ECONOMIC ISSUES CONCERNING THE MOBILITY OF SCIENTIFIC INVENTIONS AND IMPLICATIONS FOR FIRM STRATEGY

by

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Abstract

It is well recognized that there are imperfections in the market for knowledge transfer due to the nature of ideas and inventions. This is consistent with market failures commonly discussed in the economics of information literature. Some of the impediments to efficiency are examined here in three essays—one empirical, one theoretical, and one case study—all of which share the theme of scientific knowledge movement.

The first essay is empirical and measures the systematic effects of direct interaction and geographic distance between university and firm scientists on the economic performance of imported inventions. This study concludes that, with respect to licensing royalties, scientific interaction has an elasticity of approximately 3 at the mean, which is highly robust, and that distance does not have a significant effect after controlling for interaction. This suggests imperfections in the market for know-how that are sensitive to distance. The second essay is a case study of an invention from the area of robotics and control systems and augments the empirical work presented in the previous essay by illustrating specific reasons why interaction was important for the commercialization of one particular early stage invention.

The third essay develops a game theoretic model involving the strategic manipulation of incentives by an incumbent to create an 'intellectual property commons' for the purpose of *preventing* the commercial development of a disruptive technology that would otherwise threaten existing industry margins. The strategy of spoiling incentives to commercialize public sector scientific inventions by eliminating exclusive intellectual property rights—the strategy of the commons—is motivated by a fear of cannibalization and supported by a credible threat. It is shown that the degree of cannibalization to which the new technology exposes the old market is responsible for this market failure.

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Prologue

On July 23, 1999, I descended six flights of stairs in Baker Library at Harvard University to Stack 1C. The stairs were narrow and 1C was dark, cool, and musty. It was also deserted, as this entire section of the library is during summers. A small light switch chain hung at the entrance to each row of bookshelves. I was searching for the theses of my supervisors, Professors Iain Cockburn and Rebecca Henderson. As I scanned the shelves of past doctoral theses, I stopped to contemplate the future final resting place of my own thesis. When it was finished, it would also end up in a dark corner of an infrequently visited section of some library. And perhaps one day a graduate student like me would wander into such a facility, blow the dust from its cover, and see what I had worked on, what I had thought was interesting and important at the time. For this reason, I thought it important to preface this academic work with a note on the general economic environment—the feeling in the air—at the time this dissertation was written.

During 1999, the environment in the West was filled with a sense of inspiration and hope. To a large extent, these feelings were closely associated with scientific progress and technological development. Indeed, there was so much enthusiasm associated with science and technology in the stock market that the technology-laden Nasdaq Composite almost doubled during 1999, despite Federal Reserve Chairman Alan Greenspan's earlier caution against 'irrational exuberance'.[1] In a book published the same year, economist Lester Thurow dramatically pointed out that "[t]he world's wealthiest man, Bill Gates, owns nothing tangible—no land, no gold or oil, no factories, no industrial processes, no armies. For the first time in human history the world's wealthiest man owns only knowledge." [2]

At the same time, the distinction between academic science and commercial science was becoming increasingly blurred. In many cases, university research in areas such as biotechnology, software, communications, artificial intelligence, and robotics had almost immediate commercial application. In fact, during 1999 a number of America's most prestigious academic research centers, including the Whitehead Institute for Biomedical Research, Washington University School of Medicine, Stanford Human Genome Center, and the Cold Spring Harbor Laboratory, joined forces with a consortium of private-sector pharmaceutical firms in a high stakes race against private

[1] Mr. Greenspan's famous warning to the stock market was made in December 1996.

[2] Lester Thurow, Building Wealth, 1999

biotechnology companies to be the first to sequence and decipher the three billion letters that make up the complete genetic code of human DNA.

Meanwhile, universities were struggling to identify their role in the so-called 'new economy.' University business schools and engineering departments were promoting entrepreneurship and advertising their growing course offerings in technology management, new venture creation, and the financing of hi-tech start-ups. Many top business schools reported that the number of MBA graduates who were going to work for technology start-ups had reached 50%, and technology-oriented business plan competitions were attracting record numbers of participants. At the same time, a number of schools were being scolded by both the Academy and society for their deviation from 'pure' teaching and research. In fact, during the summer of 1999, two critical articles were published on the front page of *The Wall Street Journal* concerning controversy over the commercialization of particular inventions at my research site (MIT); they had a noticeable chilling effect on the campus, significantly increasing the difficulty of data collection for this thesis.[3]

It was in this context of excitement and enthusiasm, coupled with an undercurrent of uncertainty and confusion concerning university science and economic opportunity, that this thesis on the movement of scientific inventions was written. The 'feeling in the air' associated with this economic and scientific environment is not detectable in the academic literature. Thus, perhaps it is even more important that it is noted here by the reader, since at some level it must have influenced the thoughts, ideas, and perspective of the author.

[3]'MIT Students, Lured to New Tech Firms, Get Caught in a Bind—They Work for Professors Who May Also Oversee Their Academic Careers—Homework as Nondisclosure', *Wall St. Journal*, June 24, 1999, p. A1; 'MIT Seeds Inventions But Wants a Nice Cut of Profits they Yield', *Wall St. Journal*, July 20, 1999, p. A1

Acknowledgements

Over the past two years, I discovered that the process of writing a doctoral dissertation is characterized by a remarkable degree of solitude. At times, research can be rather lonely. As a result, intellectual inspiration and emotional encouragement are particularly valuable during such an endeavor. In retrospect, it is quite amazing to reflect on the dramatic impact that particular conversations, ideas, and moments of encouragement had on the final outcome of this project.

Without a doubt, Iain Cockburn and Rebecca Henderson had a tremendous influence on my work throughout this period of time. Both thesis advisors made countless contributions, each in a distinctively different way. Iain is an inspiring econometrician and encouraged me to think deeply about the modeling and interpretation issues that arose in the thesis. He also offered intellectual guidance in every other respect. Rebecca helped me to define the objectives of the thesis during the critical early stages and to maintain focus, clarity, and purpose throughout the entire process. Her persistence with important questions such as 'Why should we care?', 'Do you believe these results?', and 'What do you want others to remember about this work?' motivated many useful course corrections. Together, Iain and Rebecca inspired me, challenged me, and mentored me to research with rigor and think as a scholar.

I am also grateful to Jim Brander and Peter Lawrence who were both on my committee and offered much valuable advice. Jim made particularly significant contributions to the applied game theory chapter as well as comments on the thesis as a whole, and Peter, the single engineering professor on my committee, offered an applied perspective (perhaps even a 'reality check') in addition to useful advice as I was preparing the survey instrument for interviewing engineering faculty.

Several other professors as well as graduate students at UBC, MIT, and other universities offered useful insights from which this work greatly benefited. Four such colleagues gave of both their time and insight so generously that they should be singled out for particular gratitude: Lorenzo Garlappi, Shahram Tafazoli, Dick Nelson, and Keith Head. I very much appreciate their thoughtful contributions.

I also gratefully acknowledge the Andrew Mellon Foundation and the UBC Entrepreneurship Research Alliance for their generous financial support of this work. Without it, this research would not have been possible.

The origin of both the empirical and theoretical chapters may, in many ways, be traced back to the MIT Technology Licensing Office. Lita Nelson and Lori Pressman, the Director and Assistant Director respectively, were friendly and generous with both their time and knowledge of managing intellectual property. They provided me with access to their archive of invention licensing records which eventually became the cornerstone of my thesis. This archive afforded me a privileged view of the licensing process in terms of royalties, contracts, and IP management strategies. I appreciate their trust and helpfulness.

I am also very grateful to the MIT engineering faculty who gave generously of their time and their histories to be interviewed about their inventions. While each invention appears merely as one of many observations in the statistical analyses presented here, each is a personal victory for the inventor. I am thankful for the open and candid spirit with which they shared their stories and data.

During the process of writing this thesis, I became engaged and was adopted by my fiancé's family. Lydia and Tony Buonaguro adapted remarkably well to the fact that they had inherited a thesis-in-progress as well as a son-in-law. They were very sensitive to the time demands imposed by this project and reliably sent me clippings of any stories on university patent licensing that appeared in *The Wall Street Journal.* I appreciate their thoughtfulness and genuine interest.

I am thankful to my parents for creating an intellectual environment for my brother and me long before either of us contemplated doctoral studies. They are the reason that I was both equipped and inspired to attempt such a project. My father, who earned a doctorate degree in structural engineering, provided inspiration from his own experiences, my mother provided never-ending encouragement as she has all my life—especially during the difficult times—and my brother shared the trials and tribulations from his own 'bug' research in the area of evolutionary biology. I am deeply grateful.

Finally, I wish to thank my fiancé, Gina. I'm sure that many times during the course of this dissertation she must have felt as if she was my co-author, given the time, thought, and space this thesis has consumed from our lives. She has provided constant encouragement as well as thoughtful ideas and genuine inspiration. She has been remarkably understanding during the busiest and most stressful periods. Throughout the project, she kept me going with high spirits and good humor. I dedicate this work to her, with deepest respect and love.

Chapter 1

Introduction

The essays in this thesis are concerned with economic issues associated with the movement of scientific inventions across organizational boundaries. In particular, they are focussed on issues of information, incentives, efficiency, and performance. From a policy perspective, research on this topic is motivated by an interest in developing a greater understanding of economic growth. Basic and applied science are an important input for technological innovation, and, in turn, technology is an important input for productivity growth. Economic growth is a function of productivity growth. From a strategy perspective, research on this topic is motivated by an interest in developing a greater understanding of the source of differences in the relative ability of firms to commercialize products that are based on inventions developed outside the firm.

It is well recognized that there are imperfections in the market for knowledge transfer due to the nature of ideas and inventions. This is consistent with market failures commonly discussed in the economics of information literature. These impediments to efficiency are examined here in three essays, all of which share the theme of scientific knowledge movement. Chapter 2 is empirical and measures the systematic effects of direct interaction and geographic distance between scientists on the economic performance of imported inventions. Chapter 3 is a case study of an invention from the area of robotics and control systems and augments the empirical work presented in the previous chapter by illustrating specific reasons why direct interaction between university and industry scientists was important for the commercialization of one particular early stage invention. Chapter 4 develops a game theoretic model involving the strategic manipulation of incentives by an incumbent to create an 'intellectual property commons' for the purpose of *preventing* the commercial development of a disruptive technology that would otherwise threaten existing industry margins. Finally, Chapter 5 concludes and offers directions for future research. Each of these chapters is briefly described below.

Chapter 2, entitled *Importing Scientific Inventions: Direct Interaction, Geography, and Economic Performance,* examines the effect of direct scientific interaction and geographic distance, both measured between scientists at the inventor's lab and the importing firm, on the economic performance of imported inventions. Regression analysis supports the hypothesis that direct scientific interaction has a positive effect on the *likelihood* and *degree* of commercial success of imported inventions that is both statistically significant and economically important. Also, while geographic distance between the inventor's lab and the importing firm does not seem to have a significant effect on commercial success, the associated coefficients are consistently negative. The negative effect is reduced by a factor of ten, almost fully disappearing, after controlling for direct interaction. This result suggests imperfections in the market for direct interaction that are sensitive to geographic distance. Overall, these results imply that firms which invest in the development of imported inventions may increase their productivity by way of innovations in: contracting for scientific interaction (incentives external to the firm), organizational strategies vis-a-vis research collaboration (incentives internal to the firm), recruiting strategies, and investments in relationships with relevant research institutions and individuals. In addition, firms may consider options that reduce the cost of interaction, such as location.

In order to run this experiment, a unique data set was constructed from inventor interviews, licensing records, and patent databases, amongst other sources. The data consists of 124 license agreements associated with inventions from MIT and contains information regarding inventors, firms, interaction, the inventions themselves, and their economic performance. Finally, the variable employed to control for invention quality in this experiment is constructed from forward citation measures and maintains a robust, positive relationship with the economic performance of the invention. This result may be of some interest to scholars who utilize bibliometric measures for research in innovation-related research.

Chapter 3 analyses cross-organizational movement issues of a single invention. The motivation for this study is to offer context to the empirical findings of the previous chapter by way of illustration. In other words, this chapter provides a case study to illustrate the set of reasons why direct interaction was important for importing one particular invention. The invention under examination is from the general area of electrical engineering and computer science. Specifically, the invention is a dynamic, real-time payload monitoring system developed at an advanced robotics and control systems laboratory in a university setting. The study points out that the quality of this invention was high in terms of standard industry performance measures. It also illustrates that the invention was unique and that there was a significant market demand for it. However, the key observations are the reasons why potential importing firms were of the strong belief that despite these positive characteristics of the invention, modifications would be necessary for commercialization and these would require direct interaction with the inventor's lab.

Industry experts concluded that they would need to make significant modifications to the prototype in order to redesign for scale, cost, and operational robustness. Such redesign required a deep understanding of the physics of the system in terms of gravitational and frictional effects as well as of advanced robotics. Although the invention would be described in a patent and components of the invention were described in academic publications, scientists and engineers from the importing firms did not feel confident that they could make the modifications necessary to develop a commercial product on their own in a reasonable amount of time.

They did not have a deep understanding of robotic systems in-house, although some firms did have an extensive in-house R&D capability. At the same time, they could not glean a deep understanding of advanced robotics in general or this application in particular from the information contained in the related patents or journal publications. For these reasons, no firm would make an investment in the new technology without first securing a long-term contractual relationship with the inventor, thus illustrating a case where direct interaction was considered very important.

Chapter 4, entitled *Public Sector Science and the Strategy of the Commons,* presents a theoretical model of university licensing. Specifically, this essay considers corporate sponsorship and exclusive versus non-exclusive licensing regimes. Incumbent firms frequently sponsor university research in areas related to their business. In some cases, these firms request *ex ante* that discoveries resulting from the sponsored lab be distributed through *non-exclusive* licensing agreements only. Upon first glance, this request seems non-profit maximizing and thus irrational. Indeed, sponsoring firms are often 1) engaged in product areas that may benefit from these particular research outcomes, 2) richer than entrants in resources, and 3) recipients of asymmetric information with regard to intermediate results and ongoing research activities of the labs they sponsor. So, the puzzle addressed here is why incumbent firms would remove the ability to gain exclusive access to potential intellectual property rights. In addition, if there is a rational explanation, why does it only apply in some cases?

This paper presents a game theoretic model that compares the economic implications of two types of university innovations, sustaining and disruptive, under exclusive and non-exclusive licensing regimes and offers an explanation for such contractual behavior. Under particular cost and demand conditions defined as a 'disruptive technology,' the incumbent chooses to employ a 'strategy of the commons' by requesting a non-exclusive licensing regime that applies to all research output from a particular lab as a condition of sponsorship. Such an action creates an intellectual property commons that prevents any firm, including the incumbent, from obtaining the private intellectual property rights necessary to appropriate monopoly rents. There is good reason to believe that in certain circumstances, intellectual property protection is important for appropriating monopolistic rents, while in other cases this may be accomplished through other means such as superior manufacturing capacity or distribution channels. This paper addresses those cases characterized by the former.

Therefore, creating an intellectual property commons weakens the incentive required for any firm to invest in the development and commercialization of the invention. The incumbent uses this strategy to *neutralize* research areas in universities which are likely to develop innovations which might threaten their existing industry margins. These results offer a theoretical framework for future detailed investigations of cases such as Kodak's sponsorship of university research in digital photography, AT&T's sponsorship of university research in multimedia communications such as Internet telephony, and SNP's (a consortium of large pharmaceutical companies) sponsorship of university research on the human genome project - which has been explicitly described as an attempt to prevent small biotech firms from obtaining exclusive rights to any crucial gene-finding processes.

Each essay presented in this dissertation is intended as a contribution to the innovation-oriented business strategy and public policy literature. For example, while there exists a rich literature, both within economics and in other disciplines such as sociology, engineering, and the administrative sciences, that has acknowledged and discussed the importance of tacit knowledge transfer to the movement of scientific inventions, the essay in Chapter 2 is amongst the first to attempt to quantify this phenomenon and to measure its effect in terms of economic performance. The case study that is Chapter 3 provides context for the empirical findings of the previous chapter. The corporate sponsorship of university research with the associated contractual design described in Chapter 4 is a relatively new phenomenon, brought to the attention of the author by the MIT Technology Licensing Office. The strategic behavior on the part of large firms that is described in this chapter has a potential for significant impact on the development of new technologies and the growth of new firms, especially in technical areas where public research activity and private commercial activity are closely related. Examining the 'Strategy of the Commons' may offer useful insights for a deeper understanding of intellectual property management strategies from the perspective of both firm strategy and public policy. It is hoped that together these essays will push forward thinking on economic issues concerning the mobility of scientific inventions and thereby offer a contribution to this stream of research that is both intellectually rigorous and economically significant.

Chapter 2

Importing Scientific Inventions: Direct Interaction, Geography, and Economic Performance

Abstract

This essay examines the effect of direct scientific interaction and geographic distance, both measured between the inventor's lab and the importing firm, on the economic performance of imported inventions. Regression analysis supports the hypothesis that direct scientific interaction has a positive effect on the *likelihood* and *degree* of commercial success of imported inventions that is both statistically significant and economically important. Also, while less robust, geographic distance between the inventor's lab and the importing firm has a negative effect on commercial success. However, this negative effect becomes insignificant after controlling for direct interaction. This result suggests imperfections in the market for direct interaction which are sensitive to distance. Overall, these results suggest that firms which invest in the development of imported inventions may increase their productivity by way of innovations in contracting for scientific interaction, organizational strategies vis-a-vis research collaboration, recruiting strategies, and investments in relationships with relevant research institutions and individuals. In addition, firms may benefit from strategies, such as location decisions, that reduce the cost of interaction.

In order to run this experiment, a unique data set was constructed from inventor interviews, licensing records, and patent databases, among other sources. The data consists of 124 license agreements associated with inventions from MIT and contains information regarding inventors, firms, interaction, the inventions themselves, and their economic performance. In addition, the variable employed to control for invention quality in this experiment is constructed from forward citation measures and maintains a robust, positive relationship with the economic performance of the invention. This result may be of some interest to scholars who utilize bibliometric measures for studies in innovation-related research. Finally, a case study of an invention from the area of robotics and control systems included in the following chapter supplements this empirical work by illustrating specific reasons why direct interaction was important for the commercialization of one particular early stage invention.

2.1 Introduction

This essay examines the relationship between scientific interaction, geography, and the economic performance of imported inventions.[1] 'Imported inventions' refer to early-stage scientific inventions which are moved across organizational boundaries for the purpose of development and commercialization. The paper is motivated by an interest in developing a deeper understanding of these two factors—interaction and geography—which have long been considered important to the movement of inventions in the innovation economics literature. This is an important problem since even large firms that invest heavily in in-house research develop only a minority share of the total innovations in any particular field of applied science. Thus, it seems plausible that firms which develop an ability to utilize externally-generated scientific inventions more effectively than their competitors will enjoy a valuable competitive advantage.

Journal publications and scientific conferences are the normal mechanisms for sharing ideas within the scientific community. Cohen and Levinthal (1989, 1990), amongst others, suggest that firms need to participate in the scientific community in order to benefit from it. They describe the two faces of in-house R&D as, first, providing research results directly relevant to the firm and, second, providing an ability to utilize research results generated outside the firm. They refer to the latter as absorptive capacity.

Recent empirical studies have built on this hypothesis and focussed on R&D productivity effects from direct interaction between scientists from different organizations. For example, Cockburn and Henderson (1998) measured benefits in pharmaceutical research productivity associated with *con-*

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[1]In this chapter, I am particularly grateful for thoughtful advice from Richard Nelson, Keith Head, Adam Jaffe, Scott Stern, Jim Brander, and participants of the NBER Productivity Seminar. I am thankful for useful comments from Peter Lawrence regarding the inventing process in the early stages of designing the interview instrument. I am indebted to Lori Pressman and her staff at the MIT Technology Licensing Office for answering my many questions regarding the licensing process as well as for granting me access to their files. I am also indebted to the many professors from the Departments of Mechanical Engineering and Electrical Engineering and Computer Science (EECS) at MIT who gave generously of their time to be interviewed and to discuss their experiences and insights regarding moving their scientific inventions from the campus to the private sector. Without their input, the detailed level of analysis reported in this chapter would not have been possible. Finally, I am grateful to Iain Cockburn and Rebecca Henderson for their thoughtful guidance throughout this research. Errors and omissions are fully my responsibility.

nectedness , the degree to which firms collaborated with university researchers. In another study, Zucker and Darby (1998) measured a strong positive correlation between the location of new biotechnology firms and the location of university 'star scientists,' suggesting positive effects from direct scientific interaction.

The evidence presented in this essay contributes to this stream of research. Although in-house research is likely important for *identifying* useful scientific ideas generated outside the firm, the results presented here suggest that such a reseach capability may not be enough to effectively develop imported inventions. In many cases, direct interaction between the firm's research scientists and the inventor's lab is necessary for the effective movement of scientific inventions. This is the first study, to the author's knowledge, that directly measures the success of commercializing imported scientific inventions as a function of the degree of interaction between the firm's scientists and the inventor's lab.

2.2 Literature

While there exists a rich theoretical literature in economics on the movement of scientific inventions, very little empirical work has been done in this area. Early works in the economics of innovation, beginning with Schumpeter (1943) and including Nelson (1959) and Arrow (1962), often consider the transfer of knowledge to be costless, characterized by the 'waterfall' model in which knowledge generated at publicly funded research institutions spills over and is used downstream by firms, at no cost. The implicit assumption in this view is that ideas are completely codified and can therefore be perfectly transmitted by way of publications. This view of invention movement is embodied in many of the common theoretical licensing models which assume that there is a perfect and complete movement of knowledge in patent licensing(Gallini and Winter, 1985; Kamien and Tauman, 1986; Katz and Shapiro 1986, Bhattacharya et al, 1990; Gallini and Wright, 1990).

More recent theories build on work by Cohen and Levinthal (1989, 1990) and advance the hypothesis that firms must make investments in in-house basic research in order to be able to absorb spillovers from upstream research. There is a particular stream within this research that has focused attention on the importance of direct interaction and collaboration between scientists and engineers from different organizations. This essay builds on this hypothesis and therefore a few of the key papers from this literature are briefly described below.

Arora (1995) presents a theoretical paper in which patent licensing and the movement of scientific ideas are explicitly modeled. In this model, licensing contracts take the form of two lump sum payments where the first sum is paid upon the initial agreement and the assignment of licensing rights and the second sum is paid after the invention has been fully transferred. There is an explicit cost to the inventor associated with transferring the scientific knowledge. This paper was amongst the first contributions to this literature in which direct interaction as a component of idea movement was explicitly modeled, in this case by way of a cost, in the licensing process. No empirical evidence of direct interaction was offered in this paper, although there were references to the documentation of this phenomenon.[2]

Cockburn and Henderson (1998) examined the productivity of large pharmaceutical firms in the area of small molecule discovery. They found strong evidence of a relationship between productivity and 'connectedness', while controlling for a variety of firm characteristics such as size, propensity to patent, and organization and scope of research.[3] Connectedness was measured by the number of institutional co-authorships between firm scientists and university scientists, again suggesting that important productivity effects result from direct communication and collaboration.

In a similar spirit, Zucker, Darby et al. (1998, and related papers) present a series of papers that provide compelling evidence that the timing and location of the formation of biotechnology firms in the US before 1990 was a function of the number of 'star' scientists in the same geographic area.[4] At the firm level, they also present evidence of a relationship between the number of 'linked stars', which refer to university star scientists who have collaborated with scientists from a firm, and firm productivity.[5] These re-

[2]Arora refers to Spitz (1988: 329) who documents an unsuccessful attempt by a US firm to build a phthalic anhydride plant despite having access to the relevant patents and a 'great deal of technical information' from similar plants. He also refers to Hounshell and Smith (1988) for additional anecdotal evidence.

[3]In this case, productivity was measured by the number of 'important' small molecule patents that were awarded to each firm.

[4]Zucker, Darby et al. defined stars as those scientists who had reported at least 40 genetic sequencing discoveries in Genbank or published at least 20 genetic-sequence discoveries.

[5]In this case firm productivity was measured as the number of products in development, the number of products on the market, and changes in employment.

sults clearly suggest that direct interaction was important in biotechnology, at least during this period, and that complete knowledge was not transmitted through formal but indirect channels such as publications and conferences.

Jenson and Thursby (1998) provide interesting descriptive statistics regarding the embryonic state of most university inventions.[6] The view regarding the importance of direct interaction is so strong in this work that university patents that are licensed by firms and are not accompanied by any direct interaction are modeled such that they succeed with zero probability. The assumption in this paper is that to facilitate complete idea transfer, the inventor must work in collaboration or communication with the licensee.

Finally, it is important to note that there is a broad and rich literature on the general topic of 'technology transfer' outside traditional economics. This includes a number of papers that discuss the importance of direct interaction to technology transfer. For example, a search in the *Web of Science* for papers on technology transfer that specifically discuss interaction or collaboration as an important factor returns 56 articles published between 1987 and 1998.[7] These studies are generally intuition or case-based and provide valuable insights and examples. They are published in a wide variety of journals such as *IEEE Transactions on Engineering Management,* the *International Journal of Technology Management,*the *Journal of Information Science, Technovation,* and the *Journal of Business Venturing.*[8] In addition, technology transfer practitioners, such as university technology licensing officers and corporate technology transfer personnel, commonly use expressions

[6]Jenson and Thursby conducted a survey of 62 US research universities (technology licensing directors and officers) and from this determined that over 75% of the inventions licensed were only a proof of concept (48%) or a lab scale prototype (29%) at the time of license.

[7]The Web of Science (www.webofscience.com) is published by the Institute for Scientific Information and includes the Science Citation Index, the Social Sciences Citation Index, and the Arts & Humanities Citation Index.

[8]Examples of studies published in these journals include: 1) Randazzese, L.P. (1996). 'Exploring university-industry technology transfer of CAD technology', *IEEE Transactions on Engineering Management* , 43: 4, Novermber, pp. 393-401. 2) Williams, J.C. (1998). 'Frederick E. Terman and the rise of Silicon Valley', *International Journal of Technology Management,* 16: 8, pp. 751-760. 3) Irwin H, and E More (1991). 'Technology-transfer and communication - lessons from Silicon Valley, Route 128, Carolinas Research-Triangle and Hi-Tech Texas', *Journal of Information Science,* 17: 5, pp.273-280. 4) Tither D. (1994). 'The people factor in collaboration and technology-transfer', *Technovation,* 14:5, June, pp. 283-286. 5) Harmon B. et al (1997). 'Mapping the university technology transfer process', *Journal of Business Venturing,* 12:6, November, pp. 423-434.

such as 'Ideas don't move. People do.' and 'Technology transfer is a contact sport.'[9] In other words, many scientists, administrators, practitioners, and scholars, both within and outside of economics, are already familiar with the idea that direct interaction is important for the effective movement of scientific ideas.

2.3 Hypotheses

This study investigates three principal hypotheses concerning the effects of direct scientific interaction and geographic distance on the economic performance of imported inventions. Each hypothesis is investigated from two perspectives, the *likelihood* of commercialization, and the *degree* of commercial success. These hypotheses are stated below:

Hypothesis 1A
Direct scientific interaction between the inventor's lab and the importing firm has a positive, systematic effect on the *likelihood* of commercialization of imported inventions.

