2. The standard comparative statics:

$$\frac{\partial G^*}{\partial j} = \left(\frac{\partial^2 E\Pi}{\partial F_a \partial j} \frac{\partial^2 EU_g}{\partial G \partial F_a} - \frac{\partial^2 EU_g}{\partial G \partial j} \frac{\partial^2 E\Pi}{\partial F_a^2} \right) / D \text{ and } \frac{\partial F_a^*}{\partial j} = \left(\frac{\partial^2 EU_g}{\partial G \partial j} \frac{\partial^2 E\Pi}{\partial F_a \partial G} - \frac{\partial^2 E\Pi}{\partial F_a \partial j} \frac{\partial^2 EU_g}{\partial G^2} \right) / D,$$

for $j = x_a, \beta, q_a, x_c, q_c, L, \gamma$ where $D = \frac{\partial^2 EU_g}{\partial G^2} \frac{\partial^2 E\Pi}{\partial F_a^2} - \frac{\partial^2 EU_g}{\partial G \partial F_a} \frac{\partial^2 E\Pi}{\partial F_a \partial G} > 0$ by the assumption the equilibrium is locally stable.

$$\begin{aligned} \frac{\partial^2 EU_g}{\partial G^2} &= \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial e_a}{\partial G} [U_g(R_{gs}) - U_g(R_{gf})] - V''(G) < 0; \\ \frac{\partial^2 EU_g}{\partial G \partial F_a} &= \frac{\partial^2 p_a}{\partial e_a^2} \cdot \frac{\partial e_a}{\partial F_a} [U_g(R_{gs}) - U_g(R_{gf})] < 0; \\ \frac{\partial^2 E\Pi}{\partial F_a^2} &= \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial e_a}{\partial F_a} l(\beta) (\Pi_u - L) - \frac{\partial^2 p_c}{\partial e_c^2} \frac{\partial e_c}{\partial F_a} \Pi_c < 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial G} &= \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial e_a}{\partial G} l(\beta) (\Pi_u - L) < 0; \\ \frac{\partial^2 EU_g}{\partial G \partial x_a} &= \frac{\partial^2 p_a}{\partial e_a \partial x_a} [U_g(R_{gs}) - U_g(R_{gf})] < 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial x_a} &= \frac{\partial^2 p_a}{\partial e_a \partial x_a} l(\beta) (\Pi_u - L) < 0; \\ \frac{\partial^2 EU_g}{\partial G \partial \beta} &= 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial \beta} &= \frac{\partial p_a}{\partial e_a} l'(\beta) (\Pi_u - L) > 0; \\ \frac{\partial^2 EU_g}{\partial G \partial q_a} &= \frac{\partial^2 p_a}{\partial e_a \partial q_a} [U_g(R_{gs}) - U_g(R_{gf})] > 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial q_a} &= \frac{\partial^2 p_a}{\partial e_a \partial q_a} l(\beta) (\Pi_u - L) > 0; \\ \frac{\partial^2 EU_g}{\partial G \partial x_c} &= 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial x_c} &= -\frac{\partial^2 p_c}{\partial e_c \partial x_c} \Pi_c < 0; \\ \frac{\partial^2 EU_g}{\partial G \partial L} &= 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial L} &= 0; \\ \frac{\partial^2 EU_g}{\partial G \partial \gamma} &= 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial \gamma} &= 0; \\ \frac{\partial^2 EU_g}{\partial G \partial F} &= 0; \\ \frac{\partial^2 E\Pi}{\partial F_a \partial F} &= -\frac{\partial^2 p_c}{\partial e_c^2} \Pi_c > 0; \\ \frac{\partial^2 EU_g}{\partial G \partial q_c} &= 0; \text{ and } \frac{\partial^2 E\Pi}{\partial F_a \partial q_c} = -\frac{\partial^2 p_c}{\partial e_c \partial q_c} \Pi_c > 0. \end{aligned}$$

The sign of $\frac{\partial G^*}{\partial j}$ (or $\frac{\partial F_a^*}{\partial j}$) the sign of the numerator because $D > 0$. Therefore, $\frac{\partial G^*}{\partial x_a} = \frac{\partial^2 EU_g}{\partial G \partial x_a} \left(\frac{\partial^2 p_c}{\partial e_c^2} \Pi_c \right) > 0$;
 $\frac{\partial F_a^*}{\partial x_a} = \frac{\partial^2 E\Pi}{\partial F_a \partial x_a} V''(G) < 0$; $\frac{\partial G^*}{\partial \beta} < 0$; $\frac{\partial F_a^*}{\partial \beta} > 0$; $\frac{\partial G^*}{\partial q_a} = \left(\frac{\partial^2 p_a}{\partial e_a \partial q_a} \Delta U \right) \left(\frac{\partial^2 p_c}{\partial e_c^2} \Pi_c \right) < 0$;
 $\frac{\partial F_a^*}{\partial q_a} = \frac{\partial^2 E\Pi}{\partial F_a \partial q_a} V''(G) > 0$; $\frac{\partial G^*}{\partial x_c} < 0$; $\frac{\partial F_a^*}{\partial x_c} > 0$; $\frac{\partial G^*}{\partial q_c} > 0$; $\frac{\partial F_a^*}{\partial q_c} < 0$; $\frac{\partial G^*}{\partial L} > 0$;
 $\frac{\partial F_a^*}{\partial L} < 0$; $\frac{\partial G^*}{\partial \gamma} = \frac{\partial F_a^*}{\partial \gamma} = 0$. ■

Proof of Proposition 2.4.1. $\frac{\partial x_a^*}{\partial \beta^*} = -\frac{\frac{\partial^2 EU_a}{\partial x_a \partial \beta}}{\frac{\partial^2 EU_a}{\partial x_a^2}}$. $\text{Sign}\left(\frac{dx_a^*}{d\beta^*}\right) = \text{sign}\left(\frac{\partial^2 EU_a}{\partial x_a \partial \beta}\right)$ because

$$\begin{aligned} \frac{\partial^2 EU_a}{\partial x_a^2} < 0 \text{ (see proof of proposition 4). } \quad \frac{\partial^2 EU_a}{\partial x_a \partial \beta} = \\ \left[\frac{\partial^2 p_a}{\partial e_a^2} \left(\frac{\partial G^*}{\partial \beta} + \frac{\partial F_a^*}{\partial \beta} \right) \left(\frac{\partial G^*}{\partial x_a} + \frac{\partial F_a^*}{\partial x_a} \right) + \frac{\partial^2 p_a}{\partial e_a \partial x_a} \left(\frac{\partial G^*}{\partial \beta} + \frac{\partial F_a^*}{\partial \beta} \right) \right] \Delta U + \frac{\partial p_a}{\partial e_a} \left(\frac{\partial G^*}{\partial \beta} + \frac{\partial F_a^*}{\partial \beta} \right) \Delta \frac{\partial U}{\partial x_a}. \end{aligned}$$

Notice that $\left(\frac{\partial G^*}{\partial \beta} + \frac{\partial F_a^*}{\partial \beta} \right) = \frac{\partial^2 E\Pi}{\partial F_a \partial \beta} \left(\frac{\partial^2 EU_g}{\partial G \partial F_a} - \frac{\partial^2 EU_g}{\partial G^2} \right) + \frac{\partial^2 EU_g}{\partial G \partial \beta} \left(\frac{\partial^2 E\Pi}{\partial F_a \partial G} - \frac{\partial^2 E\Pi}{\partial F_a^2} \right) > 0$
because $\left(\frac{\partial^2 EU_g}{\partial G \partial F_a} - \frac{\partial^2 EU_g}{\partial G^2} \right) > 0$ and $\left(\frac{\partial^2 E\Pi}{\partial F_a \partial G} - \frac{\partial^2 E\Pi}{\partial F_a^2} \right) > 0$.
 $\left(\frac{\partial G^*}{\partial x_a} + \frac{\partial F_a^*}{\partial x_a} \right) = \frac{\partial^2 E\Pi}{\partial F_a \partial x_a} \left(\frac{\partial^2 EU_g}{\partial G \partial F_a} - \frac{\partial^2 EU_g}{\partial G^2} \right) + \frac{\partial^2 EU_g}{\partial G \partial x_a} \left(\frac{\partial^2 E\Pi}{\partial F_a \partial G} - \frac{\partial^2 E\Pi}{\partial F_a^2} \right) < 0$. Thus, $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} >$

0. ■

Proof of Proposition 2.4.2. Let $\frac{\partial T^*}{\partial j} \equiv \left(\frac{\partial G^*}{\partial j} + \frac{\partial F_a^*}{\partial j} \right) = \frac{\partial^2 E\Pi}{\partial F_a \partial j} \left(\frac{\partial^2 EU_g}{\partial G \partial F_a} - \frac{\partial^2 EU_g}{\partial G^2} \right) + \frac{\partial^2 EU_g}{\partial G \partial j} \left(\frac{\partial^2 E\Pi}{\partial F_a \partial G} - \frac{\partial^2 E\Pi}{\partial F_a^2} \right)$ for $j = q_a, q_c, x_c, L, \gamma, x_a, \beta$. Thus, $\frac{\partial T^*}{\partial q_a} > 0, \frac{\partial T^*}{\partial q_c} < 0, \frac{\partial T^*}{\partial x_c} > 0, \frac{\partial T^*}{\partial L} < 0$, and $\frac{\partial T^*}{\partial \gamma} = 0$. Using the standard comparative statics: $\frac{\partial x_a^*}{\partial j} =$