Hypothesis 1B
Direct scientific interaction between the inventor's lab and the importing firm has a positive, systematic effect on the *degree* of commercial success of imported inventions.

Hypothesis 2A
Geographic distance between the inventor's lab and the importing firm has a negative, systematic effect on the *likelihood* of commercialization of imported inventions.

Hypothesis 2B
Geographic distance between the inventor's lab and the importing firm has a negative, systematic effect on the *degree* of commercial success of imported inventions.

[9] Interviews with the Director and Assistant Director of the MIT TLO. November 1998 and March 1999.

Hypothesis 3A
Geographic distance between the inventor's lab and the importing firm has no systematic effect on the *likelihood* of commercialization of inventions after controlling for direct scientific interaction.

Hypothesis 3B
Geographic distance between the inventor's lab and the importing firm has no systematic effect on the *degree* of commercial success of inventions after controlling for direct scientific interaction.

2.4 Methodology

2.4.1 Unit of Analysis

The unit of analysis used to test the hypotheses expressed above is the license agreement. Licensing agreements offer a useful insight into the movement of scientific inventions that are commercialized since they document the 'last mile' of movement that necessarily occurs within the private sector. Specifically, a firm that utilizes an invention that has been invented outside the firm and protected by a patent must enter into a licensing agreement with the assignee in order to use the invention. To this end, agreement records maintained by organizations, such as universities, often archive three of the four data requirements necessary to address the hypotheses: i) the inventor identity, ii) the licensee identity, and iii) the royalties, a measure of economic performance. The only primary data requirement for this study not included in agreement records is information concerning the level of interaction. It is important to note that out of this data, only the inventor is recorded on the actual patent. Patent-related databases do not include the other information on the identity of licensees or on the amount of royalties generated.

2.4.2 The Basic Model

The basic models to be tested are:

$$E_i = f(I_i) \tag{2.1}$$

where E_i is the economic performance of the i^{th} license agreement, I_i is the amount of scientific interaction associated with that invention, and the expected derivative is $\frac{\partial E_i}{\partial I_i} > 0$.

$$E_i = f(D_i) \tag{2.2}$$

where D_i is the distance in miles between the inventor's lab and the importing firm associated with the i^{th} license agreement and the expected derivative is $\frac{\partial E_i}{\partial D_i} < 0$.

$$E_i = f(I_i, D_i) \tag{2.3}$$

where the expected derivatives are $\frac{\partial E_i}{\partial I_i} > 0$, and $\frac{\partial E_i}{\partial D_i} = 0$.

The conceptual variables introduced here as well as control variables for invention, inventor, firm, and geography effects are defined and operationalized in sections 4.3 and 4.5, respectively. The important point to note here is that measures for economic performance, scientific interaction, and geographic distance are required to estimate these equations.

2.4.3 Key Variables

Dependent Variables

Commercialize
COMMERCIALIZE is a measure of economic performance. It is a binary variable that indicates whether an innovation was commercialized. It equals '1' if a product which utilizes the licensed invention has been sold. In other words: $if Royalties > 0 \rightarrow Commercialize = 1$. The motivation for using COMMERCIALIZE is to examine the effects of interaction and distance on a measure of commercial success that is less influenced by other factors, such as marketing and distribution which are very important to the overall commercial success of the invention. These factors will have a greater influence on the value of 'royalties per year', discussed below, and therefore both measures are examined.

Royalties per Year
RPY is also a measure of economic performance. It is the sum of the royalty payments divided by the number of years the agreement was active. This information was collected on a confidential basis from the TLO under the condition that licensee identities would not be revealed. Present values of past royalty income were generated using an annual discount rate of 8%

and an annual inflation rate of 3%. Running royalty payments were usually specified in the license agreement as a percentage of net sales of the product resulting from the invention. The value of 'net sales' is generally determined by the licensee's billings for the licensed product or process less the sum of the following: 1) discounts allowed in amounts customary in the trade for quantity purchases, cash payments, prompt payments, wholesalers, and distributors, 2) sales, tariff duties, and/or use taxes directly imposed and with reference to particular sales, 3) outbound transportation prepaid or allowed, 4) amounts allowed or credited on returns, and 5) allowance for bad debt, not to exceed a specified fraction (often 5%) of total net sales per calendar year. There are, however, other methods by which royalties may be charged such as a fixed fee per unit sold.

There are several types of income generated from a licensing agreement. These include royalties, license issue fees, and license maintenance fees. However, only royalties are used in this analysis since only royalties directly reflect commercial success. The license issue fee includes patent reimbursement costs and may also include extra administrative costs. These charges are also levied to confirm the seriousness of the licensee. Similarly, license maintenance fees are collected on a regular basis to confirm the continued interest of the licensee in developing the invention. Once a product is commercialized, running royalties are collected against the license maintenance fee such that no maintenance fee is charged if the royalties collected exceed the maintenance fee. Since all sources of income were recorded together in the license agreement record, line item royalty payments were extracted and totalled separately for this study. RPY may take a value that is positive or zero. A value of zero indicates that the invention was licensed but a commercial product was never sold.

Explanatory Variables

Interact

INTERACT measures the number of hours that professors, graduate students, and research scientists collaborated with firms and worked on problems that were directly related to an invention *after* it was licensed and *before* it began to generate revenues. This work was only counted if it was done in collaboration or close communication with the licensee and was motivated by the licensee.[10] The data for this measure was collected by way of interviews.

[10]or at least co-motivated by the licensee. In other words, the work must have been

Faculty inventors were asked to estimate the amount of time that they or any researchers associated with their lab worked on problems in collaboration or close communication with the firm after the invention was licensed. Initial responses were often general, such as "two master's theses". Professors were asked to estimate the number of person hours involved in this research collaboration (1 year = 2000 hrs, 1 month = 160 hrs, 1 week = 40hrs, 1 day = 8hrs.).

Graduate students usually carried this work out in the context of Masters or Ph.D. theses if they were current students, and in the capacity of a consultant, employee, or founder otherwise. Professors usually carried out this work in the context of independent research or otherwise in the capacity of a consultant, employee, shareholder, or founder. This measure also includes visiting scientists. If the licensee sent a research scientist to carry out research at MIT during the time period discussed below, these hours were included in INTERACT.

The boundaries on the time period over which these variables were measured reflect a deliberate effort to minimize endogeneity problems. The reason for restricting the hours counted to those spent before commercialization was to minimize endogeneity resulting from graduate students working on a project because it was already commercially successful. This measure was not meant to reflect quality and thus estimates of the total number of hours spent working on the invention were not collected. The collection of this measure was attempted in the first phase of this study, but it quickly became apparent that most inventions resulted from complex histories of research in multiple areas and across multiple people and laboratories.

INTERACT is an estimate of the amount of direct interaction. Firms that license an invention have the right to develop it utilizing any resources they wish. There are no contractual terms in the sample of agreements studied here in which the licensee is legally bound to involve the inventor's research lab for further research or development. It is therefore assumed that engagement in interaction reflects the licensee's perception that this will contribute to the successful commercialization of the end product.

Recruit

RECRUIT is another measure of interaction. It is a count of the number of researchers from the inventor's lab that were recruited to work as full

directly relevant to the licensed invention.

time employees at the importing firm. Consulting and contract work is not included in this measure. These hours are included in INTERACT. There is a positive correlation between INTERACT and RECRUIT since firms often hire researchers with whom they have interacted. In this case, interaction hours *prior* to employment are counted in INTERACT.

Distance

DISTANCE is a measure of the number of miles between MIT and the importing firm.

2.4.4 The University Setting

The objective of this study is to measure the importance of interaction between researchers at the inventor's lab and the importing firm. This may be studied in a variety of settings. Inventions may be imported within firms across divisional boundaries, across firms within the private sector, or from public research institutions to private firms. Each of these environments has particular characteristics that influence the ability to gather data for the purposes of studying this phenomenon. These differences are discussed below in terms of data availability, accessibility, and consistency. It is explained why the university-to-firm setting is the most suitable setting for the purposes of this study.

Within Firms

In principle, inventions that are imported within firms across divisional boundaries could be examined for this experiment. Divisions may or may not be geographically separated. However, the data required for this type of study may not be available from firms that import inventions internally since they are not required to record accounting information in terms of revenues generated from a particular invention. Also, both financial and interaction data may be difficult to access with private sector firms since they are often concerned about secrecy. Finally, it may be necessary to collect data from a number of firms in order to generate a significant sample size. It may be the case that firms employ different accounting practices which would lead to inconsistency of this data.

Across firms

Inventions that are imported from one firm to another could also be used for this experiment. It is more likely that the accounting information regarding the economic performance of a particular invention would be available in this setting compared to the former since the importing firm would likely be responsible for paying royalty fees for the use of the invention. However, as in the above case, financial and interaction data may be difficult to access since firms are often concerned about secrecy. Again, it may also be necessary to collect data from a number of firms in order to generate a significant sample size and it may be the case that firms employ different accounting practices which would lead to inconsistency of this data.

University-to-Firm

The university-to-firm setting seems to offer the best environment for collecting the necessary data. First, it is important to note the intermediary role played by the Technology Licensing (TLO) Office (see *Figure 1*). This is important since it creates a single organization which manages intellectual property for many inventors and many firms. This solves two of the problems discussed earlier. First, accounting data is available since firms are obliged to record revenues attributable to products containing a particular invention in order to calculate royalty payments. Second, since this information is all coordinated through one organization, the accounting, licensing, and other relevant procedures are relatively standardized which results in reasonable data consistency. In addition, because the TLO is a university organization, it is sympathetic to scholarly research interests and thus reduces the accessibility problem.[11] Finally, the inventors are professors, also generally sympathetic to research interests, and thus happy to share information concerning their interaction with firms, in most cases.

2.4.5 Control Variables

There are four sets of control variables. These include controls for invention, inventor, importing firm, and geographic region characteristics. Each set of control variables is discussed below.

[11]Access to royalty and licensee data was kindly permitted by the TLO under the condition that it be presented in aggregated form only. Company names and identifying characteristics remain confidential.

Invention-Related Control Variables

Four invention-related control variables are included in the model: quality, age, sponsor, and software. These are described below.

Quality

QUALITY is a measure of the 'quality' or 'importance' of the invention. It is measured by counting the number of times a patent (or patents) in a licensing agreement are cited by subsequent patents. In cases where there are more than one patent included in an agreement, QUALITY is assigned a value equal to the maximum number of citations associated with any one patent in that set. A five year window, measured between the issue date of the licensed patent and the application date of the citing patent, is used in order to minimize the effect of forward truncation. Lanjouw and Schankerman (1999) found forward citations to be a reasonably good measure of patent 'quality' as it was significantly related to patent renewals and infringement litigations. In addition they found that results using a five year window were highly correlated with those obtained by using a 10 year window (> 0.8) and a 15 year window (> 0.7). This result is important since it enables the use of recent data with some level of confidence. However, the most recent license agreements in the sample used in this study were still penalized, even though they were at least five years old. This is because patents that were filed at the end of the five year period may still not be issued. Therefore, even though they were filed within the specified time period, and may be pending, they were not counted in this measure. This concern is supported by the data as AGE and QUALITY are indeed negatively correlated (-0.15).[12]

Age

AGE is a measure of the age of the license agreement. This is calculated as the number of years between the activation date of the license agreement and August 1 1999, the time at which the royalty data was collected. It is important to note that although some of the license agreements were activated at the same time the patent was issued, others were activated while the patent was still pending, and yet others were activated after the patent was issued.

[12] It is important to note that this is not an exact measure of what we are interested in since AGE is counted from the activation date of the license, not from the issue date of the patent. However, the age of the license and the age of the patent are sufficiently related that it can be assumed that this relationship is highly reflective of the true relationship.

Sponsor
SPONSOR is a binary measure that indicates whether the research that led to the invention was sponsored by the licensee. The motivation for this control is the assumption that sponsors might be able to influence the direction of research such that the resultant inventions are more easily commercialized. The primary weakness with this measure is that it does not contain information regarding the size of the sponsorship. Therefore, a large sponsorship program that spans several years and funds many researchers is treated as equivalent to a small sponsorship contribution that funds the work of one graduate student for a single year, or the purchase of a single piece of equipment. The difficulty with using actual sponsorship amounts is data accessibility. A thorough review of the financial records, spanning back 25 years in some cases, would be required to collect this data since sponsorship information is not stored centrally. It is assumed here that despite this problem with the measure, it is useful for identifying a systematic effect from licensee sponsorship in general, if one exists.

Software
SOFTWARE is a binary variable that indicates whether the invention licensed was software. Software is characterized by some properties that may influence the probability of successful commercialization. For example, software may be more difficult to protect, may have a greater fixed to variable cost ratio, and may involve knowledge that is more (or less?) easily codified. However, this control is employed without strong priors regarding whether software may be more or less amenable to successful commercialization.

Inventor-Related Control Variables

Three inventor-related control variables are included in the model: Star20, industry funding, and EECS. These are described below.

Star20
STAR20 is a measure of intellectual 'stardom' and is constructed in the spirit of the star measure employed by Zucker, Darby et al (1998, and related papers) who identify academic 'stars' as those researchers who reported a large number of genetic sequencing discoveries. While STAR20 is in a similar spirit

to the measure used by Zucker and Darby, it is not the same measure. It is a count of the number of articles the inventor had published after 1983 and before the earlier of August 1999 or the agreement termination date, in science or engineering oriented journals, that have received at least 20 citations. This data was collected from the Institute of Scientific Information's *Science Citation Index.* The selection of 20 citations was arbitrary, although this measure was quite highly correlated with a similar measure for publications with 50 citations (0.62). The data for this measure was refined when professors reviewed the list of their publications during the interview and subsequently eliminated papers published by authors accidentally included because they had the same last name and first and middle initials. [13]

There are several problems with this measure. The greatest problem is that older professors may have done their most important work before 1983 and these papers are not included in the analysis. One method for reducing this problem involves estimating the average productivity curve of the average professor in this field over the duration of a research career. This would allow one to control for the particular part of a professor's career that is represented by the available data window. However, no such corrections were made here.

The variation in the duration of agreements also poses a problem for this measure. STAR20 is meant to control for the star effect on the successful commercialization of an invention. However, if an agreement is ten years old and the inventor was just entering his or her peak publishing period at the time of the invention, the inventor may have appeared as much less of a star at the beginning of the agreement than was the case later on. The STAR20 measure is taken at the end of the agreement or at the end of 1999 and therefore suffers from inconsistency across agreements.

Another problem with this measure is that some professors achieve intellectual 'stardom' through mechanisms other than peer reviewed journal publications. The most common alternative is monographs. Several professors interviewed referred to books they had written as their greatest contribution to the field. Books, conference presentations, and other forms of participation in the research community are not captured by STAR20, only peer reviewed journal publications. Finally, there is a truncation problem. Influential papers that were written recently may be too new to have accu-

[13] An interesting note for scholars who use citation measures is that this refinement process effected approximately 5% of the identified publications.

mulated twenty or more citations. However, it is conceivable that recognition for their recent work might increase interest in licensing their inventions. Despite these problems, the measure does seem to offer a crude approximation of publication output and identifies very prolific scholars in the same manner as Zucker and Darby's dichotomous star measure.

Industry Funding

INDUSTRY FUNDING is a measure of the inventor's general 'closeness' to industry. The motivation for this control is predicated on the assumption that the more involved a professor is with industry in general, the greater the fraction of his/her funding that will be from industry. At the same time, the more involved a professor is with industry, the more likely it will be that his/her inventions will be 'industry ready', or more easily commercialized. INDUSTRY FUNDING is a measure of the average percentage of a professor's funding that came from industry during the year the invention was licensed. Funding from the military is not included in industry funding. It is conceivable that professors that maintain a greater closeness to industry have greater exposure to industry relevant research questions and therefore generate inventions that are more amenable to commercialization. There is a potential for a high margin of error in the accuracy of this measure, especially for older inventions, since it relied on professor's memory of their funding sources at the time.

EECS

EECS is a binary variable that indicates whether the inventor was appointed to the Department of Electrical Engineering and Computer Science (EECS) or Mechanical Engineering. This control variable was included to capture systematic differences that may exist between inventors from these two departments in terms of either technology areas or cultures that are relevant to commercialization.

Firm-Related Control Variables

Four firm-related control variables are included in the model: Publications, Start-up, Public, and Size. These are described below.

Publications

PUBLICATIONS is a measure of the absorptive capacity of the importing firm. Cohen and Levinthal (1989, 1990) amongst others have developed this concept which refers to the ability of firms to utilize knowledge spillovers as a function of their internal R&D capital. It is measured by counting the number of publications by scientists at the firm during a five year window, beginning at the activation date of the license agreement. Since there is generally a lag of one to three years between the time of the work and publication, this window generally represents research that was performed by the firm during a few years before and a few years after the activation date. There are several problems with this measure. First, some firms do research but don't publish. It is not clear how this would effect their absorptive capacity. Some scholars suggest that participating in the scientific community by way of publishing is necessary in order to develop absorptive capacity. Also, Lim (1999) discusses issues concerning the composition of R&D. Namely, he creates a typology that distinguishes between basic research, applied research, and development. Careful measures, such as those that he creates, differentiate between publications in applied and basic science journals. The measure used here is relatively crude and only provides a general indication of whether the importing firm was participating in the publishing community at the time it licensed the invention. A lack of publications may indicate that either the firm was not doing research, or that although the firm was doing research, it was not publishing. The measure doesn't distinguish across the type or quality of publication. Finally, it also does not differentiate across the area of publication. Therefore this measure does not distinguish between publications by small, single product firms that publish only in areas that are relevant to the licensed invention, and publications by large firms who publish in areas that are less relevant or not relevant at all. Therefore, this measure is simply used as a general indication of overall research culture at the firm.

Start-up

START-UP is a binary variable that indicates whether the importing firm was a start-up company, founded on the basis of the licensed technology. This information and classification was collected from the MIT Technology Licensing Office records. This control is motivated by the belief that the successful development of an imported idea might be more important to a start-up since it is more important, relatively, to the company's overall business. At the same time, established firms may be better equipped, in terms of experience and resources, to develop inventions.

The primary problem associated with this measure concerns the classification of firms. Start-ups are defined as firms founded on the basis of the licensed technology. Therefore classification requires determining whether the licensed technology was actually the basis of the new firm. There is a tendency to classify firms that are founded at approximately the same time that the technology was licensed as start-ups. It is likely that the data, which was collected from TLO records, is biased in this direction. However, it is not obvious that this bias will influence this experiment.

Public

PUBLIC is a binary variable that indicates whether the importing firm was a publicly traded company at the time the license agreement was activated.

Size

SIZE is a measure of the size of the importing firm. It is measured in terms of the number of employees at the time the license agreement was activated. This data was collected from a number of sources (see Section 4.7 on 'Data Sources'). Size measures for small private firms suffer from a greater degree of inaccuracy than their larger, especially publicly traded, counterparts since this information was often not publicly recorded.

Geographic Region-Related Control Variables

Three geographic region-related control variables are included in the model: Route128, Silicon Valley, and USA. *Route128* is a binary variable and indicates if the firm was located in Massachusetts. All Massachusetts firms were located within 50 miles from MIT. *Silicon Valley* is also a binary variable and indicates if the firm was located in California. Although the majority of firms in California were located in the Bay area, some were located further south, near Los Angeles. These firms were also included in this measure. Finally, *USA* is a binary variable that indicates whether the firm was located in the United States.

2.4.6 Sample

The sample used for this experiment was drawn from license agreements based on inventions developed by MIT faculty who were appointed to the departments of Mechanical Engineering or Electrical Engineering and Computer Science during the 1998-99 academic year. It was necessary to select inventions by current faculty so that the inventors could be interviewed to collect interaction information that was critical to this study. There were 438 such agreements. Next, agreements that were activated before 1983 or after 1994 were removed from the sample. The former limitation was introduced because publication citation data was only available after 1982. The latter limitation was applied for two reasons. First, to allow time for inventions to be commercialized. [14] Second, the quality measure utilized five years of forward patent citations. These restrictions reduced the number of observations to 187. Finally, the author was able to arrange interviews with faculty inventors for inventions associated with 124 licensing agreements. These agreements form the basis of the sample.

2.4.7 Data Sources

Data was drawn from five sources for this experiment. Royalty, license agreement, invention, firm, and sponsorship data were collected from the MIT Technology Licensing Office. Publication citation information was collected from the Institute of Scientific Information's Science Citation Index. Patent citation information was collected from the USPTO and IBM patent web sites. Firm size and status was collected from Standard & Poor's Corporate Registry, Lexis Nexis, various directories of private firms, and interviews where necessary. Finally, information about the inventor and the inventor-licensee relationship such as funding and degree of direct interaction was collected through interviews with MIT faculty.

2.5 Empirical Analyses

2.5.1 Summary Statistics

Table II provides an overview of the measures used in the analyses. Of the 124 license agreements included in the sample, only 58 (47%) were commercialized. In other words, 66 license agreements did not successfully commercialize a product. [15] While the mean value of royalties per year was approximately

[14] This restriction allowed for a minimum of five years to commercialize.

[15] Although all of these license agreements were at least five years old, it is possible that some of these agreements may yet commercialize a product.

$63,000, 19 (15%) generated less than $10,000 and an additional 20 generated less than $50,000. Nineteen license agreements generated more than $50,000 per year and of those two generated more than $1 million per year. *Figure 2.2* illustrates the distribution of royalties per year.

While the average amount of interaction firms had with researchers from the inventor's lab was approximately 760 hours, firms had no interaction in 46 (37%) cases. Thirty-three (27%) engaged in less than three person months of interaction (480 hours). An additional 20 engaged in less than six person months (1000 hours) and 16 (13%) engaged in less than one year (2000 hours). In nine cases (7%), the importing firm engaged in more than one person year of interaction. *Figure 2.3* illustrates the distribution of interaction hours.

In addition, importing firms recruited at least one researcher from the inventor's lab in 40 (32%) cases. Specifically, one person was recruited in 24 (19%) cases, two people in 10 (8%) cases, and three people in 6 (5%) cases. In other words, firms did not recruit any researchers from the inventor's lab in 84 (68%) cases.

Distance was measured in miles between the importing firm and MIT. While the average distance was approximately 1,500 miles, just over half the width of the continent, over 50% of the license agreements were made with firms in the New England area including 46 (37%) that were licensed to firms in Massachusetts, within 50 miles from MIT. Twenty-four (19%) were made with firms in California, and 18 (15%) were made with firms elsewhere in the United States. In other words, 89 (83%) of the US license agreements were made with firms located in either New England or California. In addition, 17 (14%) inventions were licensed to foreign firms in countries including Japan, Germany, France and Israel. *Figures 2.4 and 2.5* illustrate the distribution of distances.

Inventions included in the sample had an average quality of approximately 6.8 (patent citations in 5 years). Thirty-two (26%) had no citations and an additional 38 (31%) had less than 5 citations. Twenty-four (19%) had between 5 and 10 citations, 22 (18%) had between 10 and 20, and 8 (6%) had more than 20. *Figure 2.6* illustrates the distribution of quality.

2.5.2 Regression Analyses

This section turns to the evaluation of the principal hypotheses of this paper. Regression results are reported in a series of tables from V through XIV. *Tables V-VII* contain the results from testing the invention performance equation, with no controls. *Tables VIII-IX* introduce invention-related controls including quality, age, sponsor, and software. *Tables X-XI* introduce inventor-related controls including star20, industry funding, and EECS, as well as firm-related controls including publications, start-up, public, and size. Finally, *Tables XII-XIV* introduce geographic region-related controls including Route128, Silicon Valley, and USA.

These tables contain logit, tobit, and OLS specifications. Tobit specifications were employed where royalties per year was used as the dependent variable because this measure was bounded below zero. This correction, however, did not change the sign or significance of the results, relative to OLS. The values reported from the logit regression represent 'odds ratios', which are the amounts by which the odds favoring $Y = 1$ (that the invention is commercialized) are multiplied per 1-unit increase in the particular X variable, assuming the other X variables remain constant. In other words, logit results refer to the effects of explanatory variables on the *likelihood* of commercialization while tobit and OLS results refer to the effects of explanatory variables on the *magnitude* of economic performance (royalties per year).

Effects on the Likelihood of Commercial Success

As *Equation VIII-2* reports (Table VIII), interaction has a positive, systematic effect on the likelihood of commercialization. Thus, the null hypothesis associated with Hypothesis 1A is rejected. Specifically, the coefficient on interaction, 1.25, indicates that the marginal effect of a one unit increase in interaction (100 hours, or 2.5 weeks) results in a 25% increase in the odds of commercialization. In other words, the odds of commercialization are multiplied by 1.25, resulting in an increase from 1.47 to 1.84.

The same table also reports that recruit has a reasonably robust, positive effect on the likelihood of commercialization (*Equation VIII-3*). Specifically, the coefficient on recruit, 3.32, indicates that the marginal effect of a one unit increase in recruit (an additional person recruited from the inventor's lab) results in a 232% increase in the odds of commercialization. In other words, the odds of commercialization are multiplied by 3.32, resulting in an increase from 0.91 to 3.02.

As *equation VIII-4* reports, distance has a negative effect on the likelihood of commercialization. This result supports Hypothesis 2A. The marginal effect of a unit increase in the logarithm of distance multiplies the odds of commercialization by approximately 0.88 or, in other words, an increase in distance of 360 miles at the mean (from 210 to 570 miles) decreases the odds by 12% from 0.88 to 0.77. As *equations VIII-5 and VIII-6* report, this negative effect disappears after controlling for interaction. This result supports Hypothesis 3A.

It is important to note that all three hypotheses concerning the likelihood of commercialization (Hypotheses 1A, 2A, and 3A) are supported by the results reported in Table VIII. However, the equations in Table VIII only include invention-related controls. As additional controls are added for inventor, firm, and region characteristics, only the interaction result appears robust. For example, *Equation X-5* indicates that the negative distance effect is statistically insignificant when inventor and firm controls are introduced, even before controlling for interaction. In other words, these results suggest strong support for Hypothesis 1A, but less so for 2A and 3A.

It is also interesting to note that the distance effect becomes significantly stronger (negative) when geographic region-related controls are included (Table XII). This is a result of the 'Silicon Valley' effect which is 2,500 miles from MIT and has positive effects on the likelihood of commercialization. In addition, it is interesting that certain control variables, namely quality, industry funding, and EECS, have robust, systematic effects on commercialize. The marginal effect of a unit increase in the logarithm of quality increases the odds by 103% (*Equation VIII-6*). This result also remains reasonably robust as various additional controls are introduced. Also, each point increase in the percentage of a professor's funding that came from industry increases the odds of commercialization by approximately 29% and if the professor was appointed to EECS, rather than Mechanical Engineering, the odds of commercialization are decreased by 69%.

Most of the other control variables, although not statistically significant, seem to operate in the direction expected (*Equation XII-7*). Age, sponsor, publications, Star20, Silicon Valley, and USA all have positive coefficients. Software also has a positive coefficient, although the author had no priors concerning this variable. Start-up has a consistently negative coefficient, which is somewhat surprising.