$\left(\frac{\partial^2 EU_a}{\partial \beta \partial j} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} - \frac{\partial^2 EU_a}{\partial x_a \partial j} \frac{\partial^2 EU_a}{\partial \beta^2} \right) / D$ and $\frac{\partial \beta^*}{\partial j} = \left(\frac{\partial^2 EU_a}{\partial x_a \partial j} \frac{\partial^2 EU_a}{\partial \beta \partial x_a} - \frac{\partial^2 EU_a}{\partial \beta \partial j} \frac{\partial^2 EU_a}{\partial x_a^2} \right) / D$ where $D = \frac{\partial^2 EU_a}{\partial x_a^2} \frac{\partial^2 EU_a}{\partial \beta^2} - \frac{\partial^2 EU_a}{\partial \beta \partial x_a} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} > 0$ by the requirement of a strict local max. That is, for $EU_a(x_a^*, \beta_a^*)$ to be a strict local maximum, the Hessian $D^2 EU_a(x_a^*, \beta_a^*)$ must

be a negative definite symmetric matrix. For its two principal minors to alternate in sign, it must be that $\frac{\partial^2 EU_a}{\partial x_a^2} < 0$ since in $\frac{\partial^2 EU_a}{\partial \beta^2} < 0$. Therefore, $\left| \frac{\partial^2 EU_a}{\partial x_a^2} \right| < 0$

$$\text{and } \begin{vmatrix} \frac{\partial^2 EU_a}{\partial x_a^2} & \frac{\partial^2 EU_a}{\partial x_a \partial \beta} \\ \frac{\partial^2 EU_a}{\partial \beta \partial x_a} & \frac{\partial^2 EU_a}{\partial \beta^2} \end{vmatrix} > 0; \quad \frac{\partial^2 EU_a}{\partial \beta^2} = \frac{\partial^2 p_a}{\partial e^2} \left(\frac{\partial T^*}{\partial \beta} \right)^2 \Delta U - V''(\beta) < 0;$$

$$\begin{aligned} \frac{\partial^2 EU_a}{\partial x_a \partial q_a} &= \left[\left[\frac{\partial^2 p_a}{\partial e_a \partial q_a} + \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial q_a} \right] \frac{\partial T^*}{\partial x_a} + \frac{\partial^2 p_a}{\partial x_a \partial q_a} + \frac{\partial^2 p_a}{\partial x_a \partial e_a} \frac{\partial T^*}{\partial q_a} \right] \Delta U + \left[\frac{\partial p_a}{\partial q_a} + \frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial q_a} \right] \Delta \frac{\partial U}{\partial x_a} < \\ 0; \frac{\partial^2 EU_a}{\partial \beta \partial q_a} &= \left[\frac{\partial^2 p_a}{\partial e_a \partial q_a} \frac{\partial T^*}{\partial \beta} + \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial q_a} \frac{\partial T^*}{\partial \beta} \right] \Delta U > 0; \frac{\partial^2 EU_a}{\partial x_a \partial q_c} = \left[\frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial q_c} \frac{\partial T^*}{\partial x_a} + \frac{\partial^2 p_a}{\partial x_a \partial e_a} \frac{\partial T^*}{\partial q_c} \right] \Delta U + \\ \left[\frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial q_c} \right] \Delta \frac{\partial U}{\partial x_a} &> 0; \frac{\partial^2 EU_a}{\partial \beta \partial q_c} = \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial q_c} \frac{\partial T^*}{\partial \beta} \Delta U < 0; \frac{\partial^2 EU_a}{\partial x_a \partial x_c} = \left[\frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial x_c} \frac{\partial T^*}{\partial x_a} + \frac{\partial^2 p_a}{\partial x_a \partial e_a} \frac{\partial T^*}{\partial x_c} \right] \Delta U + \\ \left[\frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial x_c} \right] \Delta \frac{\partial U}{\partial x_a} &> 0; \frac{\partial^2 EU_a}{\partial \beta \partial x_c} = \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial x_c} \frac{\partial T^*}{\partial \beta} \Delta U < 0; \frac{\partial^2 EU_a}{\partial x_a \partial \gamma} = \left(\frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial x_a} + \frac{\partial p_a}{\partial x_a} \right) \left[\frac{\partial U(R_s, W_s)}{\partial W} L \right] + \\ p_a \frac{\partial^2 U(R_s, W_s)}{\partial R_s \partial W_s} \frac{\partial R}{\partial x_a} L &< 0; \frac{\partial^2 EU_a}{\partial \beta \partial \gamma} = \frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial x_a} \frac{\partial U(R_s, W_s)}{\partial W_s} L > 0; \frac{\partial^2 EU_a}{\partial x_a \partial L} = \left(\frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial x_a} + \frac{\partial p_a}{\partial x_a} \right) \left[\frac{\partial U(R_s, W_s)}{\partial W_s} \gamma \right] + \\ \left[\frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial L} \frac{\partial T^*}{\partial x_a} + \frac{\partial^2 p_a}{\partial x_a \partial e_a} \frac{\partial T^*}{\partial L} \right] \Delta U &+ p_a \frac{\partial^2 U(R_s, W_s)}{\partial R_s \partial W_s} \frac{\partial R_s}{\partial x_a} \gamma + \left[\frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial L} \right] \Delta \frac{\partial U}{\partial x_a} < 0; \end{aligned}$$