Effects on the Magnitude of Commercial Success

As *Equation IX-2*reports (Table IX), interaction has a positive, systematic effect on the degree of commercial success. Thus, the null hypothesis associated with hypothesis 1B is rejected. This model estimates an interaction coefficient of 0.427 which implies an elasticity at the mean equal to $(0.427) * (7.63) = 3.26$ For example, if the amount of interaction is increased by 10% (i.e. from 763 to $763+76 = 839 hours$) the royalties per year would be estimated to increase by 33% from $63,000 to $84,000. This result persists as controls are added and the lowest marginal effect of interaction at the mean, when all controls are included (*Equation XIII-7*), is $(0.35) * (7.73) = 2.71$. The same tables also report that recruit has a reasonably robust, positive effect on the magnitude of commercialization. *Equation IX-3* estimates a recruit coefficient of 3.77 which implies an elasticity at the mean equal to $(3.77) * (0.51) = 1.92$

As *Equation IX-4* reports, the logarithm of distance has a negative effect on the magnitude of economic performance, with an elasticity of -0.6033. However, when interaction and recruit are introduced (*Equation IX-5 and IX-6*), the coefficient becomes insignificant and is also reduced by a factor of two and three, respectively. These results support hypotheses 2B and 3B. Once again, however, the results pertaining to distance are not robust to inventor, firm, and region controls. When these additional controls are included in the model, the distance effect becomes statistically insignificant, even before controlling for interaction.

It is also interesting to note that quality has a robust relationship with commercialize. The elasticity, 2.00, is consistently statistically significant (*Equation IX-6*).

2.6 Conclusions

Conclusions drawn from this type of empirical research must be regarded with great caution. Studies of this nature are fraught with potential hazards, including conceptual errors (is one measuring what one thinks s/he is measuring?), accuracy errors (measurement accuracy), and causality misinterpretations. With these caveats in mind, interpretations of the results from this experiment are discussed.

First, direct scientific interaction seems to be very important. Regression results indicate that interaction has a positive effect on the commercial success of imported inventions that is both statistically significant and economically important. Why is direct interaction important? The study of a robotics invention included in the following chapter illustrates a set of specific reasons why interaction was important in one particular case. The most obvious *general* explanation is that interaction is required to transfer tacit knowledge, or 'know-how', from the inventor to the importing firm. This is important if tacit knowledge transfer is critical to the successful commercialization of imported inventions. As discussed in the introduction, there is some ambiguity in the literature concerning the definition of tacit knowledge, whether it refers to knowledge that is *not able* to be codified, or is *not normally* codified. The measure of interaction used in this study would seem to capture either type of knowledge transferred. However, interaction may also capture other effects, in addition to tacit knowledge transfer. For example, it may capture a 'championing' effect where the researcher from the inventor's lab promotes the development of the invention within the firm. This may be especially true in cases where researchers from the inventor's lab have been recruited by the firm.

There is also room for serious causality misinterpretations. The most obvious is that researchers from the inventor's lab may be more likely to interact with the importing firm if they suspect the invention is of higher quality and thus has a greater probability of commercial success. In other words, an alternative hypothesis is that professors and graduate students are able to 'pick winners'. It is certainly plausible that inventors enjoy a significant information asymmetry relative to licensee's concerning the quality of the invention.

However, the author strongly believes in the causality direction implied in this paper. This is for several reasons: i) The interaction hours and recruiting measures that are used in this study are limited to the time *before* the invention is first commercialized. This eliminates any 'herding' effect that may occur if faculty and graduate students are drawn to a project after the invention has already become a commercial success. ii) Each invention has passed through several 'screens' before it is licensed. In order for an invention to be included in this sample, it must be licensed. Thus, to reach this stage, the invention has to have been considered commercially viable by the inventor, the licensing officer, and the licensing firm. This eliminates any inventions that do not have a reasonably obvious market application. iii) The inventions are developed by different inventors. If all the inventions in the sample were generated by one inventor, it might be plausible that the single inventor would survey his or her portfolio of inventions and decide to interact with firms for those that were most likely to succeed. However, this is not the case. There are many different inventors associated with the inventions in this sample and so the decision or opportunity to interact is not a function of other people's inventions. iv) The model specification includes a control for the 'quality' of the invention as indicated by patent citations during the first five years. v) Finally, interviews associated with each invention revealed that in most cases inventors did not feel they could 'pick winners'. So, while causality-related concerns remain, the author's intuition is to favor the interpretation suggested herein.

The second and third hypotheses, considered together, suggest that while the geographic distance between the inventor's lab and the importing firm has a negative effect on the likelihood and degree of commercial success, this effect disappears after controlling for direct interaction. How could this be? Two related interpretations of this result concern transaction costs and market failures. In terms of transaction costs, if the license to use the invention is considered the 'good' being traded, interaction for the purpose of transferring know-how may be considered a component of the associated transaction costs. These costs may increase with distance. For example, if interaction requires collaboration at the same facility, travel costs will be included in the transaction costs. On a related note, the higher these costs, the higher will be the threshold above which engineers from either organization will consider a face-to-face meeting worthwhile. Therefore informal, impromptu meetings will be less likely. These types of meetings, in aggregate, may be critical to the overall development of the invention. In terms of market failures, imperfections in the market for tacit knowledge may be sensitive to distance. This could result from a small numbers problem in terms of the number of scientists that are available from the inventor's lab. Firms that are further away from the inventor's lab may find it more difficult to contract for interaction because the few scientists who are able to supply this 'service' are adverse to travel in a way that is disproportionate to the cost associated with travel. Researchers from the inventor's lab may not be willing to supply interaction services that will require travel exceeding particular distances.

It is also worthwhile to draw attention to the variable used in this experiment to control for invention quality which was constructed from forward citation measures and maintains a robust, positive relationship with the economic performance of the invention. This result may be of some interest to scholars who utilize bibliometric measures since, to the author's knowledge, this is the first construction of such a measure that finds a systematic relationship between citations and economic performance. This result is a useful contribution to the literature since many studies use citation measures, but do not have access to the corresponding economic data. These studies often refer to citation measures as measures of impact, leaving the economic interpretation of 'impact' somewhat vague. Therefore, the results presented here suggest a direct correlation between impact and economic performance. At the same time, however, these results must be interpreted carefully since the sample in this study was drawn from a set of *licensed* inventions, rather than just patented inventions.

It is important to note two additional caveats. The first addresses the concern that the results presented here may be an artifact of university inventions, rather than inventions in general. For example, university inventions may be more 'basic' on average than industry patents (Trajtenberg, Henderson & Jaffe, 1992) and it is likely that tacit knowledge transfer is more important for inventions that are more basic. In addition, there may be a weaker negative distance effect in the case where inventions are imported from firms since these organizations are guided by profit-seeking incentives and thus may be more amenable than universities to contracting for interaction. These are valid concerns and any generalization of the results presented here to firm-to-firm invention mobility should be treated with caution.

The second caveat concerns cross-discipline generalizability. The data for this experiment were collected from electrical engineering, computer science, and mechanical engineering exclusively. It is likely that interaction may be less important in other fields, such as biotechnology, where the majority of information required for utilizing the invention is codified. Thus, caution should be exercised in extending the results reported here to other technological areas. In fact, the variation in the importance of interaction across technical areas offers an interesting direction for future research.

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Table I - Variables[1] & Definitions

Variable	Definition	Source
Dependent Variables		
Commerc-ialize (binary)	Binary variable indicating whether a product employing the licensed invention as developed and sold (Royalties>0)	TLO financial records
Royalties/year (1999 dollars)	Revenues from royalties collected from licensee (present values)	TLO financial records
Key Explanatory Variables		
Interact (hours, 00's)	Number of hours researchers (faculty, graduate students, research scientists) from the inventor's lab collaborated with scientists from the importing firm	MIT faculty interviews
Recruit (people)	Number of researchers from the inventor's lab that were recruited to work full time for the importing firm	MIT faculty interviews
Distance from MIT (miles)	Number of miles from MIT, measured between zip code centers (by geographic coordinates for internatnl licensees)	MIT TLO licensee records/ESRI Dbase
Invention-Related Control Variables		
Quality (patent citatns)	Number of forward patent citations (measured 5 years from date of issue of original MIT patent to filing date of citing patent)	USPTO database, IBM patent website
Age (years)	Number of years since license agreement (measured to September 1999)	MIT TLO agreement records
Sponsor (binary)	Binary variable indicating whether the research leading to the licensed invention was sponsored by the importing firm	MIT TLO licensee files
Software (binary)	Binary variable indicating whether the invention is software	MIT TLO agreement records
Inventor-Related Control Variables		
Star20 (publications)	Number of publications by the lead inventor with 20 or more citations	Science Citation Index
Industry Funding (percentage)	Average percentage of funding received by the inventor from the private sector during the five years prior to the activation of the licensing agreement.	MIT faculty interviews
EECS (binary)	Binary variable indicating if the key inventor is appointed to EECS (else Mech Eng.)	MIT faculty appointment records
Importing Firm-Related Control Variables		
Publications (publications)	Number of publications generated by the licensee during the 5 year period following the date of the license agrmnt.	Science Citation Index
Start-up (binary)	Binary variable indicating if the importing firm was founded on the basis of the licensed technology	MIT TLO licensee files
Public (binary)	Binary variable indicating if the importing firm was publicly traded when the licensing agreement was activated	Standard & Poors Corporate Registery
Size (employees)	Number of employees at time of license agreement	S&P's Corp Reg., Lex/Nex, interviews
Region-Related Control Variables		
Route128 (binary)	Binary variable indicating if importing firm is located in Massachusetts	MIT TLO licensee files
SiliconValley (binary)	Binary variable indicating if importing firm is located in California	MIT TLO licensee files
USA (binary)	Binary variable indicating if importing firm is located in the United States	MIT TLO licensee files

[1] The natural logarithm of a variable, X, will be denoted LN X.

Table II
Means & Standard Deviations
(N = 124)

Variable	Mean	Std Dev	Min	Max
Dependent Variables				
Commercialize (binary)	0.4677	0.5010	0	1
Royalties/year (1999 dollars)	63,150	289,360	0	2.7m
Key Explanatory Variables				
Interact (hours, 00's)	7.63	11.10	0	40.00
Recruit (people)	0.51	0.86	0	3
Distance from MIT (miles)	1516	2013	0	6,824
Invention-Related Control Variables				
Quality (patent citations)	6.83	7.41	0	37
Age (years)	9.55	3.56	5	16
Sponsor (binary)	0.145	0.354	0	1
Software (binary)	0.169	0.377	0	1
Inventor-Related Control Variables				
Star20 (publications)	10.1	5.8	0	24
Industry Funding (percentage)	32.5	23. 8	0	100
EECS (binary)	0.645	0.480	0	1
Firm-Related Control Variables				
Publications (in Science Citation Index)	259	1117	0	7,587
Start-up (binary)	0.306	0.463	0	1
Public (binary)	0.194	0.397	0	1
Size (employees)	18120	61530	1	396k
Region-Related Control Variables				
Route128 (binary)	0.371	0.485	0	1
Silicon Valley (binary)	0.194	0.397	0	1
USA (binary)	0.863	0.345	0	1

Table III
Cross-Tabulation: Commercialize Against Interaction

	Interaction			
Commerc-ialize	**0 hrs**	**0<X<1,000 hrs**	**X > 1,000 hrs**	**Total**
0	40	19	7	**66**
1	6	16	36	**58**
Total	**46**	**35**	**43**	**124**

Table IV
Geography: Location of Importing Firms

Distance, D, from MIT (miles)	**States/Countries**	**Number of Invention Licenses**
D < 50	MA	46 (37%)
50< D < 400	NH, NJ, NY, DE, ME, PA, VA	19 (15%)
400 < D < 1500	OH, IL, MO, MN, NC, IN	10 (8%)
1500 < D < 2500	NM, TX, WA, CO	8 (6%)
2500 < D < 3000	CA	24 (19%)
D > 3000	Japan, Germany, France, Israel	17 (14%)
	TOTAL	**124**

Table V
Invention Performance Equation
(No Controls)
[Logistic: Odds Ratio]

	Dependent Variable = Commercialize N = 124 observations				
	(V-1) Interact only	**(V-2)** Recruit only	**(V-3)** Distance only	**(V-4)** Interact and Distance	**(V-5)** Combination model
Interaction & geography					
Interact	1.262*** (0.0606)			1.260*** (0.0605)	1.241*** (0.0586)
Recruit		2.487*** (0.6771)			1.824* (0.5988)
LN Distance			0.9119 (0.0610)	0.9304 (0.0797)	0.9733 (0.0883)
Chi2(4)	56.39	14.58	1.92	57.10	60.78
Prob > Chi2	0.000	0.0001	0.1658	0.000	0.000
Pseudo R2	0.3290	0.0851	0.0112	0.3332	0.3546

*significant at the 0.1 level, ** 0.05, ***0.01

Table VI
Invention Performance Equation
(No Controls)
[Tobit]

	Dependent Variable = LN Royalties/Year N = 124 observations (66 left-censored observations)				
	(VI-1) Interact only	**(VI-2)** Recruit only	**(VI-3)** Distance only	**(VI-4)** Interact and Distance	**(VI-5)** Combination model
Interaction & geography					
Interact	0.4835*** (0.0676)			0.4785*** (0.0674)	0.4293*** (0.0666)
Recruit		4.096*** (1.028)			2.024** (0.8497)
LN Distance			-0.4796 (0.3663)	-0.2677 (0.2765)	-0.1080 (0.2745)
Constant	-2.370** (1.153)	-1.249 (1.269)	3.212 (2.180)	-0.9061 (1.837)	-2.334 (1.925)
Chi2	49.29	15.86	1.72	50.23	55.82
Prob > Chi2	0.0000	0.0001	0.1892	0.0000	0.000
Pseudo R2	0.0936	0.0301	0.0033	0.0953	0.1060

* significant at the 0.1 level, ** 0.05, ***0.01

Table VII
Invention Performance Equation
(No Controls)
[OLS]

	Dependent Variable = LN Royalties/Year N = 124 observations				
	(VII-1) Interact only	**(VII-2)** Recruit only	**(VII-3)** Distance only	**(VII-4)** Interact and Distance	**(VII-5)** Combination model
Interaction & geography					
Interact	0.3093*** (0.0323)			0.3070*** (0.0325)	0.2786*** (0.0330)
Recruit		2.387*** (0.5068)			1.264*** (0.4394)
LN Distance			-0.2138 (0.1726)	-0.1152 (0.1319)	-0.0208 (0.1322)
Constant	2.427*** (0.434)	3.572*** (0.5047)	5.927*** (1.035)	3.059*** (0.8444)	2.129** (0.8816)
R-Squared	0.4284	0.1538	0.0124	0.4320	0.4687
Adj R-Sqr	0.4238	0.1469	0.0043	0.4226	0.4554

*significant at the 0.1 level, ** 0.05, ***0.01

Table VIII
Invention Performance Equation
(Invention-Related Controls)
[Logistic]

	Dependent Variable = Commercialize N = 124 observations					
	(VIII-1) Invention -Related Controls	**(VIII-2)** (VIII-1) with Interact	**(VIII-3)** (VIII-1) with Recruit	**(VIII-4)** (VIII-1) with Distance	**(VIII-5)** (VIII-1) w Interact and Distance	**(VIII-6)** (VIII-1) w Interact, Recruit, Distance
Interaction & geography						
Interact		1.251*** (0.0617)			1.228*** (0.0614)	1.222*** (0.0588)
Recruit			3.318*** (1.167)			2.132** (0.8134)
LN Distance				0.8795* (0.0645)	0.9117 (0.0811)	0.9712 (0.0933)
Invention-Related Controls						
LN Quality	2.518*** (0.6826)	1.741 (0.6171)	3.022*** (0.9345)	2.616*** (0.7187)	1.789* (0.6437)	2.032* (0.7811)
Age	1.025 (0.0605)	1.045 (0.0806)	1.055 (0.0689)	1.035 (0.0623)	1.052 (0.0816)	1.053 (0.0836)
Sponsor	1.465 (0.8205)	2.005 (1.302)	1.547 (0.9139)	1.429 (0.8129)	1.899 (1.230)	2.046 (1.342)
Software	2.896 (2.244)	1.779 (1.641)	3.542 (2.965)	2.778 (2.161)	1.660 (1.544)	2.218 (2.176)
Chi2(4)	16.77	60.76	33.88	19.91	61.84	66.59
Prob > Chi2	0.0021	0.000	0.000	0.0013	0.000	0.000
Pseudo R2	0.0978	0.3545	0.1977	0.1162	0.3609	0.3885

*significant at the 0.1 level, ** 0.05, ***0.01

Table IX
Invention Performance Equation
(Invention-Related Controls)
[Tobit]

	Dependent Variable = LN Royalties/Year N = 124 observations (66 left-censored observations)					
	(IX-1) Invention -Related Controls	**(IX-2)** (IX-1) with Interact	**(IX-3)** (IX-1) with Recruit	**(IX-4)** (IX-1) with Distance	**(IX-5)** (IX-1) w Interact and Distance	**(IX-6)** (IX-1) w Interact, Recruit, Distance
Interaction & geography						
Interact		0.427*** (0.0713)			0.4162*** (0.0710)	0.3616*** (0.0702)
Recruit			3.774*** (0.9373)			2.114** (0.8317)
LN Distance				-0.6033* (0.3382)	-0.3445 (0.2756)	-0.1792 0.2714)
Invention-Related Controls						
LN Quality	4.701*** (1.219)	1.723* (1.022)	4.374*** (1.111)	4.813*** (1.213)	1.858* (1.026)	1.982** (0.9919)
Age	0.0585 (0.2746)	0.0322 (0.2213)	0.1085 (0.2501)	0.1019 (0.2721)	0.0577 (0.2209)	0.0784 (0.2126)
Sponsor	1.969 (2.577)	1.972 (2.076)	2.047 (2.334)	1.970 (2.536)	1.987 (2.059)	2.022 (1.976)
Software	5.389 (3.697)	2.173 (2.956)	5.299 (3.365)	5.151 (3.649)	2.105 (2.940)	2.481 (2.833)
Constant	-8.395** (3.765)	-5.592* (2.995)	-10.05*** (3.543)	-5.738 (3.928)	-4.125 (3.162)	-6.038* (3.194)
Chi2	19.00	53.38	35.21	22.21	54.93	61.32
Prob > Chi2	0.0008	0.000	0.0000	0.0005	0.000	0.000
Pseudo R2	0.0361	0.1013	0.0668	0.0422	0.1043	0.1164

* significant at the 0.1 level, ** 0.05, ***0.01

Table X
Invention Performance Equation
(Inventor and Importing Firm-Related Controls)
[Logistic]

	Dependent Variable = Commercialize N = 124 observations						
	(X-1) Inventor Controls	**(X-2)** Inventor and Firm Controls	**(X-3)** Controls with Interact	**(X-4)** Controls with Recruit	**(X-5)** Controls with LN Distance	**(X-6)** Controls w Interact and LN Distance	**(X-7)** Controls w Interact Recruit LN Dist
Interaction & Geography							
Interact			1.259*** (0.0743)			1.271*** (0.0774)	1.26*** (0.0758)
Recruit				2.514** (1.128)			2.204 (1.139)
LN Distance					0.9897 (0.0998)	0.8827 (0.1159)	0.8782 (0.1174)
Invention-Related Controls							
LN Quality	3.324*** (1.092)	3.341*** (1.113)	2.806** (1.333)	3.643*** (1.273)	3.343*** (1.113)	2.855** (1.373)	2.956** (1.475)
Age	1.083 (0.0740)	1.073 (0.0773)	1.143 (0.1050)	1.109 (0.0849)	1.074 (0.0777)	1.158 (0.1082)	1.178* (0.1138)
Sponsor	1.860 (1.141)	2.427 (1.567)	2.769 (2.011)	2.435 (1.628)	2.419 (1.565)	2.615 (1.904)	2.307 (1.710)
Software	9.871** (9.309)	8.838** (8.597)	8.613* (10.22)	9.445** (9.294)	8.839** (8.606)	8.727* (10.52)	9.499* (11.71)
Inventor-Related Controls							
Star20	1.013 (0.0394)	1.016 (0.0414)	1.014 (0.0476)	1.031 (0.0438)	1.016 (0.0414)	1.010 (0.0478)	1.023 (0.0498)
Industry Funding	1.036*** (0.010)	1.034*** (0.0108)	1.040*** (0.014)	1.031*** (0.0112)	1.034*** (0.0108)	1.042*** (0.0146)	1.040*** (0.0150)
EECS	0.138*** (0.0770)	0.162*** (0.0945)	0.114*** (0.0840)	0.183*** (0.1099)	0.163*** (0.0972)	0.122*** (0.0914)	0.140** (0.1088)
Firm-Related Controls							
LN Pubs		1.0436 (0.1088)	1.116 (0.1395)	1.089 (0.1173)	1.045 (0.1103)	1.144 (0.1476)	1.186 (0.1578)
Start-up		2.738* (1.501)	0.9218 (0.6834)	1.4655 (0.9196)	2.655 (1.658)	0.5869 (0.5190)	0.2787 (0.2935)
Public		1.284 (0.7937)	0.8828 (0.6680)	1.031 (0.6615)	1.289 (0.7974)	0.8612 (0.6565)	0.6181 (0.5075)
Chi2	40.87	44.40	78.55	49.37	44.41	79.47	82.06
Prob > Chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo R2	0.2384	0.2591	0.4583	0.2881	0.2591	0.4637	0.4788

*significant at the 0.1 level, ** 0.05, ***0.01

Table XI
Invention Performance Equation
(Inventor and Importing Firm-Related Controls)
[Tobit]

	Dependent Variable = LN Royalties/Year N = 124 observations (66 left-censored observations)						
	(XI-1) Inventor Controls	**(XI-2)** Inventor and Firm Controls	**(XI-3)** Controls with Interact	**(XI-4)** Controls with Recruit	**(XI-5)** Controls with LN Distance	**(XI-6)** Controls Interact and LN Distance	**(XI-7)** Controls Interact Recruit LN Dist
Interaction & Geography							
Interact			0.361*** (0.0685)			0.364*** (0.0687)	0.35*** (0.0678)
Recruit				1.926* (1.101)			1.457 (0.9415)
LN Distance					-0.0346 (0.3685)	-0.1692 (0.3137)	-0.2211 (0.3110)
Invention-Related Controls							
LN Quality	4.716*** (1.136)	4.505*** (1.106)	2.110** (0.9815)	4.406*** (1.088)	4.515*** (1.112)	2.141** (0.9873)	2.136** (0.9757)
Age	0.2502 (0.2545)	0.1951 (0.2530)	0.1901 (0.2127)	0.2185 (0.2481)	0.1987 (0.2559)	0.2076 (0.2152)	0.2309 (0.2124)
Sponsor	2.663 (2.319)	3.516 (2.313)	2.787 (1.947)	3.213 (2.268)	3.512 (2.314)	2.771 (1.944)	2.551 (1.915)
Software	8.554** (3.488)	7.571** (3.411)	5.003* (2.866)	7.554** (3.350)	7.572** (3.414)	4.992* (2.877)	5.029* (2.841)
Inventor-Related Controls							
Star20	0.0680 (0.1461)	0.0672 (0.1430)	0.0638 (0.1203)	0.0929 (0.1410)	0.0665 (0.1433)	0.0608 (0.1205)	0.0800 (0.1194)
Industry Funding	0.132*** (0.0368)	0.125*** (0.0358)	0.102*** (0.0302)	0.109*** (0.0359)	0.125*** (0.0358)	0.101*** (0.0301)	0.09*** (0.0304)
EECS	-7.05*** (1.899)	-6.06*** (1.926)	-5.31*** (1.626)	-5.20*** (1.932)	-6.04*** (1.945)	-5.18*** (1.642)	-4.51*** (1.659)
Importing Firm-Related Controls							
LN Pubs		0.0973 (0.4034)	0.2344 (0.3414)	0.2095 (0.4009)	0.1031 (0.4082)	0.2642 (0.3463)	0.3552 (0.3469)
Start-up		4.299** (1.925)	0.8347 (1.718)	2.318 (2.180)	4.207* (2.158)	0.3524 (1.938)	-1.198 (2.162)
Public		1.730 (2.343)	-0.0302 (1.995)	1.052 (2.330)	1.745 (2.350)	0.0324 (1.998)	-0.4095 (1.991)
Constant	-11.2*** (3.882)	-12.5*** (4.058)	-8.87** (3.376)	-13.1*** (4.035)	-12.3*** (4.325)	-8.158** (3.602)	-8.498** (3.571)
Chi2(4)	42.14	47.10	73.48	50.13	47.11	73.78	76.16
Prob > Chi2	0.0000	0.0000	0.000	0.000	0.0000	0.0000	0.0000
Pseudo R2	0.0800	0.0894	0.1395	0.0952	0.0894	0.1400	0.1446

*significant at the 0.1 level, ** 0.05, ***0.01

Table XII
Invention Performance Equation
(Geographic Region-Related Controls)
[Logistic]

	Dependent Variable = Commercialize N = 124 observations						
	(XII-1) Base Model	(XII-2) Base Model w Route128, SiliconV, w/o Dist	(XII-3) Base Model w Route128, SiliconV	(XII-4) Base Model w USA, w/o Distance	(XII-5) Base Model with USA	(XII-6) Base Model with all controls, remove Distance	(XII-7) Base Model with all controls
Interaction & Geography							
Interact	1.263*** (0.0758)	1.268*** (0.0782)	1.276*** (0.0796)	1.274*** (0.0794)	1.275*** (0.0795)	1.278*** (0.0808)	1.277*** (0.0804)
Recruit	2.204 (1.139)	1.992 (1.035)	2.006 (1.063)	2.159 (1.127)	2.167 (1.129)	2.024 (1.062)	2.011 (1.066)
LN Distance	0.8783 (0.1174)		0.7316 (0.1940)		0.9479 (0.1439)		0.7592 (0.2778)
Invention-Related Controls							
LN Quality	2.956** (1.476)	3.082** (1.573)	3.015** (1.534)	2.733** (1.364)	2.766** (1.389)	2.865** (1.468)	2.979** (1.534)
Age	1.178* (0.1139)	1.191* (0.1186)	1.190* (0.1181)	1.157 (0.1119)	1.163 (0.1142)	1.175* (0.1181)	1.187* (0.1199)
Sponsor	2.308 (1.711)	2.848 (2.206)	2.613 (2.013)	2.190 (1.625)	2.168 (1.607)	2.491 (1.933)	2.565 (1.998)
Software	9.499* (11.719)	10.621* (13.186)	9.914* (12.304)	9.359* (11.452)	9.373* (11.543)	10.068* (12.485)	9.888* (12.271)
Inventor-Related Controls							
Star20	1.024 (0.0499)	1.035 (0.0520)	1.045 (0.0535)	1.029 (0.0502)	1.027 (0.0503)	1.034 (0.0521)	1.044 (0.0543)
Industry Funding	1.041*** (0.0150)	1.040*** (0.0147)	1.043*** (0.0153)	1.042*** (0.0151)	1.042*** (0.0152)	1.041*** (0.0151)	1.043*** (0.0154)
EECS	0.1403** (0.1088)	0.1179*** (0.0952)	0.1137*** (0.0932)	0.1283*** (0.0996)	0.1329** (0.1042)	0.1205*** (0.0974)	0.115*** (0.0943)
Importing Firm-Related Controls							
LN Pubs	1.186 (0.1578)	1.204 (0.1643)	1.221 (0.1674)	1.177 (0.1522)	1.187 (0.1571)	1.203 (0.1632)	1.219 (0.1675)
Start-up	0.2787 (0.2935)	0.3818 (0.3885)	0.2991 (0.3179)	0.3169 (0.3042)	0.2716 (0.2878)	0.3148 (0.3317)	0.2956 (0.3151)
Public	0.6182 (0.5076)	0.6379 (0.5185)	0.6024 (0.4960)	0.4938 (0.4143)	0.5026 (0.4252)	0.5275 (0.4455)	0.5820 (0.4985)
Geographic Region-Related Controls							
Route 128		1.954 (1.489)	0.4893 (0.6814)			1.512 (1.222)	0.5455 (0.8597)
SiliconValley		2.590 (2.222)	3.428 (3.120)			1.887 (1.730)	3.093 (3.539)
USA				3.0432 (2.560)	2.607 (2.471)	2.323 (2.144)	1.205 (1.527)
Chi2	82.06	82.69	84.10	83.00	83.12	83.56	84.13
Prob > Chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.4788	0.4825	0.4907	0.4843	0.4850	0.4875	0.4909