$$\begin{aligned} \frac{\partial^2 EU_a}{\partial \beta \partial L} &= \frac{\partial p_a}{\partial e_a} \frac{\partial T^*}{\partial \beta} \frac{\partial U(R_s, W_s)}{\partial W_s} \gamma + \frac{\partial^2 p_a}{\partial e_a^2} \frac{\partial T^*}{\partial L} \frac{\partial T^*}{\partial \beta} \Delta U > 0. \text{ Hence, } \frac{\partial x_a^*}{\partial q_a} > 0; \frac{\partial \beta^*}{\partial q_a} > 0; \frac{\partial x_a^*}{\partial q_c} < 0, \\ \frac{\partial \beta^*}{\partial x_c} < 0, \frac{\partial x_a^*}{\partial x_c} >, \text{ and } 0 \frac{\partial \beta^*}{\partial x_c} > 0. \text{ For } j = \gamma, L, \frac{\partial x_a^*}{\partial j} < 0 \text{ if } \frac{\partial^2 EU_a}{\partial \beta \partial j} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} - \frac{\partial^2 EU_a}{\partial x_a \partial j} \frac{\partial^2 EU_a}{\partial \beta^2} < \\ 0 \Leftrightarrow \frac{\partial^2 EU_a}{\partial x_a \partial \beta} < \frac{(\partial^2 EU_a / \partial x_a \partial j)(\partial^2 EU_a / \partial \beta^2)}{\partial^2 EU_a / \partial \beta \partial j} = M_j. \quad \frac{\partial \beta^*}{\partial j} < 0 \text{ if } \frac{\partial^2 EU_a}{\partial x_a \partial j} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} - \frac{\partial^2 EU_a}{\partial \beta \partial j} \frac{\partial^2 EU_a}{\partial x_a^2} < \\ 0 \Leftrightarrow \frac{\partial^2 EU_a}{\partial x_a \partial \beta} > \frac{(\partial^2 EU_a / \partial \beta \partial j)(\partial^2 EU_a / \partial x_a^2)}{(\partial^2 EU_a / \partial x_a \partial j)} = \bar{M}_j. \text{ Note that it is not possible for } \frac{\partial x_a^*}{\partial j} < 0 \\ \text{and } \frac{\partial \beta^*}{\partial j} > 0 \text{ simultaneously because } \frac{\partial^2 EU_a}{\partial \beta \partial j} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} - \frac{\partial^2 EU_a}{\partial x_a \partial j} \frac{\partial^2 EU_a}{\partial \beta^2} < 0 \text{ and } \frac{\partial^2 EU_a}{\partial x_a \partial j} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} - \end{aligned}$$

$\frac{\partial^2 EU_a}{\partial \beta \partial j} \frac{\partial^2 EU_a}{\partial x_a^2} > 0$ implies $\frac{\partial^2 EU_a}{\partial x_a^2} \frac{\partial^2 EU_a}{\partial \beta^2} - \frac{\partial^2 EU_a}{\partial \beta \partial x_a} \frac{\partial^2 EU_a}{\partial x_a \partial \beta} < 0$ which contradicts the condition for a strict local maximum. If $M_j > \bar{M}_j$, $\frac{\partial x_a^*}{\partial j} < 0$ and $\frac{\partial \beta_a^*}{\partial j} < 0$ when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} < M_j$, but $\frac{\partial x_a^*}{\partial j} > 0$ and $\frac{\partial \beta_a^*}{\partial j} < 0$ when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} > M_j$. If $M_j < \bar{M}_j$, $\frac{\partial x_a^*}{\partial j} > 0$ and $\frac{\partial \beta_a^*}{\partial j} > 0$ when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} < \bar{M}_j$, but $\frac{\partial x_a^*}{\partial j} > 0$ and $\frac{\partial \beta_a^*}{\partial j} < 0$ when $\frac{\partial^2 EU_a}{\partial x_a \partial \beta} > \bar{M}_j$. ■