*significant at the 0.1 level, ** 0.05, ***0.01

Table XIII
Invention Performance Equation
(Geographic Region-Related Controls)
[Tobit]

	Dependent Variable = LN Royalties/Year N = 124 observations (66 left-censored observations)						
	(XIII-1) Base Model	(XIII-2) Base Model w Route128 & SiliconV, w/o Dist	(XIII-3) Base Model with Route128 & SiliconV	(XIII-4) Base Model with USA, w/o Distance	(XIII-5) Base Model with USA	(XIII-6) Base Model with all controls, remove Distance	(XIII-7) Base Model with all controls
Interaction & Geography							
Interact	0.35*** (0.07)	0.35*** (0.07)	0.35*** (0.07)	0.35*** (0.07)	0.36*** (0.07)	0.36*** (0.07)	0.35*** (0.07)
Recruit	1.458 (0.9415)	1.248 (0.9598)	1.275 (0.9574)	1.388 (0.9292)	1.426 (0.9378)	1.289 (0.9591)	1.287 (0.9585)
LN Distance	-0.2212 (0.3110)		-0.4557 (0.6532)		-0.1127 (0.3457)		-0.3045 (0.9211)
Invention-Related Controls							
LN Quality	2.137** (0.9757)	2.077** (0.9698)	2.117** (0.9676)	2.015** (0.9652)	2.049** (0.9746)	2.022** (0.9677)	2.076** (0.9814)
Age	0.2309 (0.2125)	0.2421 (0.2131)	0.2562 (0.2136)	0.2033 (0.2089)	0.2162 (0.2128)	0.2304 (0.2132)	0.2457 (0.2182)
Sponsor	2.552 (1.915)	2.662 (1.920)	2.696 (1.914)	2.536 (1.907)	2.529 (1.907)	2.608 (1.914)	2.658 (1.919)
Software	5.029* (2.841)	5.035* (2.821)	4.947* (2.812)	5.077* (2.811)	5.062* (2.821)	5.062* (2.811)	4.991* (2.817)
Inventor-Related Controls							
Star20	0.0800 (0.1194)	0.0882 (0.1215)	0.1065 (0.1241)	0.0983 (0.1198)	0.0942 (0.1206)	0.0982 (0.1220)	0.1054 (0.1240)
Industry Funding	0.090*** (0.0304)	0.0932*** (0.0307)	0.0931*** (0.0306)	0.0904*** (0.0303)	0.0898*** (0.0303)	0.0922*** (0.0306)	0.09*** (0.0306)
EECS	-4.51*** (1.659)	-4.886*** (1.702)	-4.828*** (1.698)	-4.663*** (1.632)	-4.569*** (1.657)	-4.805*** (1.701)	-4.8*** (1.699)
Importing Firm-Related Controls							
LN Pubs	0.3552 (0.3469)	0.3956 (0.3533)	0.4372 (0.3578)	0.3882 (0.3504)	0.3975 (0.3519)	0.4315 (0.3574)	0.4414 (0.3584)
Start-up	-1.199 (2.162)	-1.135 (2.163)	-1.317 (2.172)	-0.9907 (1.976)	-1.262 (2.149)	-1.340 (2.177)	-1.359 (2.176)
Public	-0.4096 (1.991)	-0.6573 (2.016)	-0.7369 (2.014)	-0.9887 (2.062)	-0.8698 (2.095)	-0.9954 (2.077)	-0.8793 (2.105)
Geographic Region-Related Controls							
Route 128		1.534 (1.860)	-0.4387 (3.366)			1.135 (1.943)	0.0171 (3.895)
SiliconV		1.457 (2.048)	2.028 (2.205)			1.063 (2.121)	1.642 (2.754)
USA				2.111 (2.274)	1.745 (2.537)	1.581 (2.417)	0.7908 (3.399)
Constant	-8.498** (3.572)	-10.41*** (3.605)	-7.719 (5.189)	-11.11*** (3.905)	-10.36** (4.518)	-11.44*** (3.966)	-9.126 (7.988)
Chi2	76.16	76.51	77.00	76.53	76.63	76.94	77.05
Prob > Chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.1446	0.1452	0.1462	0.1453	0.1455	0.1460	0.1463

*significant at the 0.1 level, ** 0.05, ***0.01

Table XIV
Invention Performance Equation
(Geographic Region-Related Controls)
[OLS]

	Dependent Variable = LN Royalties/Year N = 124 observations						
	(XIV-1) Base Model	(XIV-2) Base Model w Route128, SiliconV, w/o Dist	(XIV-3) Base Model w Route128, SiliconV	(XIV-4) Base Model w USA, w/o Distance	(XIV-5) Base Model with USA	(XIV-6) Base Model with all controls, w/o Dist	(XIV-7) Base Model with all controls
Interaction & Geography							
Interact	0.24*** (0.04)	0.24*** (0.04)	0.24*** (0.04)	0.25*** (0.04)	0.25*** (0.04)	0.24*** (0.04)	0.24*** (0.04)
Recruit	0.9948* (0.5139)	0.8735* (0.5262)	0.8948* (0.5277)	0.9758* (0.5101)	0.9725* (0.5149)	0.8974* (0.5285)	0.8989* (0.5305)
LN Distance	-0.0545 (0.1513)		-0.2615 (0.3238)		0.0113 (0.1678)		-0.2022 (0.4584)
Invention-Related Controls							
LN Quality	0.9106** (0.4584)	0.9093* (0.4607)	0.9348** (0.4625)	0.8697* (0.4589)	0.8699* (0.4609)	0.8786* (0.4639)	0.9176* (0.4739)
Age	0.1054 (0.1093)	0.1041 (0.1094)	0.1084 (0.1097)	0.0947 (0.1079)	0.0934 (0.1102)	0.0971 (0.1101)	0.1048 (0.1119)
Sponsor	1.114 (1.003)	1.205 (1.007)	1.202 (1.009)	1.0756 (0.9995)	1.078 (1.005)	1.146 (1.013)	1.181 (1.020)
Software	1.999 (1.306)	2.028 (1.309)	2.019 (1.312)	2.034 (1.294)	2.044 (1.308)	2.039 (1.313)	2.025 (1.318)
Inventor-Related Controls							
Star20	0.0277 (0.0598)	0.0345 (0.0607)	0.0452 (0.0622)	0.0348 (0.0599)	0.0351 (0.0604)	0.0388 (0.0612)	0.0444 (0.0627)
Industry Funding	0.045*** (0.0156)	0.0465*** (0.0157)	0.0469*** (0.0157)	0.0450*** (0.0155)	0.045*** (0.0156)	0.0462*** (0.0157)	0.047*** (0.0158)
EECS	-2.143** (0.8436)	-2.364*** (0.8574)	-2.312*** (0.8612)	-2.164*** (0.8196)	-2.176** (0.8451)	-2.303*** (0.8639)	-2.3*** (0.8671)
Importing Firm-Related Controls							
LN Pubs	0.1160 (0.1729)	0.1371 (0.1752)	0.1547 (0.1769)	0.1378 (0.1734)	0.1369 (0.1746)	0.1504 (0.1767)	0.1556 (0.1777)
Start-up	-0.5590 (1.071)	-0.4898 (1.069)	-0.6127 (1.082)	-0.6554 (1.005)	-0.6305 (1.075)	-0.6147 (1.087)	-0.6312 (1.091)
Public	-0.1469 (1.014)	-0.2644 (1.023)	-0.3234 (1.028)	-0.4018 (1.039)	-0.4127 (1.056)	-0.4316 (1.053)	-0.3721 (1.066)
Geographic Region-Related Controls							
Route 128		0.4484 (0.9182)	-0.7251 (1.719)			0.2297 (0.9719)	-0.5401 (1.999)
SiliconV		0.9098 (0.9945)	1.198 (1.0581)			0.6677 (1.055)	1.043 (1.358)
USA				1.036 (1.059)	1.070 (1.179)	0.8074 (1.154)	0.2998 (1.633)
Constant	-0.5295 (1.653)	-1.096 (1.578)	0.4722 (2.503)	-1.573 (1.714)	-1.649 (2.065)	-1.5964 (1.735)	-0.0693 (3.876)
R-Squared	0.5488	0.5518	0.5545	0.5521	0.5521	0.5538	0.5546
Adj R-Sqr	0.4954	0.4942	0.4926	0.4992	0.4946	0.4918	0.4880

*significant at the 0.1 level, ** 0.05, ***0.01

Figure 2.1
Research Methodology for Tracing Direct Interaction, Geography, and Economic Performance

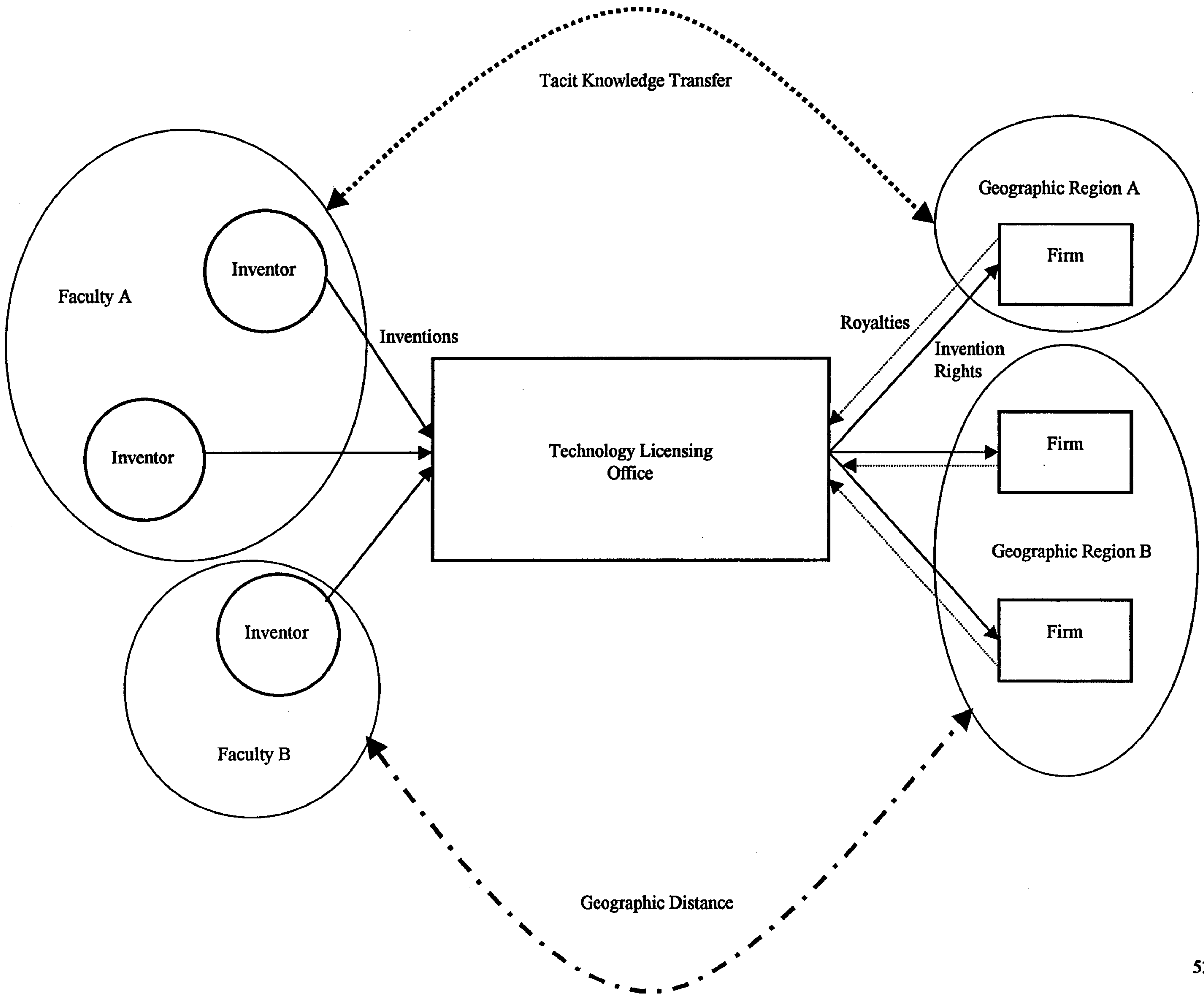


Figure 2.2
Distribution of Royalties in $/Year

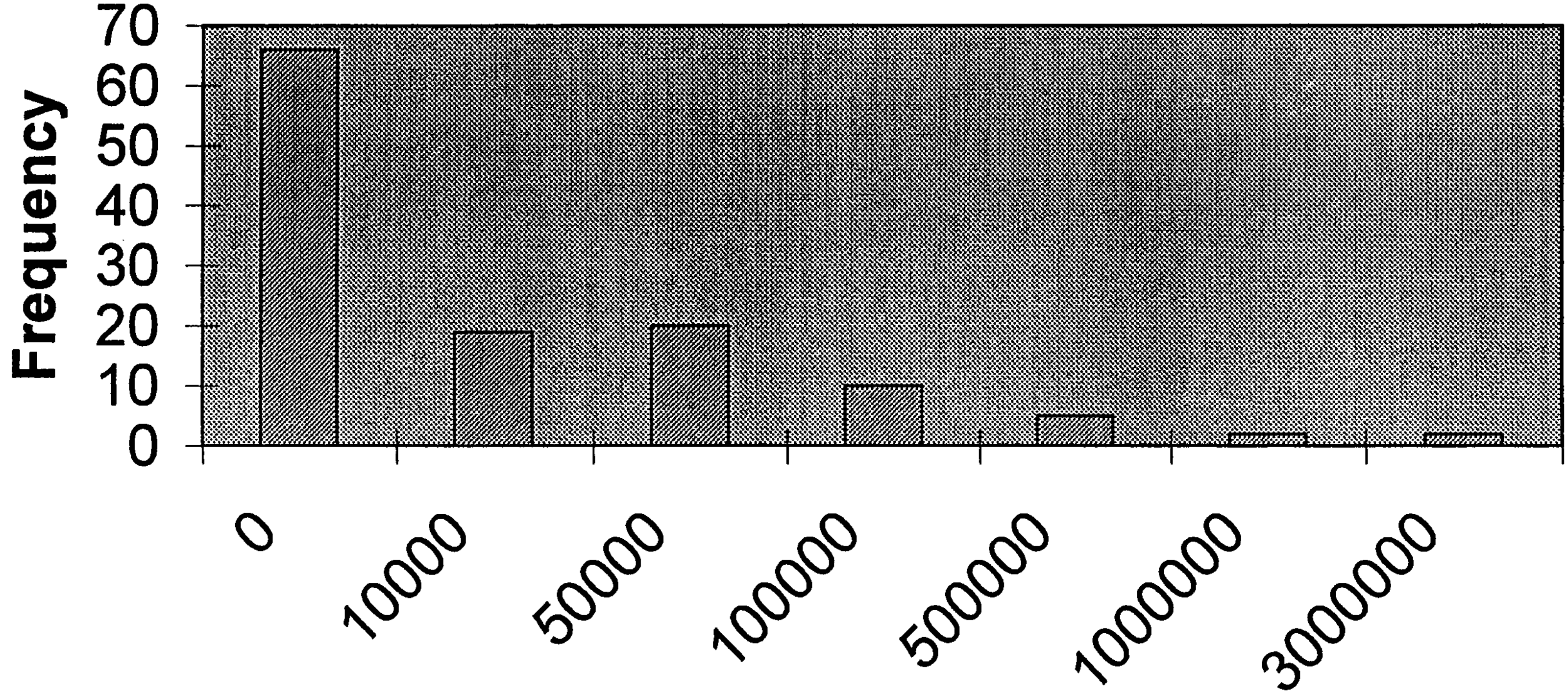


Figure 2.3
Distribution of Interaction (hours)

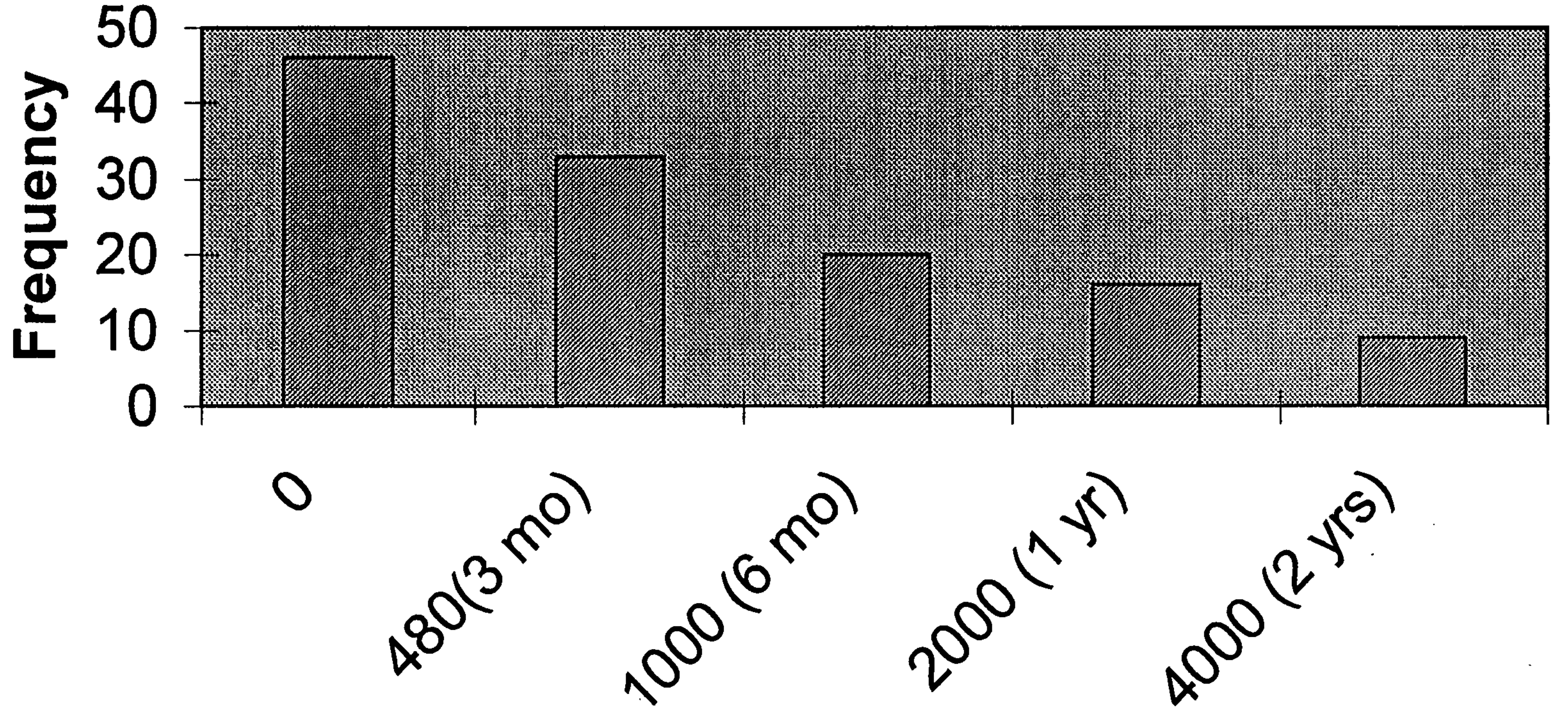
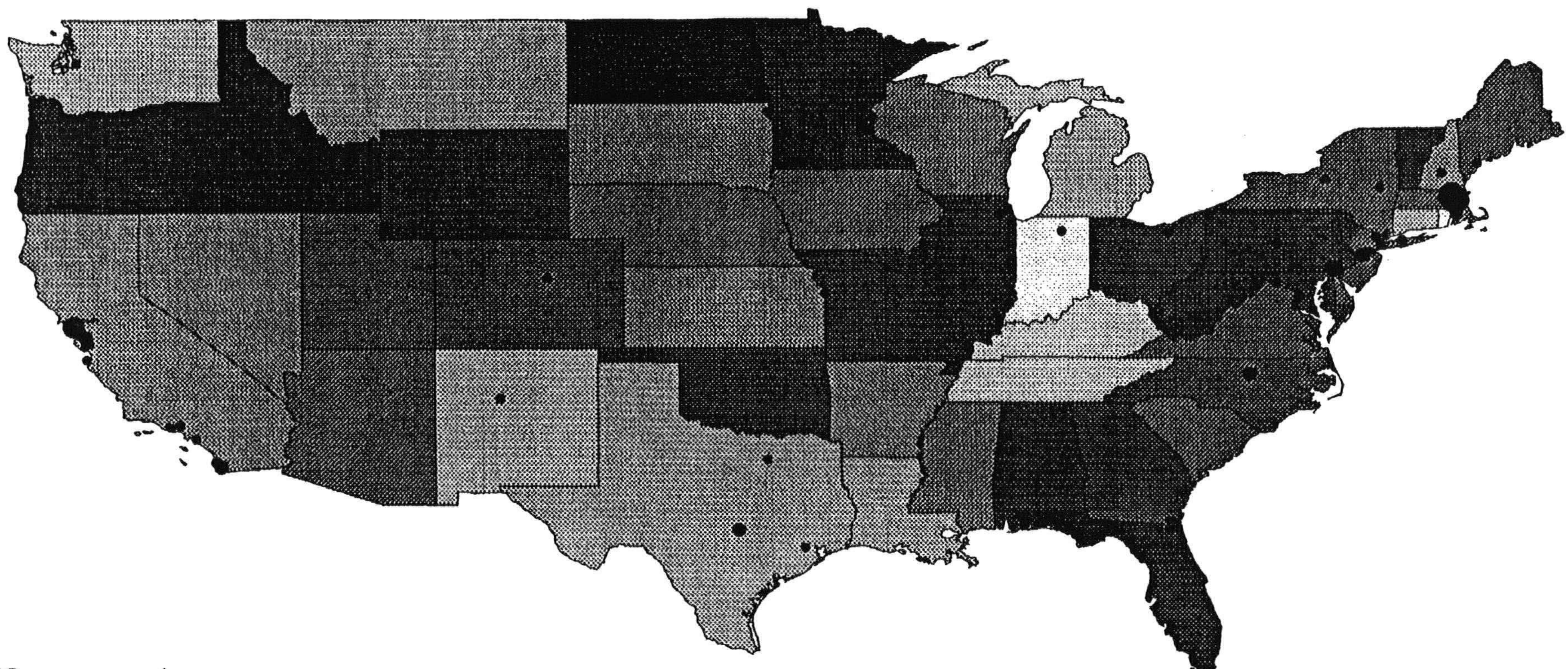
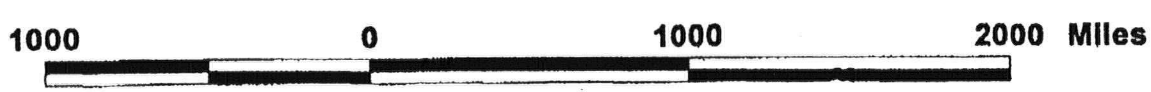


Figure 2.4

Map Showing Development Sites of MIT Inventions License Agreements (1983-1994)



107 US agreements
(Graduated marker size :1-6 inventions in zip code)
17 Foreign agreements
Japan (10), Germany (3), France (2), Israel (2)



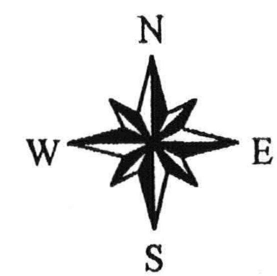


Figure 2.5

Map Showing Development Sites of MIT Inventions (Massachusetts)

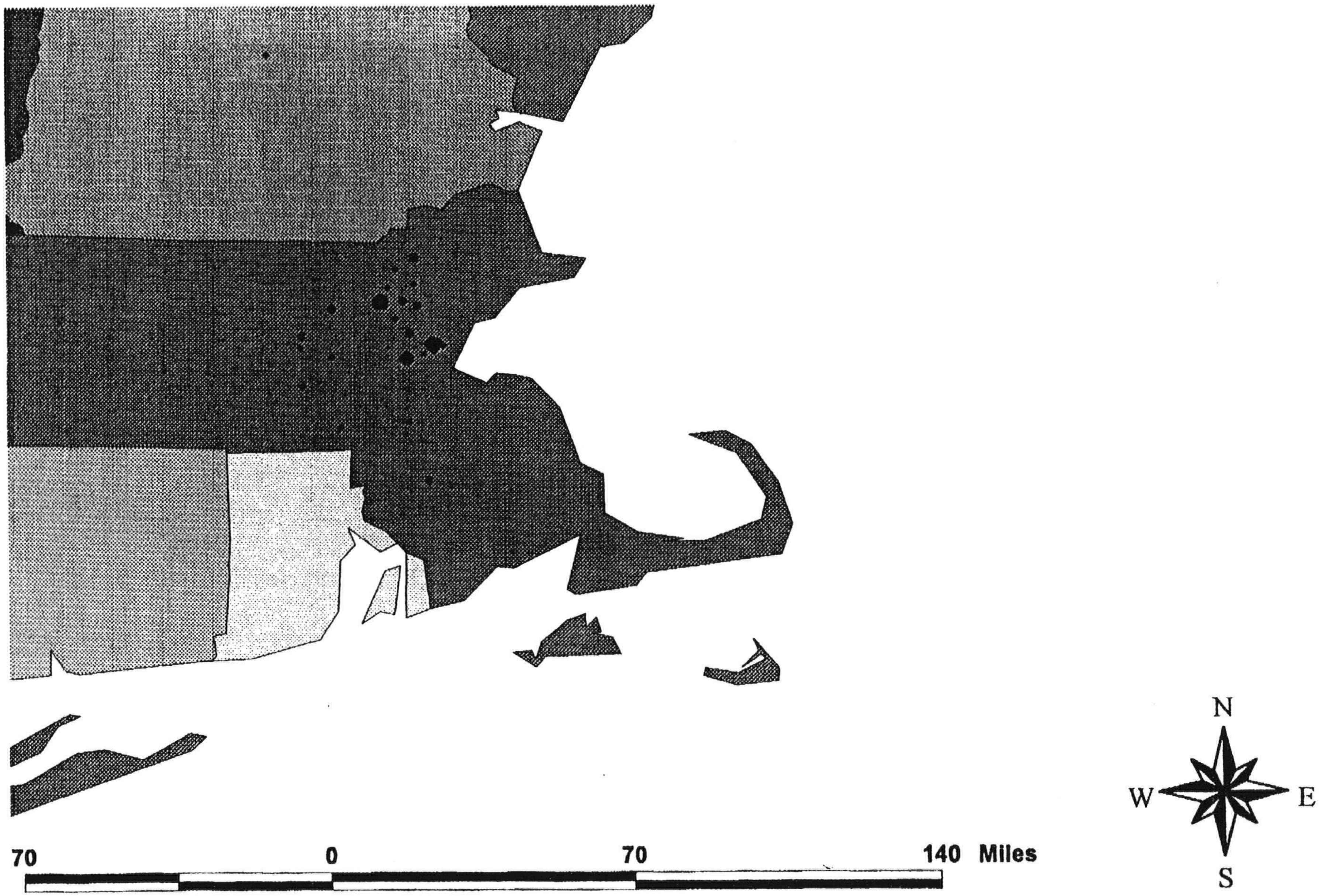
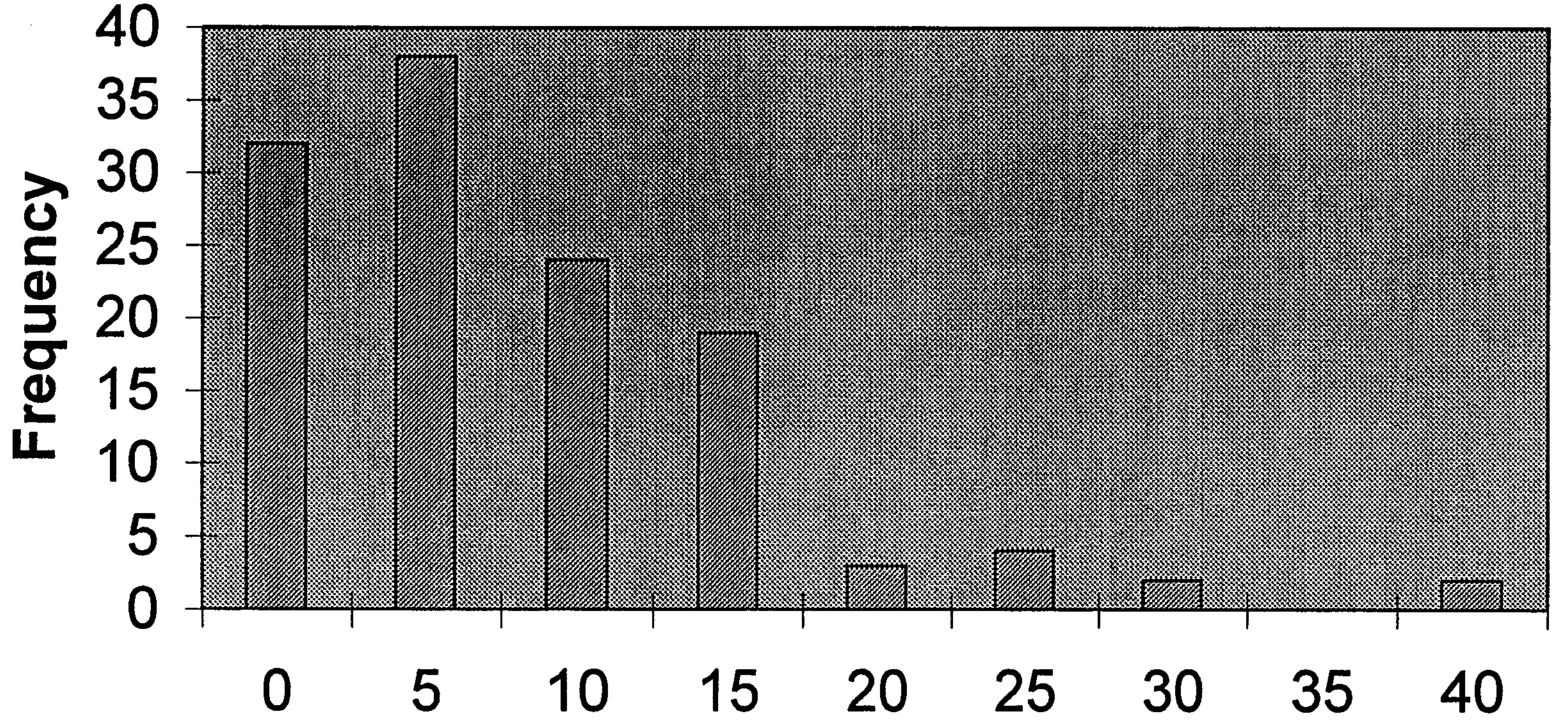


Figure 2.6
Distribution of 'Quality' (patent citns)



Chapter 3

The Application of Advanced Robotics and Control Systems to Real-Time Payload Monitoring: A Case Study to Examine the Role of Direct Interaction

Abstract

This chapter provides an analyses of the knowledge transfer issues of a single invention. The motivation for this study is to offer context by way of illustration to the empirical findings of the previous chapter. In other words, this chapter uses a case study to illustrate a set of reasons why direct interaction with the inventor's lab may be important for importing inventions. The particular invention under examination is from the general area of electrical engineering and computer science. Specifically, it is a dynamic, real-time payload monitoring system developed at an advanced robotics and control systems laboratory in a university setting.

The study points out that the quality of this invention was high in terms of standard industry performance measures. It also illustrates that the invention was unique and that there existed a significant market demand for it. However, the key contribution of this case is the analysis of the knowledge associated with the invention. The complex nature of the tacit knowledge embedded in the calibration and estimation algorithms necessitated interaction in order to transfer the ability to modify the algorithms in any meaningful way. This explains why no firm would make an investment in the new technology without first securing a long-term contractual relationship with the inventor.

3.1 Introduction

In 1998 a graduate student and his professor from the Robotics and Control Systems laboratory made an invention disclosure to the technology licensing office.[1] The invention was a dynamic force measurement system for articulated hydraulic arms.[2] The suggested application was a payload monitoring device for heavy-duty machines such as excavators, mining shovels, and log-loaders. In other words, the function of this system was to measure the weight of a load in a machine bucket while its arm was in motion.[3]

3.2 Why is this Invention Non-obvious?

Upon first glance, this may seem like a trivial problem. However, firms in the industry had tried to solve this problem for over ten years, with no success.[4] The problem was complex because it was not possible to directly measure the payload weight while the machine was in motion since the geometry of the machine changes as it moves. Consequently, payload measurement had to be carried out indirectly using hydraulic fluid pressures and joint

[1]In this chapter, I am grateful to Dr. Shahram Tafazoli, the primary inventor of the invention described in this case study, who gave generously of his time to discuss both technical and business issues associated with the commercialization of the payload monitoring system. I am indebted to Professor Peter Lawrence who is one of the long time directors of the Robotics and Control Systems Laboratory where this invention was made and who made useful contributions describing related research at his lab over time. I am also thankful to experts from the weighing systems industry, especially those from SI Technologies in Seattle, Washington and Actronic Inc. in Auckland, New Zealand for their overall industry insights as well as assessments of the particular invention under investigation. Finally, I am grateful to Iain Cockburn and Rebecca Henderson for their advice throughout this research. Errors and omissions are my own.

[2]This example is taken from the University of British Columbia (Discussions with Dr.Shahram Tafazoli, former graduate student, February 1999).

[3]The following case is useful as an illustration of the know-how transfer problem. This case is offered not as an example of how to manage or not manage university generated intellectual property but rather to provide a context in which to consider the issues of tacit knowledge or know-how transfer discussed in this essay.

[4]The industry is defined as the producers of weighing systems for heavy equipment. The industry is described in the following section. Comments regarding industry attempts to solve this problem came from a number of discussions with industry engineers, in particular Michael Dague, SI Technologies, Seattle, WA and Peter Jenkins, Actronic Inc., Auckland, NZ (January - March, 1999).

angle measures which required compensation for gravitational and dynamic effects of multiple links as well as friction in the cylinders. Products had been developed that could calculate the payload if the machine was stopped, but this proved to be an unacceptable solution since the industry was very sensitive to performance and 'down time'.[5]

The multiple link structure of the machine complicated the problem since changes in the geometry of the arm cause the position of the center of gravity of each link to change constantly. In addition, the length and weight of each link (boom, stick, and bucket) varies across machines. This complexity is not present in simple single link machines such as front-end loaders.[6] In fact, the industry for weigh-in-motion systems for front end loaders was quite mature in 1998. Such systems had been available for over ten years and by 1998, although there had been approximately 10 firms in the market, the industry had consolidated such that 3 firms had over 70% of the market share. Thus, although the weighing system industry was quite mature, a solution for multi-linked machines had not been developed and no acceptable commercial products were available. This supports the claim that the payload monitoring solution for multi-link machines was non-obvious.

3.3 Industry Interest in Dynamic Payload Monitoring

Dynamic weighing systems are valuable for four reasons: 1) to optimize truck loading mass which eliminates costly overload fines, weigh bridge fees, vehicle damage due to overloading, and inefficiency due to under loading 2) to facilitate computation of the daily throughput for the loader, providing the management information system necessary for overall site performance optimization 3) to solve agency problems by reducing monitoring costs since operators are often paid by weight which is otherwise estimated by truckload, and 4) to improve safety since forces on the system are computed and operators can be alerted of machine tipping risks.

Therefore, it is understandable that firms in the industry indicated significant interest in a "weigh-in-motion" system for excavators. This was

[5]'Down time' refers to the duration of time that a machine is stopped, or down, in order to measure the payload. Any machine stoppage was considered unacceptable in this industry.

[6]Appendix B illustrates single-link versus multi-link machines.

especially evident amongst firms that already manufactured and produced these systems for other machines since many of their customers who owned front end loaders also owned excavators. In other words, this technology would offer a natural extension to their existing product lines and fit well into their existing distribution systems, allowing these firms to enjoy benefits from economies of scope. There was a large number of excavators in use in the US and abroad and the fraction of excavators being produced, relative to other heavy duty equipment, was reported to be increasing.

3.4 Inventor's Research Unit - 15 years of Related Research

The solution to this problem came from the application of robotics and control systems theory to a particular machine type. Table 9 lists publications by the inventing professor that are related to the general area of research that led to the invention. The most recent publication in this list was co-authored with the graduate student who lead the invention disclosure.[7] This list illustrates that related work began in this lab in the mid-eighties, assuming a modest publication lag. It is also interesting to note that none of these related papers have been highly cited, at least not yet.

It is important to clarify that this list is not meant to trace a lineage of theoretical development. In fact, the theory regarding linearity of manipulator dynamics in parameters which is the cornerstone of the solution to this problem was not developed in this particular lab. The linearity property was first addressed in two pioneering benchmark papers written elsewhere and has since been extensively used for dynamic identification of various robotic manipulators.[8]

[7]This particular paper is only indirectly related to the disclosed invention. Publications that are directly related to this invention include: Tafazoli and Lawrence et al. "Parameter estimation and friction analysis for a mini-excavator," *IEEE Int. Conf. on Robotics and Automation,* Minneapolis, 1996. (This paper presents a solution for static payload monitoring.) Tafazoli, S. "Identification of frictional effects and structural dynamics for improved control of hydraulic manipulators," *Ph.D Thesis,* Jan. 1997.

[8]These papers are: Khosla and Kanade, "Parameter identification of robot dynamics," *IEEE Conference on Decision and Control,*Dec. 1985. and Atkeson, An, and Hollerbach, "Estimation of inertial parameters of Manipulator loads and links," *The International Journal of Robotics Research,*Fall 1986. The excavator payload monitoring system employs a well-known property of rigid-body dynamics which was discovered approximately

This list is meant to illustrate a stream of work on industrial hydraulic manipulators such that the application of the linearity theory to the particular problem of excavator payload monitoring was possible to accomplish since the supervising professor as well as other professors and former and current graduate students had worked on other problems and in the process the 'lab' had accumulated knowledge regarding operational characteristics of the machine, methods for instrumenting the machine, the general application of advanced robotics to this set of hydraulic manipulators, and indeed the practical relevance of this particular research question.[9] This accumulation of tacit knowledge was important to the successful development of the invention in the given period of time. It is likely that the same invention would have been significantly more difficult and taken longer had it been attempted in an environment absent of this knowledge.

3.4.1 An elegant, but academic, solution

Over a dozen representatives including engineers and technical and sales managers from four unrelated firms in the industry came to the university laboratory to examine the system performance demonstrated on a mini-excavator. In general, performance is measured on two dimensions: speed and accuracy. Speed refers to the time it takes for the system to calculate the weight of the load. Performance slower than three seconds is considered unacceptable since operator cycle times are often this short. Accuracy refers to the maximum difference between the actual weight and the measured weight expressed as a percentage of the full load weight. An accuracy of 5% is considered the absolute minimum for a commercial product. Most firms were hesitant to release a product with more than 3% measurement error.

Each of the firms who attended a demonstration came with the clear intention of examining the technology for its potential application in their own products. In other words, each of these firms was a potential licensee

fifteen years ago. This early work determined that the coupled nonlinear dynamics of any rigid-link manipulator can be expressed in a form where equations are linear in a set of well-defined dynamic parameters. Thus, straight linear least squares estimation can be used to identify those unknown dynamic (inertia and friction related) parameters from experimental data. The parameters may then be used in a load monitoring algorithm in order to estimate the joint torques in the absence of the bucket load.

[9]'Instrumenting the machine' refers to the application of sensors to the arm of the excavator in order to collect the necessary data and of processors inside the cab to enable real time data analysis.

Table XV: **Research History - Inventor's Lab**

PAPER TITLE	JOURNAL	YEAR	CITE
Tracking control of an electrohydraulic manipulator in the presence of friction	IEEE Trans. Control Syst. Technol.	1998	0
Kinematic calibration of industrial hydraulic manipulators	Robotica	1996	0
Simulation and experimental studies of gear backlash and stick-slip friction in hydraulic excavator swing motion	J. Dyn. Syst. Meas. Control-Trans. ASME	1996	2
Fuzzy control of a class of hydraulically actuated industrial robots	IEEE Trans. Control Syst. Technol.	1996	3
COORDINATED-MOTION CONTROL OF HEAVY-DUTY INDUSTRIAL MACHINES WITH REDUNDANCY	Robotica	1995	2
FUZZY POSITION CONTROL OF HYDRAULIC ROBOTS WITH VALVE DEADBANDS	Mechatronics	1995	3
PERFORMANCE OF GENERALIZED PREDICTIVE CONTROL WITH ONLINE MODEL ORDER DETERMINATION FOR A HYDRAULIC ROBOTIC MANIPULATOR	Robotica	1995	2
HYDRAULIC COMPLIANCE IDENTIFICATION USING A PARALLEL GENETIC ALGORITHM	Mechatronics	1994	0
RESOLVED-MODE TELEOPERATED CONTROL OF HEAVY-DUTY HYDRAULIC MACHINES	J. Dyn. Syst. Meas. Control-Trans. ASME	1994	2
ITERATIVE INVERSE KINEMATICS WITH MANIPULATOR CONFIGURATION CONTROL	IEEE Trans. Robot. Autom.	1993	0
GENERALIZED PREDICTIVE CONTROL OF A ROBOTIC MANIPULATOR WITH HYDRAULIC ACTUATORS	Robotica	1992	6
CASCADE CONTROL OF HYDRAULICALLY ACTUATED MANIPULATORS	Robotica	1990	9
A DISCRETE-TIME OPTIMAL ADAPTIVE-CONTROL LAW FOR A ROBOT ARM	Optim. Control Appl. Methods	1989	0
ROBOT CONTROL USING ADAPTIVE TRANSFORMATIONS		1988	3

of the invention. In general, all engineers who participated were suitably impressed by the performance of the system. At that time, the system was performing at approximately 5% accuracy in 3 seconds.[10] This solution was elegant in that the performance met industry specifications - even at the boundary conditions. In other words, the algorithms performed adequately even when the arm was fully extended, fully retracted, accelerating at a maximum rate, etc. However, each firm acknowledged that a significant amount of work remained in order to develop the invention into a marketable product. A 'Research Collaboration Plan' was designed to address these research and development issues and is summarized in Appendix A. The main areas of development are listed below:

Robustness to scale: The solution had only been tested on a mini-excavator. Some engineers were worried that problems might arise when it was implemented on much bigger machines.

Robustness to geometry: The solution had only been tested on one particular excavator model. Some engineers were worried that problems might arise when it was implemented on other models with different geometric properties (i.e. lengths and weights of links in different proportions).

Minimization of Instrumentation: The system involved three joint angle sensors and four pressure sensors. This instrumentation was located on the arm of the excavator and subject to the harsh operating environment outside the cab. Firms were interested in reducing the number of sensors required for data capture for reasons of both system robustness and cost.[11]

Robustness to operator behavior: The system must be robust to shocks. Shocks may be caused by operators banging the bucket on the ground to shake loose dirt and rocks stuck between the teeth or in the bucket.

Robustness to slope operation: Experiments in the lab were conducted on a flat surface. Excavator work often takes place in environments where the cab is working on a slope.

Robustness to horizontal swing: The solution had been designed for vertical motion. Horizontal motion exerts additional forces.

[10] Improvements in performance have been made since then.

[11] Cost includes both cost of components and cost of installation and servicing.

3.5 Firm Difficulties in Employing the Technology

Three types of companies were interested in potentially licensing the invention. These included OEM's, weighing system manufacturers, and end users. OEM's are manufacturers of excavators and would install the weighing system directly on new machines as they were assembled. Weighing system manufacturers produce a variety of weighing systems and generally sell their products to end users and install them as retrofits. This product would be the same. End users include firms in industries that use heavy equipment such as mining, forestry and construction. Each of these types of companies expressed interest in the invention.

All of these companies, however, expressed concern over their ability to develop the invention on their own, in light of the modifications required for commercial use described above. The invention involved treating the excavator as a robotic arm and employed theories and experience from robotics engineering and control systems. Although most of these firms employed electrical and mechanical engineers in-house, none felt confident to develop the invention without some collaboration with one of the inventors.

Different types of firms had different levels of experience with the dynamic weighing problem. Weighing system manufacturers were the most sophisticated, having invested significantly in their own attempts to develop a product for excavators. Engineers at these firms were very familiar with the types of problems, both hardware and software, involved with such a product. Several OEM engineers had also experimented with developing a dynamic weighing system, but apparently to a lessor degree. Engineers from end user firms, particularly mining companies, were very interested in the problem and very familiar with the performance demands for the system and difficulties presented from the operational environment, but in general were not sophisticated in terms of possible solutions. None of these firms, from any of the categories described above, had in-house robotics or control systems expertise.

3.6 Taxonomy of Knowledge Applied to Payload Monitoring Invention

The previous sections in this chapter describe the industry interest in this invention but claim that despite this interest firms would not license the rights to the intellectual property and subsequently invest in its development without securing a collaborative relationship with the inventor first. This section addresses the question 'Why did firms believe it was necessary to interact with the inventor?'

A taxonomy of knowledge is introduced here to provide a framework for addressing this question. A number of taxonomies have been proposed in the literature on tacit knowledge and know-how, including Rogers (1980), Winter (1987), and Zander and Kogut (1995). The latter is used here. Zander and Kogut propose five central constructs by which to characterize various dimensions of tacit knowledge. The authors state *"It would be nonsensical to believe that there is a single dimension called tacitness."* These constructs are listed and described below.

Codifiability refers to the degree to which the knowledge can be represented by symbols.

Teachability refers to the degree to which the knowledge can be taught in schools or on the job.

Complexity refers to the degree to which the knowledge embodies multiple kinds of competencies.

System dependence refers to the degree to which the knowledge requires many different experienced people for its application.

Product observability refers to the degree to which competitors are able to learn the knowledge by observing the functions of the product.

The knowledge involved with the payload monitoring system is characterized in terms of these dimensions, below.

The invention is comprised of a system of components which include pressure and angle sensors located on the arm of the manipulator, a processor and screen located in the cab, and algorithms (software) that calibrate the sensors, calibrate the arm, and estimate the loads using the data collected by the sensors. It is important to note that while the inventor developed a working prototype of the system, including all components, the real innovation is the knowledge in the software that estimates the loads. All of the hardware used in the prototype was 'off the shelf'.

In this classification scheme, the knowledge embodied in the software is considered codifiable. Indeed, Zander and Kogut mention software as an example of fully codifiable knowledge. However, an important caveat needs to be introduced here. While the software which embodies the algorithms may be easily moved from the university lab to the licensee firm, the knowledge of how the algorithms work is not evident from the code. That is, the knowledge that would be required to make modifications to the algorithms is not evident from the software code.

Regarding teachability, the inventors estimated that it would take approximately three person months to teach an individual or group of engineers how the algorithms work such that they would be able to modify them on their own. It is assumed here that the recipient engineers have graduate level training in advanced robotics, including courses on topics such as filters and estimation, optimal control, adaptive control, and digital control in order for the know-how transfer to be effective. The inventors claimed that the required knowledge transfer would not be possible without such previous training.

Regarding complexity, the knowledge associated with this invention may be considered only moderately complex. First, this knowledge resided in the head of a single individual - the inventor. In other words, it is possible for one person to have the complete set of knowledge regarding the software for this system. At the same time, the knowledge may be considered moderately complex, rather than simple, since it is necessary to be competent in a number of areas associated with robotics and control systems (kinematics, dynamics, estimation, digital signal processing), as well as with hydraulics.

Regarding system dependence, the knowledge associated with this invention is reasonably dependent on the system in which it operates. The two main components are the hardware (sensors) and the software. There are many types of sensors, and many ways in which they can be applied to manipulators. The licensee firms would manufacture and install the sensors, so this is not knowledge that must be passed from the university to the firm. However, the university software must be able to perform to the required specifications with the firm's sensors. Thus, while there is no knowledge transfer associated with the sensors, the performance of the software is dependent on the system, including hardware.

Finally, regarding product observability, the knowledge associated with this invention is not observable. Competitors are able to observe the number, type, and configuration of sensors applied to the arm of the manipulator. However, they are not able to decipher the calibration or estimation algorithms from the executable code. The inventors claim that this is very difficult to do, even from the source code.

Given this analysis of five constructs of the tacit component of the knowledge associated with the invention, it is reasonably understandable why firms insisted on securing a collaborative relationship prior to licensing or investing in development. While the intellectual property rights could be transferred easily, by way of a licensing agreement or sale, and the existing solution could also be transferred easily, by giving the firm a copy of the software, the firm's ability to modify the algorithms in any way required the transfer of know-how and this would require interaction. In summary, the inventors estimated that a complete transfer would involve the transfer of the code and three months of training the firm's engineers who were already educated in advanced robotics.

Given this examination of the tacitness of the knowledge associated with this invention, it is useful to note three additional points regarding 1) taxonomy, 2) patenting, and 3) complementary assets. First, it is interesting to note that none of the three knowledge taxonomies referenced here offer a distinction between transferring an ability to *use* an invention and an ability to *modify* an invention. In this case, firms expected to develop multiple generations of the product over its life cycle. Each new generation would involve improvements conceived by the firm or by users. This is common in most product life cycles.

However, the distinction between transferring knowledge for use versus knowledge for modification is not clear in the taxonomy. In this case, the software is codified and thus the existing invention can be transferred without interaction. Know-how transfer is not required to use this invention, only to modify it. One solution to improve the clarity of this taxonomy is to add a meta construct that distinguishes between moving inventions for use versus for modification. Under such a framework, this invention would be neatly categorized as requiring no know-how transfer for the former, and the know-how transfer that was described in this section for the latter.

Second, it is interesting to consider implications of the tacit knowledge analysis presented here on the strategic use of intellectual property protection, namely patents. Since the invention has very low product observability and the inventors believe that it would take approximately three months to explain how the calibration and estimation algorithms work, it seems that this invention is better off not patented. The inventors believe that it is very likely that competitors could learn a lot about the algorithms from the claims that would need to be described in a patent and there would be a reasonable probability that competitors could 'invent around' the claims listed in the patent, based on this disclosure. At the same time, just as it is difficult for competitors to decipher how these algorithms work based on the executable code, it would be difficult for the inventors to prove that their invention was copied by taking apart a competitor's product. Also, litigation regarding patent violation is very time consuming and expensive.

Finally, in terms of system dependence, it is interesting to consider the complementary assets. The complementary assets in this case are the sensors and other hardware that are required to collect and process the data. At a general level, the inventor has a certain bargaining power with the licensee firm since there are several firms who are able to develop the hardware, while there is only one software solution. However, once a particular firm signs an exclusive licensing agreement with the university, the specific hardware components will be purchased or manufactured by that firm. This may require some know-how transfer from the firm back to the inventor since the inventor may need to adjust the algorithms in order to perform estimations based on the nature of the data that is collected from these particular sensors.

3.7 Demonstrated Need for Tacit Knowledge Transfer to Commercialize this Invention

This chapter illustrates a case in which direct interaction with the inventor's lab was very important for the importing firm. Although the particular technical issues of concern discussed here are specific to this case, this example provides some insight into the *types* of reasons that direct interaction might be important in general.

It clearly would have been difficult for any of the firms interested in the invention to develop a commercial product without the assistance of one of the inventors, or someone else from the inventor's research lab. This would involve a significant commitment to the project on the parts of both inventor and licensee. Firms were interested in working with the inventor to develop the initial product and to learn how it worked, in terms of the algorithms, the underlying physics and the relevant principles of robotics, so that they could make improvements and modifications on their own in the future. Thus, potential licensees who expressed interest in licensing the technology did so conditional on the ability to collaborate closely with one of the inventors for the development phase of the first commercial product.

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Chapter 4

Public Sector Science and "The Strategy of the Commons"

Abstract

This paper provides a game-theoretical explanation for the puzzling behavior of large firms and private sector consortia (incumbents) which, while sponsoring university research labs, at the same time require all inventions generated by the sponsored labs be licensed openly on a purely non-exclusive basis. Under certain conditions, this results in an intellectual property 'commons' with the consequence that no firm has the incentive to innovate, despite the potential profitability of the new technology. The strategy of spoiling incentives to develop public sector inventions by eliminating exclusive intellectual property rights—the *strategy of the commons*—is motivated by a fear of cannibalization and supported by a credible threat. This chapter shows that the *degree of cannibalization* to which the new technology exposes the old market is responsible for this market failure and characterizes the subgame perfect equilibrium in which the strategy of the commons is played. Within this framework, welfare implications, strategy and policy issues are investigated.

4.1 Introduction

In this chapter, a game-theoretic model is developed to investigate an interesting puzzle that has recently become the topic of considerable controversy and debate at the MIT Technology Licensing Office (TLO).[1] In recent years, the Institute, as well as many other public sector research institutions, has been approached by a number of large firms and private sector consortiums that wish to sponsor particular research laboratories. In return for their sponsorship, these organizations have requested that all inventions generated by the sponsored labs be licensed openly, on a non-exclusive basis only. At first glance, this seems surprisingly generous—in fact, altruistic. Hence, the puzzle.