A.2 Proofs of Propositions in Chapter 3

Proof of Proposition 3.2.1. For the scientist to create a new venture, $p(q)B + K(ap(q) - r(q)) > 0$. Rearranging the equation, we get $B > \bar{B} = K \left(\frac{r(q)}{p(q)} - a \right)$. $\frac{\partial \bar{B}}{\partial q} = \frac{r'(q)p(q) - p'(q)r(q)}{p(q)^2}$. The sign of $\frac{\partial \bar{B}}{\partial q}$ depends on the sign of $r'(q)p(q) - p'(q)r(q)$. For $\frac{\partial \bar{B}}{\partial q}$ to be decreasing in q it must be that $r'(q)p(q) - p'(q)r(q) > 0$. That is, $\frac{r'(q)}{r(q)} < \frac{p'(q)}{p(q)}$. If $\frac{\partial \bar{B}}{\partial q} < 0$ it must be that $r'(q)p(q) - p'(q)r(q) > 0 \Leftrightarrow \frac{r'(q)}{r(q)} > \frac{p'(q)}{p(q)}$ ■

Proof of Proposition 3.2.2. Based on equation (3.2.1), the academic scientist decides to found a new venture if, and only if, $p(q)(B + aK) > r(q)K \Leftrightarrow a > \frac{r(q)}{p(q)} - \frac{B}{K} = a_s$. Furthermore, the university will only consider licensing to an established firm if $p_F(a) \geq \frac{V_F(a)}{R}$. Otherwise, the university will not search for a potential licensee. Since $p_F(a_f) = \frac{V_F(a_f)}{R}$, the university will search if $a > a_f$. First, consider the case of $a_f \leq a_s$. When $a < a_f$, at information set S.1 and S.2, the scientist does not create new ventures. At information set U.2, the university will not search for firm a licensee because $a < a_f$. Since at S.2 the scientist does not create a new venture, at U.1 the university shelves. When $a_f < a < a_s$, at information set S.1 and S.2, the scientist does not create a new venture. At information set U.2, the university searches for a firm licensee. At U.1, the university does not shelve the invention. When $a_f < a_s < a$, at S.1 and S.2, the scientist creates a new venture. Creating new ventures is increasing in a since the right hand side of $p(q)(B + aK) > r(q)K$ is increasing in a . However, whether the scientist can create the venture depends on the university's decision at U.2 and U.1. At U.2, the university supports the scientist's venture if $EU_{Us} \geq EU_{Ul} \Leftrightarrow p(q)B_U + LV_{Us} \geq p_F(a)B_U + LV_{Ul} \Leftrightarrow [p(q) - p_F(a)]B_U > V_{Us} - V_{Ul}$. Increasing

a , decreases the left hand side of the equation. Hence, it becomes less likely that the university decides to support scientist entrepreneurs and more likely that the university licenses the invention to an established firm. At information set U.1, the university does not shelve. Next we consider the case of $a_f > a_s$. When $a < a_s$, at information set S.1 and S.2, the scientist does not create new ventures. At information set U.2, the university will not search for a firm licensee because $a < a_f$. Since at S.2 the scientist does not create a new venture, at U.1 the university shelves. When $a < a_s < a_f$, at S.1 and S.2, the scientist creates a new venture. Creating new ventures is increasing in a since the right hand side of $p(q)(B + aK) > r(q)K$ is increasing in a . At U.2, the university does not search for a licensee because $a < a_f$, hence it offers the scientist the opportunity to create a new venture. At U.1, the university shelves the invention if $p(q) < \frac{V_{Us}-L}{B_U}$. At S.1, the scientist creates a new venture from the shelved invention. When $a_s < a_f < a$, at S.1 and S.2, the scientist creates a new venture. Creating new ventures is increasing in variable a . Again, whether the scientist can create the venture depends on the university's decision at U.2 and U.1. At U.2, the university supports the scientist's venture if $EU_{Us} \geq EU_{Ul} \Leftrightarrow p(q)B_U + LV_{Us} \geq p_F(a)B_U + LV_{Ul} \Leftrightarrow [p(q) - p_F(a)]B_U > V_{Us} - V_{Ul}$. Increasing a , decreases the left hand side of the equation. Hence, it becomes less likely that the university decides to support scientist entrepreneurs and more likely that the university licenses the invention to an established firm. At information set U.1, the university does not shelve. To see the existence of a cut-off point \bar{a} , recall that $p(q) > p_F(a)$ when $\min(a)$ and $\frac{dp(q)}{dq} < \frac{dp_F(a)}{da}$ such that $p(q) < p_F(a)$ when $\max(a)$. This implies that there exists a point where $p(q) = p_F(a)$ before which $p(q) > p_F(a)$ such that $[p(q) - p_F(a)]B_U > V_{Us} - V_{Ul}$. The cut-off point is \bar{a} where $[p(q) - p_F(\bar{a})]B_U = V_{Us} - V_{Ul}$. Let $G(a, q) \equiv [p(q) - p_F(\bar{a})]B_U - (V_{Us} - V_{Ul}) = 0$. Then, $\frac{\partial \bar{a}}{\partial q} = -\frac{\frac{\partial G(\bar{a}, q)}{\partial q}}{\frac{\partial G(\bar{a}, q)}{\partial a}} > 0$ since $\frac{\partial G(\bar{a}, q)}{\partial q} = \frac{dp}{dq} > 0$ and since $\frac{\partial G(\bar{a}, q)}{\partial a} = -\frac{dp_F(\bar{a})}{da} < 0$ ■

A.3 Proofs of Propositions in Chapter 4

Proof of Proposition 4.2.1. Since $\Pi_2 < V$, then $(1 - \alpha)q(2 - (1 + \alpha)q)\Pi_2 < (1 - \alpha)q(2 - (1 + \alpha)q)V$. If $(1 - \alpha)q(2 - (1 + \alpha)q)\Pi_2 > c$, it must also be that $(1 - \alpha)q(2 - (1 + \alpha)q)V > c$. In other words, if a team-project is value maximizing at Stage 1, it is also value maximizing at Stage 2 ■

Proof of Proposition 4.2.2. Let Δ_k be the advantage of a team-project to a solo-project at Stage $k, k \in \{1, 2\}$. $\Delta_2 = (1 - \alpha)q(2 - (1 + \alpha)q)V - c$ and $\Delta_1 = (1 - \alpha)q(2 - (1 + \alpha)q)\Pi_2 - c$. $\frac{\partial \Delta_2}{\partial V} = (1 - \alpha)q(2 - (1 + \alpha)q) > 0$ and $\frac{\partial \Delta_1}{\partial V} = ((1 - \alpha)q(2 - (1 + \alpha)q)) \frac{\partial \Pi_2}{\partial V} > 0$. $\frac{\partial \Delta_2}{\partial c} > 0$ and $\frac{\partial \Delta_1}{\partial c} > 0$.

Next, $\frac{\partial \Delta_2}{\partial q} = 2(1 - \alpha)V[1 - (1 + \alpha)q]$. Solving for q , we get $\frac{\partial \Delta_2}{\partial q} > 0$ when $q < \frac{1}{(1 + \alpha)}$ and $\frac{\partial \Delta_2}{\partial q} < 0$ when $q > \frac{1}{(1 + \alpha)}$. $\frac{\partial \Delta_1}{\partial q} = 2(1 - \alpha)(1 - (1 + \alpha)q)\Pi_2 + q(1 - \alpha)((1 - \alpha)q + (1 - q))\Pi_2'$ where $\Pi_2' = \frac{\partial \Pi_2}{\partial q}$. When $q < \frac{1}{(1 + \alpha)}$, we get $\frac{\partial \Delta_1}{\partial q} > 0$ when $0 < q < \frac{1}{(1 + \alpha)} - \frac{\Pi_2}{\Pi_2'} - \left(\frac{1}{(1 + \alpha)^2} + \frac{\Pi_2^2}{\Pi_2'^2}\right)^{\frac{1}{2}}$. Lastly, $\frac{\partial \Delta_2}{\partial \alpha} = -2q(1 - \alpha)qV < 0$ and $\frac{\partial \Delta_2}{\partial \alpha} = -2q(1 - \alpha)q\Pi_2 + (1 - \alpha)q(2 - (1 + \alpha)q)\frac{\partial \Pi_2}{\partial \alpha} < 0$. $\frac{d\left(\frac{1}{(1 + \alpha)}\right)}{d\alpha} = -(1 + \alpha)^{-2} < 0$. In addition, $\frac{\partial(\bar{q})}{\partial \alpha} = -\frac{1}{(1 + \alpha)^2} + \frac{1}{(1 + \alpha)^3 \sqrt{\frac{1}{(1 + \alpha)^2} + \frac{\Pi_2^2}{\Pi_2'^2}}} < 0$. If stage 2 is a solo-project, $\frac{\partial(\bar{q})}{\partial \alpha} = -\frac{1}{(1 + \alpha)^2} + \frac{1}{(1 + \alpha)^3 \sqrt{\frac{1}{(1 + \alpha)^2} + \frac{1}{4}(1 - q)^2}} < 0$. If stage 2 is a team-project, $\frac{\partial(\bar{q})}{\partial \alpha} = -\frac{1}{(1 + \alpha)^2} - A - \left\{ \frac{1}{2} \left(\frac{1}{(1 + \alpha)^2} + \left(\frac{\Pi_2}{\frac{\partial \Pi_2}{\partial q}} \right)^2 \right)^{-\frac{1}{2}} \left(-\frac{2}{(1 + \alpha)^3} + 2 \left(\frac{\Pi_2}{\frac{\partial \Pi_2}{\partial q}} \right) A \right) \right\} < 0$ because $\frac{\partial \Pi_2}{\partial \alpha} < 0$ and $\frac{\partial \Pi_2}{\partial q} < 0$, where $A = \frac{\frac{\partial \Pi_2}{\partial \alpha} \frac{\partial \Pi_2}{\partial q} - \frac{\partial^2 \Pi_2}{\partial q \partial \alpha} \Pi_2}{\left(\frac{\partial^2 \Pi_2}{\partial q^2} \right)^2}$. Furthermore, $\frac{\partial^2 \Pi_2}{\partial q \partial \alpha} < 0$ when $q < \frac{1}{(1 + \alpha)}$ ■