Consider three examples: 1) Kodak sponsors research in areas related to digital photography; 2) AT&T sponsors research in areas related to communication, including Internet telephony; 3) A consortium, comprised of several of the world's largest pharmaceutical firms, sponsors research related to the Human Genome Project. In each case, the sponsorship stipulates 'no exclusive licensing'. So, the puzzle is 'Why would the sponsoring firms choose to disallow exclusive licensing—which has been the norm at universities since the Bayh-Dole Act of 1980[2]—especially since these firms would be prime candidates for licensing the inventions themselves?'

One hypothesis is simply that sponsoring firms are worried that other firms might obtain the exclusive license first. This is certainly a reasonable explanation, but not altogether consistent with the evidence. Historically, sponsoring firms have enjoyed favorable information advantages regarding the

[1]In this chapter, I am grateful for thoughtful advice from Jim Brander, participants of the MIT SIM doctoral seminar, and especially Lorenzo Garlappi who graciously offered much intellectual inspiration throughout this work. I am also thankful to Lori Pressman, Assistant Director and Licensing Officer at the MIT Technology Licensing Office, for bringing to my attention the intriguing non-exclusive licensing puzzle that became the motivation for this chapter. Finally, I am grateful to Iain Cockburn and Rebecca Henderson for their thoughtful guidance throughout this research.

[2]The Bayh-Dole Act (Public Law 96-517) assigned ownership and control of patents derived from federally-funded research to performing institutions, rather than the sponsoring federal agency. Most relevant to this study, it granted non-profit organizations the right to offer *exclusive* licenses—a right that, as the Columbia University Technology Licensing Office describes, "provided the incentives for the venture capital industry to invest in unproven technology [...] The results have been dramatic. A trickle of university patents, 200 in 1980, has turned into a flood—now more than 3,000 applications a year" (*21stC: The World of Research at Columbia* (Winter,1998))

research outcomes of the labs they sponsor since they often receive interim briefings *prior* to publications or conference presentations. So, in practice, they are usually 'first in line' for any related exclusive licenses.

In this essay, a second, less obvious explanation is examined. The hypothesis modeled here is that firms request non-exclusive licensing regimes in order to altogether *prevent* the commercial development of inventions in a particular area. In other words, they sponsor research in a laboratory specifically because they do not want future inventions to be developed by anyone. They purposely spoil the incentives for all firms to develop and commercialize inventions from the sponsored lab by creating a market failure. Sponsoring firms accomplish this by creating an intellectual property 'commons' under which no firm is able to obtain exclusive property rights.

Why would they do this? Under some conditions, if the new market is related to the old market such that one will *cannibalize* the other, it may be profitable for the entrant to develop the invention but harmful for the incumbent to do so. In other words, the incumbent's profits in the original market will be reduced if the entrant develops the invention or even if the incumbent itself does so. From this perspective, one can imagine reasons why Kodak may want to delay the development of digital photography, AT&T the development of Internet telephony, and large pharmaceutical firms the development of processes for human gene mapping.[3]

Under this threat of cannibalization, one might question why the incumbent doesn't license the patent and leave the technology dormant?[4] The answer lies in the licensing contract that is hand-crafted for each agreement. Benchmarks, milestones, expenditure commitments, and other timeline components associated with product development and commercialization are specified in the contract. Technology licensing officers refer to these contractual conditions as 'use it or lose it' clauses which ensure that the mandate of the university is reflected in the conditions of the contract.[5] Indeed, anec-

[3]The latter example refers to the SNP Consortium which consists of several large pharmaceutical rivals including Novartis, Glaxo Wellcome, Pfizer, and SmithKline Beecham. This consortium was formed in 1999 for the sole purpose of sponsoring public sector research to identify and patent SNPs (Single Nucleotide Polymorphisms) in order to prevent smaller biotechnology firms from entering and obtaining exclusive rights to this genetic information. (*The Wall Street Journal* (03/04/1999), *US News & World Report* (10/18/99), *The Economist* (12/04/99). SNPs are differences in the DNA of individuals that are likely to be important in tracking the genetic causes of disease.

[4]This is known as 'keeping a sleeping patent'.

[5]The mandate of most research universities, with respect to patent licensing, is to pro-

dotal evidence suggests that the incidence of the strategy of the commons is positively correlated with an increase in the sophistication of the 'use it or lose it' contractual terms, both of which have varied across research organizations. In any case, licensing university inventions and not developing them no longer appears to be a feasible strategy for mitigating the effects of cannibalization.

The idea of market cannibalization has been well studied. The 'replacement effect' was first explicitly analyzed by Arrow (1962) who argued that a monopolist incumbent would have a lower willingness to pay for an innovation than an entrant since the incumbent would be concerned about replacing its sunk assets and thus have, relatively, less incentives to innovate. Since Arrow, many other scholars have examined particular economic effects of market cannibalization. For example, Abernathy & Utterback (1978) compare incremental and radical innovation and offer a number of reasons, including cannibalization, to explain why radical innovation is typically carried out by entrants rather than incumbents. Foster (1986) popularized the concept of the S-curve for technologies, the shape of which is defined by the increase in performance relative to the development effort expended. Discontinuities in the curve represent new technologies that are often developed by entrants because they have the potential to cannibalize the existing product market. Gans & Stern (1997) model the allocation of rents from innovation amongst incumbents and entrants that is dependent on the existence and terms available on the 'market for ideas' and use this framework to consider the way in which cannibalization effects the underlying incentives for either firm to conduct R&D. Finally, Christensen (1997) examines the concept of 'disruptive' technologies in a number of product markets, most notably the disk drive industry. In this analysis, cannibalization is once again offered as a primary explanation for the development by entrants but not incumbents.

The work presented here contributes to this stream of research by examining a particular market structure that is influenced by the effects of cannibalization. Specifically, it presents a model with two related markets, an old and a new technology market, and two players, an incumbent and

mote the development of their inventions, rather than to maximize profits. For example, the MIT Technology Licensing Office states that "[i]n our technology licensing endeavor, MIT is following the mandate of the US Congress when it gave universities title to inventions developed with federal funds: We use licenses to our intellectual property to induce development of our inventions into products for the public good." (MIT TLO promotional pamphlet, 1996).

an entrant, and seeks to identify the conditions under which the sponsoring incumbent selects a non-exclusive licensing regime in the new market. These conditions must allow it to credibly and effectively threaten to enter and invest in the invention if the entrant does. The threat is credible only if it is profitable for the incumbent to invest after the entrant has invested and it is effective only if the duopoly profits for the entrant are less than the costs of entry, deterring the entrant from entering. This strategy, in which the incumbent eliminates the incentives for any firm to develop an invention by selecting a non-exclusive licensing regime and, hence, creates an intellectual property commons, is referred to here as the *Strategy of the Commons.*[6]

It is important to be clear that while we apply the concept of cannibalization to a dynamic licensing game, this paper is intended as a contribution to the strategy literature, rather than to the game theory, substitution/cannibalization, or patenting literature. The model employs well established game theory techniques (backwards induction, credible threat, off-equilibrium solution) and makes common cannibalization and patent licensing assumptions. To this end, there has been significant research in related areas of patent racing and patent licensing in the IO literature. However, the work presented here is distinct from the patent race literature (Dasupta and Stiglitz, 1980; Reinganum 1982, 1983; Loury 1979; Grossman and Shapiro, 1987; Harris and Vickers, 1987) since the model considers university research sponsorship in a non-competitive manner. In other words, there is no element of competition modeled here at the sponsorship level. Sponsorship is exogenous.[7]

There is also a significant body of work that focuses on patent licensing such as produced by Kamien and Tauman (1986), Katz and Shapiro (1985, 1986), Gallini (1984) and Gallini and Winter (1985). These papers examine models in which the player making the licensing decision is also the recipient of licensing fees. Naturally, these decisions are made in a profit-

[6]The term 'Strategy of the Commons' is a play on the phonetically-similar term 'Tragedy of the Commons' popularized by Garret Hardin in a paper on population control in 1968. With regard to the origin of the term, Professor Hardin recognizes mathematical amateur William Forster Lloyd (1833) for an early discussion of the idea. In addition, Scott Gordon's 1956 essay on the problem of the commons closely resembles the 'Tragedy of the Commons' and thus it is unclear to whom acknowledgments for this phrase should be made.

[7]This assumption seems a fair reflection of reality since there are no reported cases of firms bidding to sponsor a particular research unit, at least at MIT.

maximizing manner. It is important to highlight the distinction that in the model presented in this paper, the profit-maximizing incumbent is afforded the licensing regime decision even though it is completely separate from the university which is the inventor and the recipient of licensing fees. As a result of this distinction, this paper may also be considered relevant to the 'raising rivals costs' research in the industrial organization literature (Salop and Scheffman, 1983; Salop, 1993; Granitz and Klein, 1996) which investigates strategic decisions that may not benefit the decision-maker directly, but may harm potential competitors.

The rest of the paper proceeds as follows. In the next section, the licensing model and the dynamics of the game are introduced. In Section 4.3 the conditions under which the strategy of the commons is an equilibrium solution is described. Social welfare implications are examined in Section 4.4 and, finally, implications for strategy, policy, and future research are discussed in the concluding Section 4.5.

4.2 The Model

In this section we develop a simple game-theoretic model to investigate the conditions under which it is possible to observe the "strategy of the commons" as a result of profit-maximizing behavior of players in the licensing game.

4.2.1 Dynamics of the Licensing Game

At the beginning of the game a sponsoring firm selects a licensing regime for the invention that will potentially be generated. We refer to this firm as the *incumbent.* We assume the incumbent firm has monopoly power in the market in which it operates. The incumbent, when sponsoring university research, can decide to select either an *exclusive* or a *non-exclusive* licensing regime.

An exclusive licensing regime is one under which only one firm may license the right to use a patented technology at any given time. This also includes technologies that are protected by copyright, trademark, and other forms of legal intellectual property protection. This is in contrast to a non-exclusive licensing regime under which more than one firm may simultaneously license the right to use a protected technology. For the sake of clarity and simplicity, issues such as sub-licensing and restricted fields of use are not considered here. The main implication that arises from the exclusivity distinction in licensing regimes is with regard to competition. In the exclusive case, the licensee firm maintains a monopoly of the technology whereas in the non-exclusive case, the licensee firm faces either direct competition or at least the threat of competition from other firms.

For exigency of tractability we assume that there exists only one potential entrant in the new market. The resulting game is hence a two-player game in which an established incumbent and a potential entrant interact in the adoption of a new technology.

The two firms are equally efficient in the utilization of the new technology which is used to develop a product that is a partial substitute for the one already produced by the incumbent. We will formalize the nature of this dependence shortly. Throughout the analysis we also assume that patents are enforceable and cannot be 'invented around'. This means that a firm must license the patent in order to produce the new technology product.

The dynamics of the game are summarized in Figure 4.1.

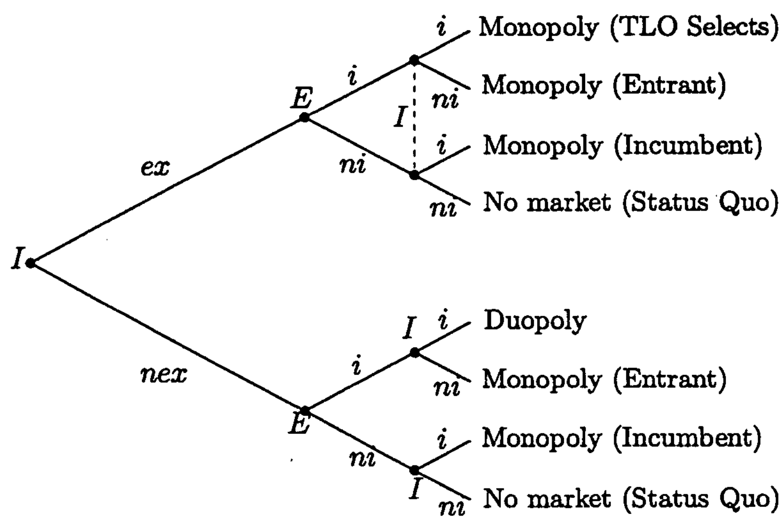

Figure 4.1: **Dynamics of the licensing game.** E indicates the entrant, I the incumbent; ex represents the exclusive licensing regime, nex the Non-exclusive licensing regime; i indicates the decision to invest in the license and ni the decision not to invest in the license.

If the incumbent selects an exclusive licensing regime then both firms decide simultaneously whether or not to license. This is because at most only one firm may obtain rights to the license. In the non-exclusive regime the licensing decisions are modeled as a sequential game with the entrant moving first since it is possible for both firms to have licensing rights to the invention simultaneously. It is important to note that the order of the sequential non-exclusive licensing subgame produces an outcome that is the same as that which would result if the subgame were infinitely repeated, with no specified order. In the infinitely repeated game, the entrant is always faced with the threat of subsequent entry by the incumbent. Therefore, what is critical is not which player is allowed to move first, but rather which player is allowed to move second. The incumbent is only able to threaten the entrant with entry if the incumbent is able to license after the entrant has already done so. In other words, the conditions under which the incumbent will play the strategy of the commons are the same when there are no rules for the order of play in the infinitely repeated game as they are when the order of play is dictated as 'entrant first' as is modeled here.

The *strategy of the commons* outcome occurs when the incumbent selects a non-exclusive licensing regime and, in the ensuing sequential game both the entrant and the incumbent decide optimally not to invest in the license, *even though* the new technology would be profitable under an exclusive licensing regime.

4.2.2 Demand and Industry Equilibrium Profits

We assume that the incumbent faces the following linear demand function in the market for the *old technology* ('O' for 'old')

$$P_O = b_O - Q_O, \quad b_O > 0 \tag{4.1}$$

where P_O is the price of the product and Q_O the quantity. The incumbent faces a constant marginal production cost c_O. Since it is a monopolist in this market its profit can be easily derived as

$$M_O = \frac{1}{4}(b_O - c_O)^2, \quad 0 \le c_O \le b_O. \tag{4.2}$$

Similarly, we assume that in the *new technology* market ('N' for 'new') the demand schedule is also linear

$$P_N = b_N - Q_N, \quad b_N > 0. \tag{4.3}$$

Since the two firms are equally efficient in developing the new technology, they face the same, constant marginal cost c_N. Hence, whoever gains a monopoly position in the new technology market will gain a monopoly profit M_N given by

$$M_N = \frac{1}{4}(b_N - c_N)^2. \quad 0 \leq c_N \leq b_N. \tag{4.4}$$

We assume $c_N \leq c_O$, i.e., the new technology represents an improvement over the old one.

In case a duopoly emerges in the new technology market[8] we assume that firms compete in quantity and the industry profits are determined as in a von Stackelberg duopoly game with the incumbent acting as the leader. It is important to stress that the von Stackelberg leader is not necessarily the first to invest in the technology. In other words we are keeping the licensing game separate from the product market game. The fact that the incumbent is able to threaten the entrant with competition in a von Stackelberg fashion in the product market is crucial in the emergence of the strategy of the commons as an equilibrium solution. The profit to the incumbent (leader) in a von Stackelberg duopoly is

$$D_N^I = \frac{1}{8}(b_N - c_N)^2 \tag{4.5}$$

whereas the profit to the entrant (follower) is

$$D_N^E = \frac{1}{16}(b_N - c_N)^2 \tag{4.6}$$

Cannibalization

As noted earlier, the new market is 'related' to the old market. We now formalize this concept. The adoption of a new technology will not only create a potential new market but, to the extent in which the new product is a substitute for the old, it will attract some customers from the old market. When this happens, the old market is said to be "cannibalized" by the emergence of the new market. The degree of this cannibalization will depend upon the degree of substitutability of the two products. We measure this quantity through the *cross-price elasticity* parameter η_{ON} defined as

$$\eta_{ON} = \frac{\partial Q_N / Q_N}{\partial P_O / P_O}. \tag{4.7}$$

[8]We noted that this is possible only in the non-exclusive regime case.

Simply, the cross price elasticity measures the percentage change in the quantity demanded of the new good given a percentage change in the price of the old good. Its value depends on the preference structure of individuals and is positive for complementary goods and negative for substitutes. In our analysis we implicitly assume that the new technology is a partial substitute for the old. A thorough analysis of the demand side would require a more comprehensive (general equilibrium) approach which is outside the scope of this paper.

The degree of cannibalization occurring in the original market is captured by the *cannibalization ratio*, k. This ratio is assumed to be a monotonic, non-decreasing function of the absolute value, $|\eta_{ON}|$, of the cross-price elasticity

$$k : [0, \infty] \rightarrow [0, 1) \tag{4.8}$$

where $k(0) = 0$. Thus, when the two markets are unrelated ($\eta_{ON} = 0$), the introduction of the new technology does not cannibalize the old market. At the other extreme, when the two markets are perfect substitutes, the introduction of the new technology totally cannibalizes the original market ($\lim_{\eta_{ON} \rightarrow +\infty} k(\eta_{ON}) = 1$). Formally, the effect of k is to translate the old market demand curve downwards. We show this in Figure 4.2. The new, "cannibalized" demand schedule will therefore be

$$P_O(k) = b_O(k) - Q_O \tag{4.9}$$

where $b_O(k) : [0, 1] \rightarrow [0, b_O]$ is a monotonic decreasing function of k with $b_O(0) = b_O$ and $b_O(1) = 0$. We assume the following simple functional form for $b_O(k)$ [9]

$$b_O(k) = (1 - k)b_O. \tag{4.10}$$

Note that, since k is a monotonic, non-decreasing function of η_{ON} then $b_O(k)$ can equivalently be considered either as a non-increasing function of k or as a non-increasing function of η_{ON}.

Once cannibalization occurs in the original market, the equilibrium quantity, price and profits must be adjusted to reflect the new cannibalized demand. If the new demand is (4.9) then the incumbent's monopoly profit in the cannibalized market, according to (4.2), will simply be

$$M_O(k) = \frac{1}{4}(b_O(k) - c_O)^2 \tag{4.11}$$

[9] Any functional form that generates a monotonic non-increasing function of k would do. We are not concerned at this point about the empirical validity of this assumption.

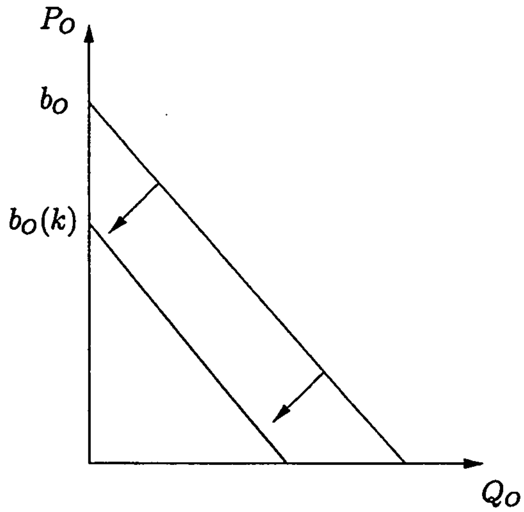

Figure 4.2: **Effect of cannibalization on demand schedule.** d represent the original demand schedule and $d(k)$ is the "cannibalized" schedule with cannibalized ratio k.

where $b_O(k)$ is defined in (4.10). To ensure economic viability in the old market, we impose an upper bound on the cannibalization, i.e., $b_O(k) \geq c_O$, or, if we assume (4.10),

$$k \leq 1 - \frac{c_O}{b_O}.$$

It is important to recognize, though, that the degree of cannibalization in the old market is not only a function of the cross-price elasticity but also of the industry structure of the new market. The prevailing industry structure, within our game, will be determined by the licensing regime selected by the consortium at the beginning of the game. It is reasonable to assume that the degree of cannibalization in the old monopoly market will be higher if a duopoly rather than a monopoly emerges in the new market. This is because the equilibrium industry quantity will be higher under duopoly conditions. This means that a higher fraction of the old technology customer base will be diverted to the new technology market when the new market is a duopoly.

Let us denote by k_D the cannibalization ratio in the old market when a *duopoly* emerges in the new market and with k_M the cannibalization ratio when a *monopoly* emerges in the new market. The above argument implies that

$$0 \leq k_M(\eta_{ON}) \leq k_D(\eta_{ON}) \leq 1, \text{ for all } \eta_{ON} \in [0, \infty). \tag{4.12}$$

Once we take the industry structure of the new market into account, we need to redefine cannibalized monopoly profits (4.11) in the old market. If the new market is a monopoly (which can happen in either the exclusive or the non-exclusive licensing regime) then (4.11) becomes

$$M_O(k_M) = \frac{1}{4}(b_O(k_M) - c_O)^2. \tag{4.13}$$

with $b_O(k_M)$ defined according to (4.10). Similarly, if the new market is a duopoly (which can happen only in the non-exclusive licensing regime) then (4.11) becomes

$$M_O(k_D) = \frac{1}{4}(b_O(k_D) - c_O)^2. \tag{4.14}$$

where $b_O(k_D)$ is defined according to (4.10).

We now have all the necessary ingredients to derive the payoffs in the licensing game and, subsequently, the conditions that guarantee that the strategy of the commons can emerge as an equilibrium solution.

4.2.3 Payoffs in the Licensing Game

Let us denote by R the licensing regime chosen by the incumbent. The regime can be either exclusive or non-exclusive, therefore $R \in \{ex, nex\}$ where ex refers to the exclusive licensing regime and nex to the non-exclusive regime. Let J be the set of players, $J \in \{E, I\}$, where E indicates the entrant and I the incumbent. Finally, we indicate with A^J the action set of player J once the licensing regime has been selected. Each player $J = E, I$ can decide whether to invest in the license for the new invention (i for 'Invest') by paying the licensing fee F or not to license (ni for 'Not Invest'). Formally, $A^J = \{i, ni\},\ \ J = E, I$. The actions selected by player J will be indicated with a^J, $J = E, I$, i.e., $a^J \in \{i, ni\}$.

We denote with

$$^J\Pi^R_{(a^I,a^E)},\ \ J \in \{E, I\},\ \ R \in \{ex, nex\},\ \ (a^I, a^E) \in \{i, ni\}^2, \tag{4.15}$$

the payoff to player J when the incumbent selects the regime R, the incumbent plays action a^I, and the entrant plays action a^E.

In the next subsections we specify the quantities (4.15) for the possible outcomes of the game in the exclusive and non-exclusive licensing regimes.

Payoffs in the Exclusive Licensing Regime

If the incumbent selects an exclusive licensing regime at the beginning of the game (upper branch in Figure 4.1) then the only possible outcome in the new technology market is either a monopoly (held by either the incumbent or the entrant) or the status quo with no entry in the new market and no new technology adoption.

In the *status quo* case ($a^I = a^E = ni$) the payoff from this outcome is obviously zero for both players.[10] Formally,

$$^{I}\Pi^{ex}_{(ni,ni)} = 0 \tag{4.16}$$

$$^{E}\Pi^{ex}_{(ni,ni)} = 0 \tag{4.17}$$

If only the incumbent invests in the license ($a^I = i$, $a^E = ni$), then its old technology market will be cannibalized and lose the amount $M_O - M_O(k_M)$, in the old market (equation (4.13)),[11] and will enjoy the monopoly profit, M_N, from the new market (equation (4.4)) net of the licensing and development fee F. The payoff for the entrant will still be 0. Formally,

$$^{I}\Pi^{ex}_{(i,ni)} = \frac{1}{4}(b_O(1-k_M)-c_O)^2 - \frac{1}{4}(b_O - c_O)^2 + \frac{1}{4}(b_N - c_N)^2 - F \tag{4.18}$$

$$^{E}\Pi^{ex}_{(i,ni)} = 0 \tag{4.19}$$

If only the entrant decides to invest in the new license ($a^I = ni$, $a^E = i$), then it will earn the profit M_N (equation 4.4) from a monopoly position in the new market, net of the licensing fee F while the incumbent will be cannibalized and lose the difference $M_O - M_O(k^M)$ in the old market. Formally,

$$^{I}\Pi^{ex}_{(ni,i)} = \frac{1}{4}(b_O(k_M)-c_O)^2 - \frac{1}{4}(b_O - c_O)^2 \tag{4.20}$$

$$^{E}\Pi^{ex}_{(ni,i)} = \frac{1}{4}(b_N - c_N)^2 - F \tag{4.21}$$

Finally, if both firms decide to invest in the license for the new invention ($a^I = a^E = i$), under the exclusive regime only one is able to obtain the

[10]The incumbent continues to enjoy her monopoly profits in the old technology market. However, these payoffs reflect the *change* in profits caused by the outcome of the licensing game.

[11]The cannibalization ratio is k_M since only a monopoly is possible in the new market under the exclusive regime.

license. We assume that the TLO undertakes a selection process similar, but not entirely, to an auction. We do not model this "auction" formally but simply assume a probability λ $(1-\lambda)$ for the incumbent (entrant) to be assigned the license. We also assume that the fee F' paid by the winner is higher than the one paid to the licensing office in the absence of competition. This reduced form model of the auction process allows us to capture (i) the uncertainty around the potential winner of the license (λ) and (ii) the (likely) higher bid ($F' > F$) that the winner ends up paying for the license. Under these conditions the incumbent will be monopolist in the new market with probability λ and the entrant will be a monopolist with probability $1-\lambda$. Using the payoffs (4.18) and (4.20) we obtain the following payoffs

$$
\begin{aligned}
{}^{I}\Pi^{ex}_{(i,i)} &= \lambda\left(\frac{1}{4}[(b_O(k_M)-c_O)^2-(b_O-c_O)^2]+\frac{1}{4}(b_N-c_N)^2-F'\right) \qquad (4.22)\\
&\quad +(1-\lambda)\left(\frac{1}{4}[(b_O(k_M)-c_O)^2-(b_O-c_O)^2]\right)\\
{}^{E}\Pi^{ex}_{(i,i)} &= (1-\lambda)\left(\frac{1}{4}(b_N-c_N)^2-F'\right) \qquad (4.23)
\end{aligned}
$$

Payoffs in the Non-Exclusive Licensing Regime

The payoffs in the non-exclusive regime (lower branch of Figure 4.1) are derived similarly.[12] The only deviation from the exclusive licensing case is that a duopoly is now possible in the new technology market. In this case, as we noted earlier, the cannibalization ratio will be $k_D \geq k_M$. This will affect the equilibrium monopoly profits in the original market $M_O(k_D)$ and, consequently, the payoffs in the game. The payoffs are identical to the payoffs derived above when at most one player decides to invest in the new technology. Thus, we only focus on the duopoly outcome here. When a duopoly emerges ($a^I = i$, $a^E = i$) then the incumbent enjoys the von Stackelberg profit D^I_N of a leader in the new market (equation (4.5)) and the

[12] It is important to note that the licensing game in the non-exclusive regime is a sequential move game. Potentially many rounds of play will occur before an equilibrium is reached. If we ignore issues related to the timing of appropriation of payoffs, then the analysis in this section is similar to the previous one, under the assumption of a flat term structure with zero interest rates. If however time is important in the determination of payoffs, then, this issue needs to be squarely addressed in the development of the sequential game. We leave this investigation for future research.

entrant the von Stackelberg profit, D_N^E, of a follower (equation (4.6)), net of the licensing and development fee F. The incumbent also loses the difference between the original monopoly profit and the cannibalized monopoly profit $M_O(k_D)$ (equation (4.14)) in the old market. Formally,

$$
\begin{aligned}
{}^{I}\Pi^{nex}_{(i,i)} &= \frac{1}{4}(b_O(k_D) - c_O)^2 - \frac{1}{4}(b_O - c_O)^2 + \frac{1}{8}(b_N - c_N)^2 - F && (4.24)\\
{}^{E}\Pi^{nex}_{(i,i)} &= \frac{1}{16}(b_N - c_N)^2 - F && (4.25)
\end{aligned}
$$

All the other payoffs are the same as in the exclusive regime. We summarize the payoffs in Figure 4.3.