Proof of Proposition 4.3.1.1. Let n_2^* and n_1^* be the team size such that

$-2\alpha'(n_2^*)qV(1 - \alpha(n_2^*)q) - c'(n_2^*) = 0$ and $-2\alpha'(n_1^*)q\Pi_2^*(1 - \alpha(n_1^*)q) - c'(n_1^*) = 0$ respectively. In addition, let n_L be the larger team size and n_S be the smaller team size, $n_L > n_S$. Suppose that $n_2^* = n_S$ and $n_1^* = n_L$. For $n_2^* < n_1^*$ it must be that $E(\Pi_2(n_S)) > E(\Pi_2(n_L))$ and $E(\Pi_1(n_L)) > E(\Pi_2(n_S))$. That is, $(\alpha(n_S) - \alpha(n_L))q(1 - (\alpha(n_S) + \alpha(n_L))q)V < c(n_L) - c(n_S)$ and

$(\alpha(n_S) - \alpha(n_L))q(1 - (\alpha(n_S) + \alpha(n_L))q)\Pi_2^* > c(n_L) - c(n_S)$ which is impossible because $\Pi_2^* < V$ ■

Proof of Proposition 4.3.1.2. Let G_k be the first-order condition at Stage k . Using standard comparative statics, $\frac{\partial n_k^*}{\partial q} = -\frac{\partial G_k/\partial q}{\partial G_k/\partial n_k^*}$, and $\partial G_k/\partial n_k^* < 0$ by the condition of a local maximum. Thus, $\text{sign}\left[\frac{\partial n_k^*}{\partial q}\right] = \text{sign}\left[\frac{\partial G_k}{\partial q}\right]$. Consider Stage 2, $\partial G_2/\partial q = (-2\alpha'(n_2^*)V)(1 - 2\alpha(n_2^*)q)$. Hence, $\partial G_2/\partial q > 0$ if $q < \frac{1}{2\alpha(n_2^*)}$ and $\partial G_2/\partial q < 0$ if $q > \frac{1}{2\alpha(n_2^*)}$. Consider Stage 1,

$\partial G_1/\partial q = (-2\alpha'(n_1^*)\Pi_2^*)(1 - 2\alpha(n_1^*)q) + (-2\alpha'(n_1^*)q)(1 - \alpha(n_1^*)q)(\partial\Pi_2^*/\partial q)$. Hence, $\partial G_1/\partial q > 0$ if $q < \frac{1}{2\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \frac{1}{2}\left(\frac{1}{\alpha(n_1^*)^2} + \left(\frac{2\Pi_2^*}{\Pi_2'^2}\right)^2\right)^{\frac{1}{2}}$ and $\partial G_1/\partial q < 0$ if $q > \frac{1}{2\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \frac{1}{2}\left(\frac{1}{\alpha(n_1^*)^2} + \left(\frac{2\Pi_2^*}{\Pi_2'^2}\right)^2\right)^{\frac{1}{2}}$ where $\Pi_2' = \partial\Pi_2^*/\partial q$ ■

Proof of Proposition 4.4.1. Using standard comparative statics, $\text{sign}\left[\frac{\partial n_k^*}{\partial q}\right] = \text{sign}\left[\frac{\partial G_k}{\partial q}\right]$ where G_k is the first-order condition at Stage k . Consider Stage 2, $\partial G_2/\partial q = (-\alpha'(n_2^*)V)(1 - 4w_{21}w_{22}\alpha(n_2^*)q)$. Thus, $\partial G_2/\partial q > 0$ if $q < \frac{1}{4w_{21}w_{22}\alpha(n_2^*)}$ and $\partial G_2/\partial q < 0$ if $q > \frac{1}{4w_{21}w_{22}\alpha(n_2^*)}$. Consider Stage 1, $\partial G_1/\partial q = -\alpha'(n_1^*)\Pi_2^*(1 - 4w_{11}w_{12}\alpha(n_1^*)q) + (-\alpha'(n_1^*)q)(1 - 2w_{11}w_{12}\alpha(n_1^*)q)(\partial\Pi_2^*/\partial q)$. Thus, $\partial G_1/\partial q > 0$ if $q < \frac{1}{4w_{11}w_{12}\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \frac{1}{4}\left(\frac{1}{(w_{11}w_{12}\alpha(n_1^*))^2} + \left(\frac{4\Pi_2}{\Pi_2'}\right)^2\right)^{\frac{1}{2}}$ and $\partial G_1/\partial q < 0$ if $q > \frac{1}{4w_{11}w_{12}\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \frac{1}{4}\left(\frac{1}{(w_{11}w_{12}\alpha(n_1^*))^2} + \left(\frac{4\Pi_2}{\Pi_2'}\right)^2\right)^{\frac{1}{2}}$ where $\Pi_2' = \partial\Pi_2^*/\partial q$. Furthermore, at Stage 2, $q_2 = \frac{1}{4w_{21}(1-w_{21})\alpha(n_2^*)}$ and $\frac{\partial q_2}{\partial w_{21}} = \frac{2w_{21}-1}{4\alpha(n_2^*)(-1+w_{21})^2w_{21}}$. Solving for w_{21} , we get $\frac{\partial q_2}{\partial w_{21}} = \frac{1}{2}$. $\frac{\partial q_2}{\partial w_{21}} > 0$ if $w_{21} < \frac{1}{2}$ and $\frac{\partial q_2}{\partial w_{21}} < 0$ if $w_{21} > \frac{1}{2}$. At Stage 1, $q_1 = \frac{1}{4w_{11}(1-w_{11})\alpha(n_1^*)} - \frac{\Pi_2}{\Pi_2'} - \left(\frac{1}{(w_{11}(1-w_{11})\alpha(n_1^*))^2} + \left(\frac{4\Pi_2}{\Pi_2'}\right)^2\right)^{\frac{1}{2}}$. Solving for $\frac{\partial q_1}{\partial w_{11}} = 0$, we get $w_{11} = \frac{1}{2}$. It follows that $\frac{\partial q_1}{\partial w_{11}} > 0$ if $w_{11} < \frac{1}{2}$ and $\frac{\partial q_1}{\partial w_{11}} < 0$ if $w_{11} > \frac{1}{2}$ ■

Proof of Proposition 4.5.1. Let F be the first-order condition. Using standard comparative statics, $\frac{\partial n^*}{\partial j} = -\frac{\partial F/\partial j}{\partial F/\partial n^*}$ for $j = A, q$ where $\partial F/\partial n^* < 0$ by the condition of a local maximum. Thus, $\text{sign}\left[\frac{\partial n^*}{\partial j}\right] = \text{sign}\left[\frac{\partial F}{\partial j}\right]$. Consider $j = A$, $\frac{\partial F}{\partial A} = -2\alpha'(n)q\frac{\partial V}{\partial A}(1 - \alpha(n)q) > 0$. Next, consider $j = q$, $\frac{\partial F}{\partial q} = -2\alpha'(n)V(n)(1 - 2\alpha(n)q) -$

$2\alpha(n)(1 - \alpha(n)q)V'(n)$. Solving for $\frac{\partial F}{\partial q} = 0$, we get $q = \frac{\alpha V' + \alpha' V}{\alpha(\alpha V' + 2\alpha' V)}$. Note that $\frac{\partial^2 F}{\partial q^2} < 0$ when $\alpha'(n) < -\frac{\alpha V'}{2V}$ and that $\frac{\partial^2 F}{\partial q^2} > 0$ when $-\frac{\alpha V'}{2V} < \alpha'(n)$. Let $\bar{q} = \frac{\alpha V' + \alpha' V}{\alpha(\alpha V' + 2\alpha' V)}$ and $\bar{\alpha} = -\frac{\alpha V'}{2V}$. It follows that $\frac{\partial F}{\partial q} > 0$ when $\alpha'(n) < \bar{\alpha}$ and $q < \bar{q}$, or when $\alpha'(n) > \bar{\alpha}$ and $q > \bar{q}$. Otherwise, $\frac{\partial F}{\partial q} < 0$ ■

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