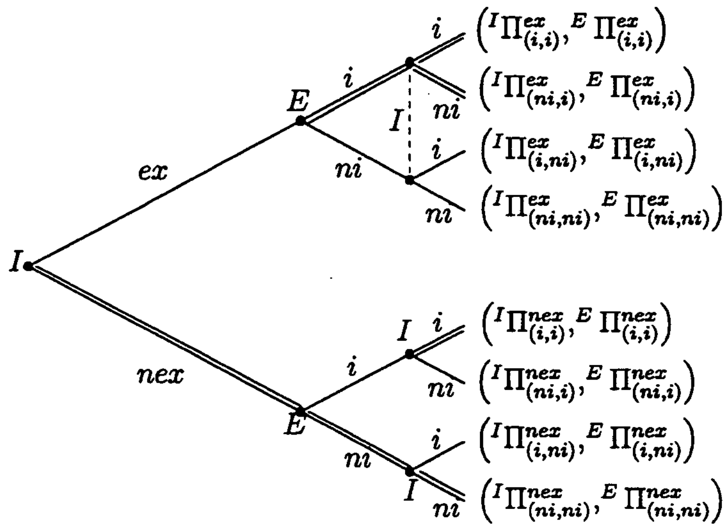

Figure 4.3: **Payoffs in the licensing game.** E indicates the entrant, I the incumbent; ex represents the exclusive licensing regime, nex the Non-exclusive licensing regime; i indicates the decision to invest in the license and ni the decision not to invest in the license. The double branches indicate the "strategy of the commons" solution.

4.3 The Strategy of the Commons as an Equilibrium Solution

In this section we show that, under certain conditions, the strategy of the commons is a subgame perfect equilibrium.

The strategy of the commons occurs when the incumbent selects a non-exclusive regime and then credibly threatens the entrant with entry if the entrant enters. The "social" outcome is therefore a situation in which, despite the potential profitability to the entrant, nobody optimally decides to invest in the license and the invention is not put into use. In Figure 4.3 we indicate with a double branch the sequence of moves that corresponds to the strategy of the commons. We formalize it in the following definition.

Definition 4.3.1. *The strategy of the commons is characterized by the following conditions*

1. Non-Exclusive Regime

$$a^E = ni, \quad a^I(a^E) = \begin{cases} i & \text{if } a^E = i \\ ni & \text{if } a^E = ni \end{cases}, \tag{4.26}$$

2. Exclusive Regime

$$a^E = i, \;\; a^I \in \{i, ni\}, \tag{4.27}$$

3. Regime Selection

$$R = nex, \tag{4.28}$$

where a^I, a^E and R are defined in (4.15).

We now show that there exists a subgame perfect equilibrium in the licensing game in which the strategy of the commons is played. We characterize first (Lemma 4.3.2) the equilibrium in the non-exclusive regime subgame and then (Propositions 4.3.3 and 4.3.4) we provide conditions on the licensing fees F and F' for which the strategy of the commons is an equilibrium. Proposition 4.3.6 characterizes the equilibrium in terms of the cannibalization ratios k_D and k_M.

Lemma 4.3.2. *Let $\xi(k_M, k_D) = M_O(k_D) - M_O(k_M)$, and $\gamma(k_M) = M_O(k_M) - M_O$. Then (ni, ni) is a Nash equilibrium in the non-exclusive regime subgame, compatible with the strategy of the commons (Definition 4.3.1), if and only if, for all $k_M \le k_D \le 1 - \frac{c_O}{b_O}$,* *(i)* $\xi(k_M, k_D) > -\frac{1}{16}b_N^2$;

(ii) $\xi(k_M, k_D) > \frac{1}{3}\gamma(k_M)$.

Proof: We will show the existence of a non-empty region of cost of the new technology (c_N) and licensing fee (F) such that (ni, ni) is a Nash equilibrium supported by an off-equilibrium credible threat of investing in the license by the incumbent. This occurs when

$$
\begin{aligned}
{}^I\Pi^{nex}_{(i,i)} &> {}^I\Pi^{nex}_{(ni,i)} &(4.29)\\
{}^I\Pi^{nex}_{(ni,ni)} &> {}^I\Pi^{nex}_{(i,ni)} &(4.30)\\
{}^E\Pi^{nex}_{(ni,ni)} &> {}^E\Pi^{nex}_{(i,i)} &(4.31)
\end{aligned}
$$

Using the definition of payoffs given above equation (4.29) can be rewritten as

$$F < \frac{1}{8}(b_N - c_N)^2 + \xi(k_M, k_D) \equiv f(c_N) \tag{4.32}$$

Similarly, (4.30) and (4.31) can be written as

$$F > \frac{1}{4}(b_N - c_N)^2 + \gamma(k_M) \equiv g(c_N) \tag{4.33}$$

and

$$F > \frac{1}{16}(b_N - c_N)^2 \equiv h(c_N) \tag{4.34}$$

Therefore (4.29)-(4.31) can be restated as follows

$$
\begin{aligned}
F &< f(c_N) &(4.35)\\
F &> g(c_N) &(4.36)\\
F &> h(c_N) &(4.37)
\end{aligned}
$$

Note that $f(c_N)$, $g(c_N)$ and $h(c_N)$ are convex functions of c_N, decreasing for $c_N < b_N$ and with a global minimum at $c_N = b_N$. Condition (i) is equivalent to $f(0) > h(0)$. Since both f and h are decreasing in $(0, b_N)$, $f(b_N) = \xi < 0$ and $h(b_N) = 0$ there exists a unique $c_N^* > 0$ such that $f(c_N^*) = h(c_N^*)$. Solving explicitly for c_N^* we find

$$c_N^* = b_N - 4\sqrt{-\xi(k_M, k_D)} > 0 \tag{4.38}$$

The above condition is hence necessary and sufficient to guarantee that (4.35) and (4.37) are compatible. Let $\hat{c}_N$ be the (unique) intersection between g and h. It is obvious that (4.36) is compatible with (4.35) and (4.37) if and only if $\hat{c}_N < c_N^*$. Solving for $\hat{c}_N$ we find

$$\hat{c}_N = b_N - 4\sqrt{-\frac{\gamma(k_M)}{3}} \tag{4.39}$$

therefore, using (4.38) and (4.39), $\hat{c}_N < c_N^*$ if and only if $\gamma(k_M) < 3\xi(k_M, k_D)$ which is condition (ii) in the proposition. ■

Figure 4.4 shows a non-empty region A such that for every $(c_N, F) \in A$, Lemma 4.3.2 holds.

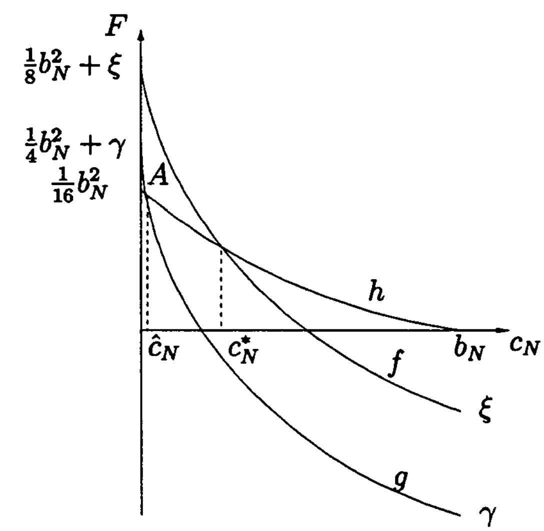

Figure 4.4: **Strategy of the commons equilibrium in the non-exclusive regime.** For every $(c_N, F) \in A$, (ni, ni) is an equilibrium in the non exclusive subgame, compatible with the strategy of the commons.

In the next two propositions we provide conditions on the licensing fees F' such that the strategy of the commons is a subgame perfect equilibrium. We recall that F' is the licensing and development fee paid by the winner of the "technology auction" in the exclusive regime, as described in Section 4.2. For simplicity we assume $F' = \alpha F$, $\alpha > 1$. Proposition 4.3.3 refers to the case in which, off-equilibrium, both firms wish to invest in the new technology while Proposition 4.3.4 addresses the case in which only the entrant invests off-equilibrium.

Proposition 4.3.3. *Let $\xi(k_M, k_D)$ and $\gamma(k_M)$ satisfy the condition in Lemma 4.3.2 and let $F' = \alpha F$, $\alpha > 1$. Then the strategy of the commons is a subgame perfect equilibrium in which, off-equilibrium, both firms invest in the new technology if $F'/F < 4$, i.e., $1 < \alpha < 4$.*

Proof: To find a subgame perfect equilibrium we need to solve the game by backwards induction. Lemma 4.3.2 provided conditions for the existence of an equilibrium in the non-exclusive subgame. We now derive similar conditions for (i,i) to be a Nash equilibrium in the exclusive regime and, finally for *nex* to be the optimal regime selection implemented by the incumbent.

(i,i) is a Nash equilibrium in the simultaneous move game characterizing the exclusive licensing regime if

$$
\begin{aligned}
{}^{I}\Pi^{ex}_{(i,i)} &> {}^{I}\Pi^{ex}_{(ni,i)} &\quad (4.40)\\
{}^{E}\Pi^{ex}_{(i,i)} &> {}^{E}\Pi^{ex}_{(i,ni)} &\quad (4.41)
\end{aligned}
$$

or,

$$F < \frac{1}{4\alpha}(b_N - c_N)^2 \equiv \hat{f}(c_N) \qquad (4.42)$$

Finally, the incumbent will select the non-exclusive regime when

$${}^{I}\Pi^{nex}_{(ni,ni)} > {}^{I}\Pi^{ex}_{(i,i)} \qquad (4.43)$$

or,

$$F > \frac{1}{4\alpha}(b_N - c_N)^2 + \frac{1}{\lambda\alpha}\gamma(k_M) \equiv \hat{g}(c_N) \qquad (4.44)$$

Hence the strategy of the commons is a subgame perfect equilibrium if (4.35)-(4.37), (4.42) and (4.44) are satisfied.

Since $\hat{f}$ is convex, decreasing in $[0, b_N]$ and $\hat{f}(b_N) = 0$ we immediately note that (4.42) is compatible with (4.35)-(4.37) if and only if $\hat{f} > h$ or

$$\frac{1}{4\alpha}(b_N - c_N)^2 > \frac{1}{16}(b_N - c_N)^2$$

which implies $1 < \alpha < 4$.

The constraint (4.44) is never incompatible if $1 < \alpha < 4$. Note, in fact, that if $\lambda\alpha < 1$ then $\hat{g} < g$ and hence the constraint is not binding. If $\lambda\alpha > 1$, let c_N^{**} be the unique intersection between $\hat{g}$ and h. Since, by Lemma 4.3.2, c_N^* (equation (4.38)) is the upper bound of c_N for which an equilibrium exists in the non-exclusive regime, the only way (4.44) can be incompatible with the equilibrium is if $c_N^{**} > c_N^*$. Solving explicitly for c_N^{**} we find,

$$c_N^{**} = b_N - \sqrt{-\frac{\gamma(k_M)}{\lambda(4-\alpha)}}$$

Hence (4.44) is incompatible with the other constraints if $c_N^{**} > c_N^*$ or

$$\lambda > \frac{3}{4-\alpha}$$

which is impossible if $1 < \alpha < 4$ and $\lambda < 1$. We hence showed that if $1 < \alpha < 4$ then there exists a non-empty region (c_N, F) such that the strategy of the commons is a subgame perfect equilibrium supported, off-equilibrium, by both firms investing in the new technology. ■

Proposition 4.3.4. *Let $\xi(k_M, k_D)$ and $\gamma(k_M)$ satisfy the condition in Lemma 4.3.2 and let $F' = \alpha F$, $\alpha > 1$. Then the strategy of the commons is a subgame perfect equilibrium supported, off equilibrium, by only the entrant investing in the new technology if $\alpha > \Gamma(\gamma, \xi)$ where*

$$\Gamma(\gamma,\xi) = \begin{cases} \frac{\xi - 2\gamma}{2\xi - \gamma} & if\ \frac{1}{8}b_N^2 \geq \xi(k_M,k_D) - \gamma(k_M) \\ \frac{1}{\frac{1}{2} + \frac{4\xi}{b_N^2}} & if\ \frac{1}{8}b_N^2 < \xi(k_M,k_D) - \gamma(k_M) \end{cases}.$$

Proof: The proof is similar to the previous proposition. (ni, i) is a Nash equilibrium in the simultaneous move game characterizing the exclusive licensing regime if

$$\begin{aligned} {}^I\Pi^{ex}_{(i,i)} &< {}^I\Pi^{ex}_{(ni,i)} && (4.45)\\ {}^E\Pi^{ex}_{(ni,i)} &> {}^E\Pi^{ex}_{(ni,ni)} && (4.46)\end{aligned}$$

or,

$$F > \hat{f}(c_N) \tag{4.47}$$

and

$$F < M_N(c_N) \tag{4.48}$$

Consequently, the incumbent will select the non-exclusive regime when

$$^{I}\Pi^{nex}_{(ni,ni)} \quad > \quad ^{I}\Pi^{ex}_{(ni,i)} \tag{4.49}$$

or,

$$0 > \gamma(k_M) \tag{4.50}$$

Hence the strategy of the commons is a subgame perfect equilibrium if (4.35)-(4.37), (4.47), (4.48) and (4.50) are satisfied. Evidently (4.50) is always satisfied if $k_M > 0$ and (4.48) is never binding since $\frac{1}{4}(b_N - c_N)^2 > max_{c_N \in [0,b_N]}\{f(c_N), g(c_N), h(c_N)\}$. Therefore the equilibrium is characterized only by condition (4.47). Let us distinguish two cases

1. $f(0) < g(0)$ or, $\frac{1}{8}b_N^2 > \xi(k_M, k_D) - \gamma(k_M)$

   Let $\bar{c}_N$ be the unique intersection between g and f (since $f(0) < g(0)$, then $\bar{c}_N > 0$) and let $\hat{c}_N$ be the unique intersection between $\hat{f}$ and g. Solving explicitly we find

   $$\bar{c}_N = b_N - 2\sqrt{2(\xi - \gamma)}, \quad \hat{c}_N = b_N - 2\sqrt{\frac{\alpha}{1-\alpha}\gamma}.$$

   Since $\bar{c}_N > 0$, an equilibrium exists if $\hat{c}_N > \bar{c}_N$, i.e. if

   $$\alpha > \frac{\xi - 2\gamma}{2\xi - \gamma} \tag{4.51}$$

   which is the first condition in the proposition. Note that the right-hand side of (4.51) is always larger than 2 for $0 > \xi > \gamma/3$ (i.e. when (ii) of Lemma 4.3.2 is true).

2. $f(0) > g(0)$ or, $\frac{1}{8}b_N^2 < \xi(k_M, k_D) - \gamma(k_M)$

   In this case an equilibrium exists if $\hat{f}(0) < f(0)$, or

   $$\alpha > \frac{1}{\frac{1}{2} + \frac{4\xi}{b_N^2}},$$

   which proves the second half of the proposition.

∎

Remark 4.3.5. Note that for $1 < \alpha < 2$ the only equilibrium in the exclusive regime (off-equilibrium condition) is (i,i) and for $\alpha > 4$ the only equilibrium in the exclusive regime is (ni,i). For $2 < \alpha < 4$ either (i,i) or (ni,i) can be an off-equilibrium conditions. It is important to emphasize however that this does not mean multiplicity of equilibria. The equilibrium in which the strategy of the commons is played is always unique, given the level of new technology costs c_N and licensing and development fees F. Moreover, note that the off-equilibrium condition (ni,i) requires a competitive fee F' at least twice as high as the base fee F.

We now characterize the condition in Lemma 4.3.2 in terms of the cannibalization ratios k_M and k_D.

Proposition 4.3.6. *(ni,ni) is a Nash equilibrium in the non-exclusive regime subgame, compatible with the strategy of the commons (Definition 4.3.1), if and only if the following conditions are satisfied for all* $0 \leq k_M \leq 1 - \frac{c_O}{b_O}$.

1. *For $b_N^2 < (b_O - c_O)^2$, $k_M \leq k_D \leq k_D(k_M)$ with*

$$k_D(k_M) = \begin{cases} \hat{k}_D(k_M) & \text{if } 0 \leq k_M < k_M^* \\ \hat{\hat{k}}_D(k_M) & \text{if } k_M^* \leq k_M < \hat{\hat{k}}_M \\ 1 - \frac{c_O}{b_O} & \text{if } \hat{\hat{k}}_M \leq k_M \leq 1 - \frac{c_O}{b_O} \end{cases} \tag{4.52}$$

2. *For $b_N^2 > (b_O - c_O)^2$, $k_M \leq k_D \leq k_D(k_M)$ with*

$$k_D(k_M) = \begin{cases} \hat{k}_D(k_M) & \text{if } 0 \leq k_M < \hat{k}_M \\ 1 - \frac{c_O}{b_O} & \text{if } \hat{k}_M \leq k_M \leq 1 - \frac{c_O}{b_O} \end{cases} \tag{4.53}$$

where

$$\hat{k}_D(k_M) = 1 - \frac{c_O}{b_O} - \frac{\sqrt{\frac{4}{3}(b_O(1-k_M) - c_O)^2 - \frac{1}{3}(b_O - c_O)^2}}{b_O}, \tag{4.54}$$

$$\hat{\hat{k}}_D(k_M) = 1 - \frac{c_O}{b_O} - \frac{\sqrt{(b_O(1-k_M) - c_O)^2 - \frac{1}{4}b_N^2}}{b_O}, \tag{4.55}$$

$$k_M^* = 1 - \frac{c_O}{b_O} - \frac{1}{b_O}\sqrt{(b_O - c_O)^2 - \frac{3}{4}b_N^2}, \tag{4.56}$$

$$\hat{k}_M = \frac{1}{2}\left(1-\frac{c_O}{b_O}\right), \tag{4.57}$$

$$\hat{\hat{k}}_M = 1-\frac{c_O}{b_O}-\frac{b_N}{2b_O}. \tag{4.58}$$

Proof: Let k_M^* be such that $\frac{\gamma(k_M^*)}{3} = \frac{1}{16}b_N^2$, i.e., from the definition of $\gamma(k_M)$,

$$k_M^* = 1-\frac{c_O}{b_O}-\frac{\sqrt{(b_O-c_O)^2-\frac{3}{4}b_N^2}}{b_O} \tag{4.59}$$

Note that k_M^* is well defined only if $\frac{1}{4}b_N^2 \leq \frac{1}{3}(b_O-c_O)^2$. Then, given conditions (i) and (ii) of Lemma 4.3.2 we can distinguish two cases

1. *Case A.* $\frac{1}{4}b_N^2 > \frac{1}{3}(b_O-c_O)^2$. This implies $\frac{1}{16}b_N^2 > -\frac{\gamma(k_M)}{3}$ for all $0 \leq k_M \leq 1-\frac{c_O}{b_O}$, and therefore condition (ii) is the only binding constraint.

2. *Case B.* $\frac{1}{4}b_N^2 \leq \frac{1}{3}(b_O-c_O)^2$. This implies the existence of a k_M^* as defined in (4.59) such that

$$\frac{1}{16}b_N^2 > -\frac{\gamma(k_M)}{3}, \text{ for all } 0 \leq k_M \leq k_M^* \tag{4.60}$$

   and

$$\frac{1}{16}b_N^2 < -\frac{\gamma(k_M)}{3}, \text{ for all } k_M^* < k_M \leq 1-\frac{c_O}{b_O} \tag{4.61}$$

   Therefore condition (ii) is binding for $k_M \in [0, k_M^*]$ and condition (i) is binding for $k_M \in [k_M^*, 1-\frac{c_O}{b_O}]$.

Let us consider case A first. We are interested in the relationship between k_D and k_M such that an equilibrium compatible with the strategy of the commons exists in the non-exclusive regime. Condition (ii) is the only binding constraint. Rewriting it using the definitions of $\xi(k_M, k_D)$ and $\gamma(k_M)$ and rearranging, we obtain

$$\frac{1}{4}(b_O(1-k_D)-c_O)^2 > \frac{1}{3}(b_O(1-k_M)-c_O)^2 - \frac{1}{12}(b_O-c_O)^2 \tag{4.62}$$

By inspection of (4.62) we note that there exists a unique

$$\hat{k}_M = \frac{1}{2}\left(1-\frac{c_O}{b_O}\right) \tag{4.63}$$

such that (4.62) is always satisfied for $k_M > \hat{k}_M$. For $k_M < \hat{k}_M$ (4.62) is satisfied for every $k_D \in [k_M, \hat{k}_D(k_M)]$ where the schedule $\hat{k}_D(k_M)$ is directly obtained from (4.62) and is equal to

$$\hat{k}_D(k_M) = 1 - \frac{c_O}{b_O} - \frac{\sqrt{\frac{4}{3}(b_O(1-k_M) - c_O)^2 - \frac{1}{3}(b_O - c_O)^2}}{b_O} \tag{4.64}$$

Hence for $\frac{1}{3}(b_O - c_O)^2 < \frac{1}{4}b_N^2$ there exists a $\hat{k}_M$ and a schedule

$$k_D(k_M) = \begin{cases} \hat{k}_D(k_M) & \text{if } k_M < \hat{k}_M \\ 1 - \frac{c_O}{b_O} & \text{if } k_M \geq \hat{k}_M \end{cases} \tag{4.65}$$

such that Lemma 4.3.2 is satisfied for $k_M \leq k_D \leq k_D(k_M)$, for all $0 \leq k_M \leq 1 - \frac{c_O}{b_O}$

Note that $\hat{k}_D(0) = 0$, $\hat{k}_D(\hat{k}_M) = 1 - \frac{c_O}{b_O}$. Moreover, $\left.\frac{\partial \hat{k}_D(k_M)}{\partial k_M}\right|_{k_M=0} = \frac{8}{3} > 1$ which guarantees that for every $k_M \in [0, 1 - \frac{c_O}{b_O}]$ there exists a $\hat{k}_D$ such that condition (ii) is satisfied.

We now turn to case B. If $k_M < k_M^*$ then (ii) is binding and $k_D(k_M)$ is determined as in (4.62). We distinguish two subcases, depending on whether $\hat{k}_M > k_M^*$ or $\hat{k}_M < k_M^*$. Using (4.59) and (4.63) we notice that $\hat{k}_M > k_M^*$ for $b_N^2 < (b_O - c_O)^2$ and $\hat{k}_M < k_M^*$ for $b_N^2 > (b_O - c_O)^2$. Therefore, for $k_M < k_M^*$ we have the following cases

B1. For $\frac{1}{4}b_N^2 \leq \frac{1}{4}(b_O - c_O)^2 \leq \frac{1}{3}(b_O - c_O)^2$, $k_M^* < \hat{k}_M$ and Lemma 4.3.2 is satisfied for $k_M \leq \hat{k}_D(k_M)$, $k_M < k_M^*$.

B2. For $\frac{1}{4}(b_O - c_O)^2 \leq \frac{1}{4}b_N^2 \leq \frac{1}{3}(b_O - c_O)^2$, $\hat{k}_M < k_M^*$ and the schedule $k_D(k_M)$ is defined as follows

$$k_D(k_M) = \begin{cases} \hat{k}_D(k_M) & \text{if } 0 \leq k_M \leq \hat{k}_M \\ 1 - \frac{c_O}{b_O} & \text{if } \hat{k}_M \leq k_M \leq k_M^* \end{cases}$$

Finally we look at $k_M > k_M^*$. In this case (i) is the binding constraint. Rewriting it using the definitions of $\xi(k_M, k_D)$ and rearranging, we obtain

$$\frac{1}{4}(b_O(1-k_D) - c_O)^2 > \frac{1}{4}(b_O(1-k_M) - c_O)^2 - \frac{1}{16}b_N^2 \tag{4.66}$$

By inspection of (4.66) we note that there exists a unique

$$\hat{\hat{k}}_M = 1 - \frac{c_O}{b_O} - \frac{b_N}{2b_O} \tag{4.67}$$

such that (4.66) is always satisfied for $k_M > \hat{\hat{k}}_M$. For $k_M < \hat{\hat{k}}_M$ (4.66) is satisfied for every $k_D \in [k_M, \hat{\hat{k}}_D(k_M)]$ where the schedule $\hat{\hat{k}}_D(k_M)$ is directly obtained from (4.66) and is equal to

$$\hat{\hat{k}}_D(k_M) = 1 - \frac{c_O}{b_O} - \frac{\sqrt{(b_O(1-k_M) - c_O)^2 - \frac{1}{4}b_N^2}}{b_O} \tag{4.68}$$

As before we need to distinguish between two subcases: $\hat{\hat{k}}_M < k_M^*$ and $\hat{\hat{k}}_M > k_M^*$. From (4.59) and (4.67), $\hat{\hat{k}}_M < k_M^*$ if $b_N^2 > (b_O - c_O)^2$ and $\hat{\hat{k}}_M > k_M^*$ if $b_N^2 < (b_O - c_O)^2$. Therefore, for $k_M > k_M^*$ we have the following cases

B3. For $\frac{1}{4}b_N^2 \leq \frac{1}{4}(b_O - c_O)^2 \leq \frac{1}{3}(b_O - c_O)^2$, $k_M^* < \hat{\hat{k}}_M$ and Lemma 4.3.2 is satisfied for $k_D \leq k_D(k_M)$ where

$$k_D(k_M) = \begin{cases} \hat{\hat{k}}_D(k_M) & \text{if } k_M^* \leq k_M \leq \hat{\hat{k}}_M \\ 1 - \frac{c_O}{b_O} & \text{if } \hat{\hat{k}}_M \leq 1 - \frac{c_O}{b_O} \end{cases}$$

B4. For $\frac{1}{4}(b_O - c_O)^2 \leq \frac{1}{4}b_N^2 \leq \frac{1}{3}(b_O - c_O)^2$, $\hat{\hat{k}}_M < k_M^*$ and the schedule $k_D(k_M) = 1 - \frac{c_O}{-}b_O$ for all $k_M > k_M^*$.

From conditions B1 and B3 we obtain (4.52) and from (4.65), B2 and B4 we obtain condition (4.53). ■

Figure 4.5 shows the region (k_M, k_D) described in the above proposition. Panel A refers to the case in which $b_N^2 > (b_O - c_O)^2$ while Panel B refers to the case in which $b_N^2 < (b_O - c_O)^2$.

It is easy to show that, in (4.52),

$$\hat{k}_D(k_M^*) = \hat{\hat{k}}_D(k_M^*) = 1 - \frac{c_O}{b_O} - \frac{\sqrt{(b_O - c_O)^2 - b_N^2}}{b_O}$$

and that

$$\left.\frac{\partial \hat{k}_D(k_M)}{\partial k_M}\right|_{k_M = k_M^*} > \left.\frac{\partial \hat{\hat{k}}_D(k_M)}{\partial k_M}\right|_{k_M = k_M^*}$$

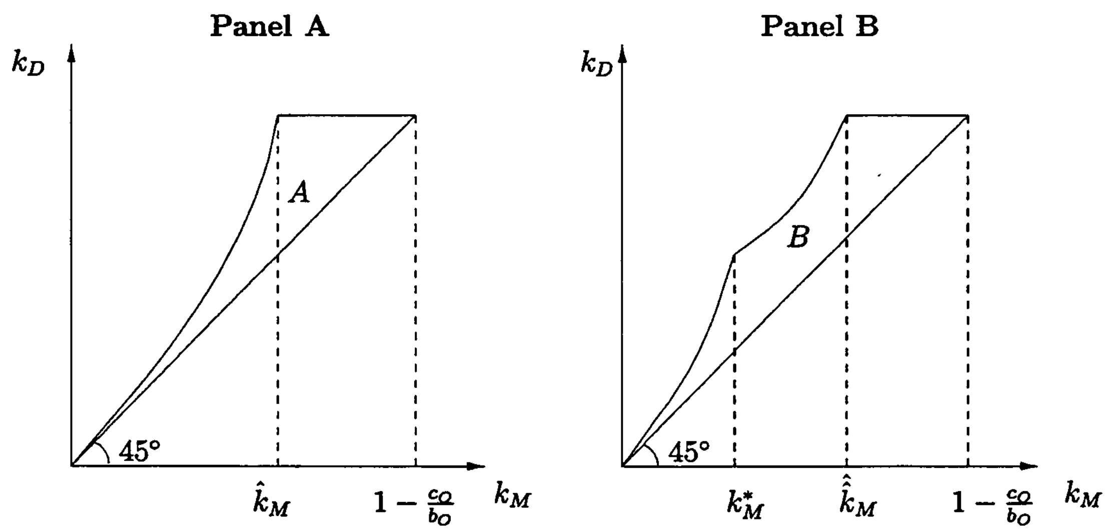

Figure 4.5: **Cannibalization and Strategy of the commons.** Regions of (k_M, k_D) for which (ni, ni) is an equilibrium in the non exclusive subgame, compatible with the strategy of the commons. In Panel A, $b_N^2 > (b_O - c_O)^2$ and Lemma 4.3.2 holds for $(k_M, k_D) \in A$ while in Panel B, $b_N^2 < (b_O - c_O)^2$ and Lemma 4.3.2 holds for $(k_M, k_D) \in B$.

therefore the pasting in k_M^* between $\hat{k}_D(k_M)$ and $\hat{\hat{k}}_D(k_M)$ is not smooth.

We conclude this section with a corollary which follows immediately from the previous results.

Corollary 4.3.7.

1. *If $0 = k_M = k_D$ or $0 = k_M < k_D$ then the strategy of the commons cannot be a subgame perfect equilibrium.*

2. *If $0 < k_M = k_D$ then there exists always an equilibrium in which the strategy of the commons is played.*

Proof: 1. is immediate since if $k_M = 0$ then $\gamma(k_M) = 0$ and consequently, according to (4.32) and (4.33) $g(c_N) > f(c_N)$. This is incompatible with conditions (4.35)-(4.37) in Lemma 4.3.2.

2. When $k_M = k_D$ then $\xi(k_M, k_D) = 0$. Since $\gamma(k_M) < 0$ this implies that there always exists a region (c_N, F) such that Lemma 4.3.2 is satisfied. ■

The corollary shows that cannibalization is indeed the crucial factor that guarantees the emergence of the strategy of the commons as an equilibrium solution. It is interesting to note that if the original monopoly is cannibalized only by a duopoly ($0 = k_M < k_D$) then there cannot be an equilibrium in which the strategy of the commons is played. This is intuitive since under these conditions the duopoly is less attractive and therefore the incumbent loses the possibility of credibly threatening the entrant in the non-exclusive game.

4.4 Social Welfare

When the incumbent plays the strategy of the commons and eliminates the ability to obtain private intellectual property rights, a market failure occurs. It is well known that market failures result in a loss of social welfare. In this section we consider the welfare implications of the strategy of the commons. Specifically, we set out to prove that social welfare losses will indeed occur when the strategy of the commons is played.

The welfare analysis is accomplished by comparing the welfare that results in the non-exclusive regime, under which the strategy of the commons is played, with that which would otherwise result from the exclusive regime. Let W_O^R (W_N^R) denote the social welfare in the old (new) technology market under the licensing regime $R = ex, nex$. The strategy of the commons generate social welfare loss when

$$W_O^{nex} + W_N^{nex} < W_O^{ex} + W_N^{ex}. \tag{4.69}$$

Under monopoly conditions, given a linear demand function and a constant marginal cost, the equilibrium quantity in the old market is $\frac{b_O - c_O}{2}$ and the social welfare under the non-exclusive regime W_O^{nex} is defined as

$$W_O^{nex} = \int_0^{\frac{b_O - c_O}{2}} (b_O - Q - c_O)\, dQ = \frac{3}{8}(b_O - c_O)^2, \quad 0 \le c_O \le b_O. \tag{4.70}$$

We recall that there is no welfare generated from the new technology under the non-exclusive regime because the strategy of the commons prevents this invention from being developed and thus prevents this market from existing. This implies

$$W_N^{nex} = 0. \tag{4.71}$$

Similarly, the welfare quantities in the exclusive regime W_O^{ex} and W_N^{ex} are derived as follows

$$W_O^{ex} = \frac{3}{8}(b_O(1-k_M)-c_O)^2, \quad 0 \le k_M \le 1-\frac{c_O}{b_O} \tag{4.72}$$

$$W_N^{ex} = \frac{3}{8}(b_N-c_N)^2, \quad 0 \le c_N \le b_N \tag{4.73}$$

The following proposition shows when the strategy of the commons will result in a welfare loss.

Proposition 4.4.8. *If $(b_N - c_N) \ge (b_O - c_O)$ then the strategy of the commons will result in a social loss for every value of the cannibalization ratio $k_M \in [0, 1-\frac{c_O}{b_O}]$. If $(b_N - c_N) < (b_O - c_O)$ then there exists an upper bound $k_M^s \le 1 - \frac{c_O}{b_O}$ of cannibalization ratios such that the strategy of the commons will result in a social loss for every $k_M \in [0, k_M^s]$.*

Proof: The proof is immediate. By looking at condition (4.69) and equation (4.70)-(4.73), a social loss occurs when

$$(b_O - c_O)^2 < (b_O(1-k_M)-c_O)^2 + (b_N-c_N)^2 \ , \ 0 \le c_N \le b_N, \tag{4.74}$$

or

$$(b_O - c_O)^2 - (b_N-c_N)^2 < (b_O(1-k_M)-c_O)^2. \tag{4.75}$$

If $(b_N - c_N) \ge (b_O - c_O)$ then (4.75) is always true for every $k_M \in [0, 1-\frac{c_O}{b_O}]$ since the left-hand-side is non-positive and the right hand side is non-negative.

If $(b_N - c_N) < (b_O - c_O)$ then there is a unique level of cannibalization

$$k_M^s = 1 - \frac{c_O}{b_O} - \frac{\sqrt{(b_O-c_O)^2-(b_N-c_N)^2}}{b_O} \tag{4.76}$$

such that (4.75) is satisfied for every $0 \le k_M \le k_M^s$. ■

We provide an intuition behind the above result. If the monopoly profit in the new market $\frac{1}{4}(b_N - c_N)^2$ is bigger than the non-cannibalized monopoly profit in the old market ($\frac{1}{4}(b_O - c_O)^2$) then, the strategy of the commons, by preventing the existence of a profitable market in the new technology, generates social welfare loss, independently of how much the old market would be hurt by the new technology. If, on the other side, the monopoly in the new market is not as profitable as the non-cannibalized profit in the old market then the strategy of the commons may generate social loss provided that the extent to which the old market is hurt is “not too high”. This means that if the cannibalization is too dramatic then the ”market failure” that the strategy of the commons generates prevents the economy to move towards a socially ”less desirable” state.

4.5 Conclusions

The results of this research suggest some interesting and important strategy and policy implications. From a *strategy* perspective, incumbents may consider ways by which to diffuse potential threats from technology fields likely to produce ‘disruptive’ innovations. One such way is to create a market failure by dismantling the legal architecture that offers the intellectual property protection that is often critical to entrants for purposes of raising capital and attracting early adopters. In fact, in many cases it is considered necessary for entrants to acquire a ‘thicket’ of related patents around the key patent in order to instill the required confidence in early stage investors. This implies that the strategy of the commons does not require the incumbent to sponsor *all* research in a particular area to be effective, only enough to prevent an entrant from obtaining *all* of the exclusive intellectual property rights to a potentially threatening substitute. In most cases, a tightly protected intellectual property position is significantly more important for an entrant than for an incumbent.

From a *policy* perspective, governments and university administrations may consider whether particular areas of technical research should be protected from incumbents playing the strategy of the commons. In other words, public sector officials may consider some areas of technological innovation particularly likely to produce ‘disruptive’ technologies that might not be developed by incumbent firms but would likely be developed by entrants. In most cases, these will be technologies that will enable products that have significant cannibalization coefficients (high cross-price elasticities with existing products). In these cases, protection of the legal architecture that establishes private intellectual property rights might be considered. In addition, to the extent that concrete evidence of the strategy of the commons can be uncovered, this may be construed as anti-competitive behavior in some jurisdictions.

Finally, the work presented in this paper offers several directions for future research. The most immediate is for case studies. A detailed examination of the nature of lab sponsorships, the innovations that result, and the subsequent licensing and commercial development of these inventions would be useful. It might prove particularly revealing to investigate the decision making processes of firms that were interested in licensing a technology, but declined because they were unable to obtain an exclusive license. Although the type of data necessary to carry out such 'failure' studies is often not available, most universities keep moderately detailed records concerning all potential licensees that indicated interest in any particular invention. Thus, this type of research seems methodologically possible, at least in principle. In the same spirit, it might prove interesting to study matched pairs of labs working in similar technical areas at different universities where one lab was sponsored while the other was not. Clearly, a positive correlation between non-sponsored labs and higher licensing probabilities would suggest support for the hypothesis modeled here. Empirical work would also offer great value. For example, time series data on the use of non-exclusive licensing sponsorships analyzed in terms of the advent of the 'use it or lose it' clause, the timing of which apparently varied across schools, might prove revealing. A positive correlation between the introduction of these clauses and a sharp increase in non-exclusive licensing sponsorship arrangements would provide compelling evidence in support of the strategy of the commons hypothesis.

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Chapter 5

Future Research

The essays in this thesis present a number of possible directions for a future research program. 'Research program' in this context refers to a general topic of inquiry, rather than specific research questions. Several potential directions for future research include university technology transfer, tacit and complex knowledge, diffusion of innovation, commercialization of early stage inventions, innovation in emerging markets, intellectual property strategies, and markets for intellectual property. Each of these is discussed briefly below.

University Technology Transfer
University technology transfer is an important area, especially since the distinction between 'basic' and commercially-oriented science has become increasingly blurred, particularly in areas such as software and biotechnology. In this thesis, I examined a number of issues such as the effects of interaction and geography on economic performance. However, there are many other interesting dimensions of technology transfer that may vary systematically with commercial success.

For example, regional characteristics vary across universities in different locations. Such characteristics may include assets that are considered complementary to the commercialization of early-stage inventions such as the variety and distribution of local industries, access to capital, and access to skilled labor. Another example is the variation in the allocation of resources across university technology licensing offices. For example, some TLO's outsource their legal work while others perform it in-house. Some TLO's have a greater fraction of licensing officers in areas related to electronics while others are weighted towards the life sciences. Also, some TLO's allocate a large fraction of their operating budget towards marketing their IP while others decidedly avoid marketing.

It would also be interesting to examine and measure the increase in sophistication of university patent licenses over time. For example, beginning in the mid-eighties, several universities began to incorporate 'use-it-or-lose-it' clauses (as described in Chapter 4) into their licensing agreements to prevent firms from strategically licensing inventions with the intention of never developing them. Both the number of university licensing offices and the average budget of these offices have increased by over 200% in the past two decades. So, it would be instructive to examine the changes in organizational structure and resource allocation over time and evaluate these changes in terms of office productivity measured by license agreement income.

Differences in licensing contracts across scientific disciplines is another interesting area for further research. There are a number of important distinctions, for example, between software innovations and biotechnology inventions. Patent protection for software is often only valuable for a few years (2-5) following the date of the invention. Biotechnology patents, on the other hand, may be valuable for much longer. However, biotechnology innovations are often not commercially productive for several years following the issue of a patent due to FDA restrictions (clinical trials) while software patents are often commercially productive even before a patent is issued. As a result of these differences, the processes and skill sets employed for licensing these different types of intellectual properties have diverged over time. This divergence, which might be measured along several different dimensions such as divergence in resource allocations, organizational structure, skill sets, and client bases, would offer valuable insights for better understanding university technology transfer.

Finally, there is a vibrant market for university inventions that occurs outside of the TLO. Some of these transactions are more 'legal' than others. While most universities require that inventions developed by graduate students or faculty be assigned to the university, many inventors have found ways around this restriction. There is significant anecdotal evidence of faculty and graduate students who have 'waited' to leave the university before having an idea. In addition, innovations that are not patented, particularly in areas such as software, are often never declared to the university. The technology licensing office seems to provide a valuable service for those inventors who wish to develop inventions for commercial purposes, but at the same time remain completely in academe. For those faculty and graduate students who enjoy managing their intellectual property themselves and being involved with the development and commercialization of their inventions, either through their own company or in collaboration with others, the value of reporting inventions to the TLO is less obvious. The author suspects there is a sizeable gray market for intellectual property that is traded outside the TLO which may be several times larger than the official university exchange. This area of study would be both interesting and valuable.

Tacit and Complex Knowledge

In chapters two and three of this thesis, the importance of interaction between scientists from the inventor's lab and the importing firm is studied. An examination of the marginal effects of different *types* of interaction is an obvious extension of this work. For example, it would be very interesting and useful to examine the variation in effect across different modes of interaction such as face-to-face, telephone, email, and video conferencing. Also, it is quite likely that the value from different modes of interaction may vary across different types of scientific inquiry. For example, email collaboration on software projects might be more effective than similar interaction on biotechnology problems. One possible methodology for this type of research could be very similar to that outlined in chapter two, but using more finely grained data that identified the type of interaction in each case.

It would also be useful to develop a deeper understanding about different types of scientific knowledge. Why is some knowledge codified while some is not? Knowledge might not be codified because it is impossible to do so (i.e. how John McEnroe serves a tennis ball—many say this information is stored in 'muscle memory') or because it is too costly to do so. For example, there may be many ways to attach a sensor to a robotic arm and the best way might depend on many factors. If this information is not necessary for a publication or patent, the inventor may not record all of the different solutions associated with each set of possible alternative parameters, but rather reveal this information on an as-needed basis when the invention is being developed. So, it would be useful and interesting to develop a robust system of taxonomy for knowledge associated with scientific inventions. This might help us better understand differences in contracts, the importance of interaction, and other dimensions that vary across scientific disciplines. This might also help our understanding of the implications of technology shocks, such as increased access to the Internet, on the market for, and diffusion of scientific knowledge.

Diffusion of Innovation

Figure 2.4 is a map that illustrates the geographic distribution of firms that have licensed a particular set of inventions from MIT between 1983 and 1995. It is obvious from this diagram, which indicates a concentration of firms located in New England relative to the rest of the country and in Massachusetts relative to New England, that there is some localization of knowledge spillovers from MIT. However, the results from the empirical study indicate that there are no systematic distance effects, after controlling for interaction. One conclusion that may be drawn from these two observations is that there are two components to the successful diffusion of innovation: i) awareness of existence and ii) effectiveness of transfer, and that distance has a negative effect on awareness, but not on effectiveness. In other words, firms that are closer to MIT are more likely to be aware of relevant inventions that are generated there, but if two firms of varying distance are both aware of an invention, either is equally likely to successfully commercialize the invention.

It would also be interesting to study the effectiveness of various government and university programs that have been established for the purpose of promoting the diffusion of innovations. Business plan competitions, funding agencies, tax relief programs, entrepreneurship centers, university-corporate partnerships, and other programs have been established for the purpose of facilitating the diffusion of commercially-valuable innovations. By examining the relative efficacy of such programs, one might increase our understanding of the diffusion process itself.

Commercialization of Early Stage Inventions

In chapters two and three, the importance of interaction and geography on the commercialization of early stage inventions was examined. There are many other factors that may vary systematically with commercialization success. Such factors include, but are not limited to, access to capital, access to talent, regulatory environment, competition, and the size and nature of demand. Early stage inventions have particular characteristics, such as high development uncertainty and high performance uncertainty, and therefore require a particular economic environment for successful commercialization. Much research has already been conducted to increase our understanding of localized hi-tech regions such as Silicon Valley and Route 128. There is still much to do on this topic.

For example, 'the incubator' is a topic of growing economic importance for the commercialization of early stage inventions. There are a variety of types of incubators that offer different services, but in general they bundle real estate, venture capital, accounting, legal, marketing, administration, and general management services into a single market offering. This offering seems to address the problem of high transaction costs associated with young technology firms which require small amounts of this diverse array of services as well as market failures that arise when such firms have access to equity but not capital. The number of private sector incubators in the United States has increased ten-fold to over six hundred during the period from 1995 to 2000. Incubators vary across the technology and industry sectors they work with, the services they offer, and their own organizational structure and reputation. Each of these parameters may be measured and compared with the performance of the incubated companies for systematic variance.

Innovation in Emerging Markets

While there has been a significant amount of research conducted in the area of innovation in developed economies, comparatively little work has been done on studying the differences in emerging markets. There have been notable changes in the pattern of innovation in several emerging markets over the past two decades. For example, pharmaceutical firms in India that have traditionally manufactured products developed elsewhere (often infringing on patents held by foreign firms) have begun to develop their own intellectual property with their own R&D capabilities. Why did this transition occur when it did? How did it happen? Some answers to these questions may be revealed in the patent and publication information, including who the inventors were and where they were trained, patent citations, publication citations, recruiting patterns, R&D expenditures, patent enforcement, government regulation, globalization of markets, foreign competition, joint ventures, and changes in organizational structure. A clearer understanding of innovation in emerging markets may also deepen our understanding of innovation in general.

Intellectual Property Strategies

Throughout this thesis, licensing agreements were treated as homogeneous. However, although each agreement originates from the same 'template' contract, each is customized for the particular invention and licensee. The manner in which these contracts are crafted is a function of the bargaining power and sophistication of the licensee firm and the university licensing officer. It would be very revealing to first identify the dimensions in which licensing contracts vary and then identify those factors that vary systematically with performance. For example, some dimensions in which licensing contracts vary include their degree of exclusivity, royalty payment terms, and development milestones. Also, some inventions are not patented for strategic reasons, but rather protected by trade secret or other forms of protection. In addition, some firms patent inventions for the purpose of having 'trading cards' for cross-licensing purposes, rather than to protect a particular technology that is relevant to their business. A better understanding of intellectual property strategies practiced by firms would provide greater insight into the nature of the market for IP.

Markets for Intellectual Property

An interesting new market has developed for trading in intellectual property. A variety of web sites have been created to buy and sell patents or patent licenses, often in an auction format. For example, large firms that develop inventions not within the scope of their business may sell the rights to their inventions in such a market. It would be very useful to examine the efficiency and effectiveness of such markets for inventions. Given the results presented in this thesis which suggest that interaction with the inventor is important for the commercialization of many early stage inventions, it is not clear that such a market would be particularly useful unless the inventor is able to include a contractual obligation to collaborate with the buyer in the market offering. This type of market is a new phenomenon and it will take some time before its effectiveness can be evaluated. However, it does provide many interesting new questions about the transfer of ideas and may eventually provide data that will reveal some answers.

Appendix A

University-Firm Research Collaboration Plan

University-Industry Research Collaboration Plan

Technical Objectives

The main objective of the proposed collaborative research was an experimental identification based solution to the problem of dynamic payload monitoring for multi-link hydraulic manipulators. The following performance specifications were set with potential licensees:

- The system should be easy to install, require minimal maintenance, and use rugged sensors on the links.
- The system should have a simple self-calibration capability.
- The acceptable accuracy for payload measurement is 3% of the full-scale load.
- The payload estimation result should be ready, without the need to stop the links from motion, in less than 2 seconds after loading the bucket.
- The system should be scalable for different types and makes of the multi-link hydraulic manipulators.

Figure 1 shows a picture of the Takeuchi TB035 mini-excavator which was located in the UBC CICSR Robotics and Control Laboratory. This machine was used for payload monitoring experiments in the course of this project.

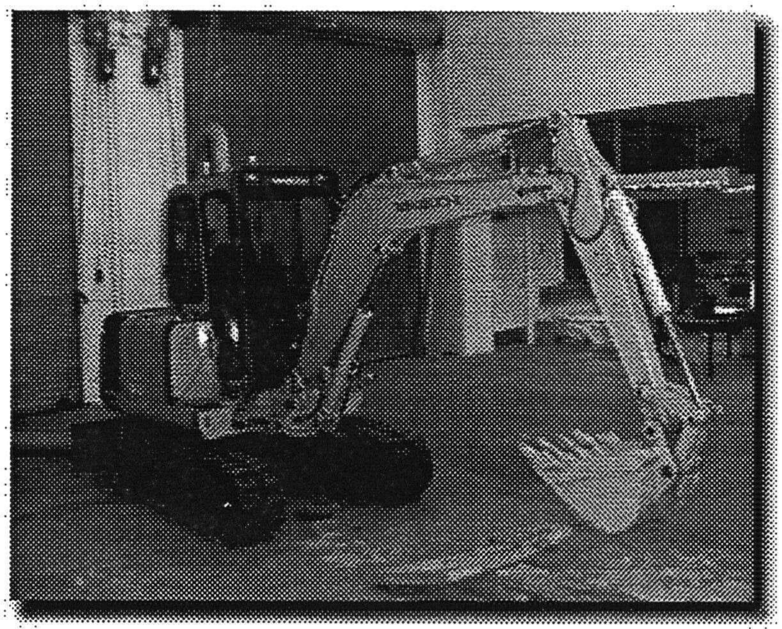


Figure 1. The Takeuchi TB035 mini-excavator located at the UBC CICSR Robotics Laboratory.

Figure 2 shows details of the instrumentation on the machine arm which included the following:

- ♦ Digital resolvers for direct measurement of the joint angles
- ♦ Hydraulic pressure transducers for sensing the head-side and rod-side pressures of the main cylinders
- ♦ On board electronics (power supply, sensor interface circuitry, etc.)
- ♦ On board computer (VME cage with SPARC 1E processor board, A2D board, R2D board, etc.)

The programs – written in C language and compiled on Unix machines – were downloaded to the embedded computer via Ethernet to run under the VxWorks real-time operating system.

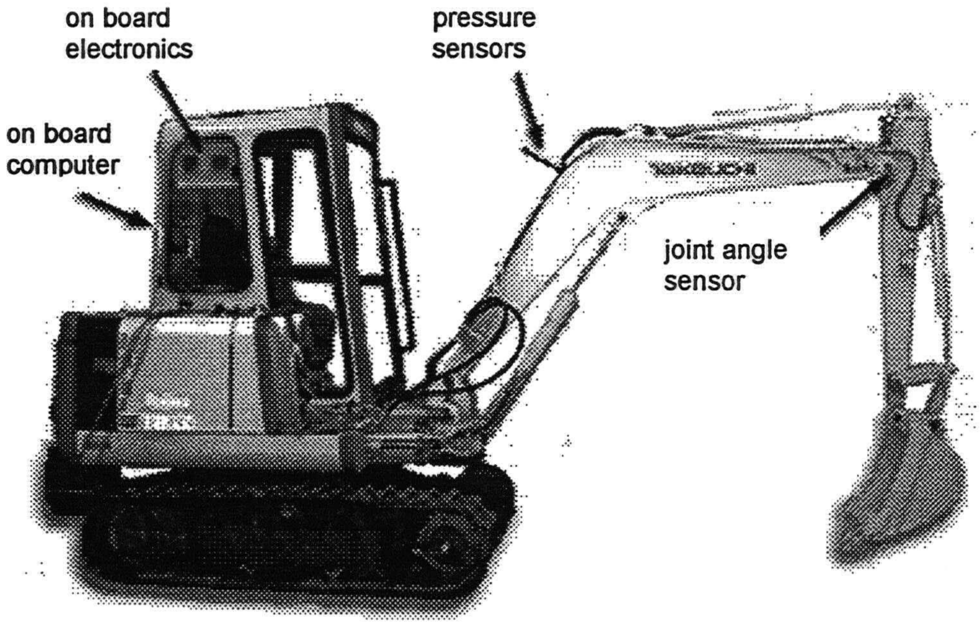


Figure 2. Instrumentation of the Takeuchi mini-excavator.

Figure 3 shows schematic of the mini-excavator along with the conventional names of the links. The excavator shown in this figure is holding a mass of M=82 Kg inside its bucket. A typical display of the payload monitoring system is shown in this figure. Note that both instantaneous and accumulative measurements are displayed to the machine operator.

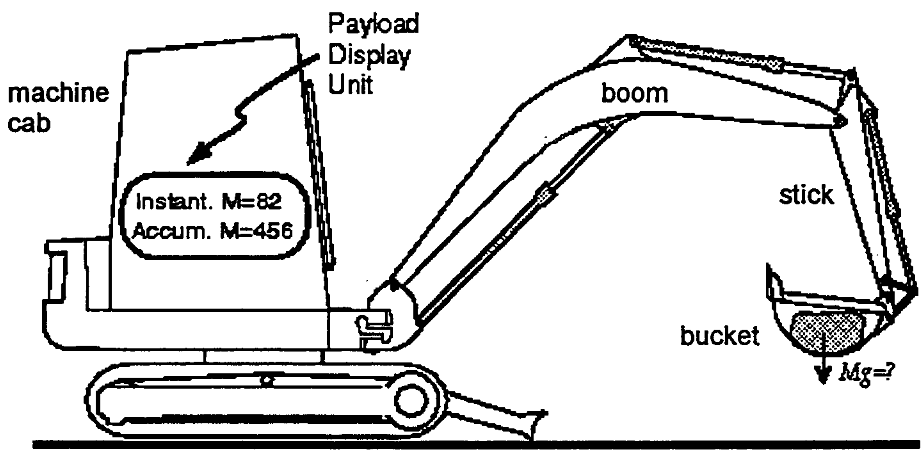


Figure 3. Mini-excavator schematic while holding a load with a mass of $M=82\ Kg$ in its bucket.

The results of Dr. Tafazoli's Ph.D. work on experimental identification of the manipulator dynamics provide the basis for the proposed payload monitoring algorithm. The approach can be concisely expressed as follows:

> First, in a one-time calibration procedure, determine the parameters that specify the manipulator dynamics. Then, use these fixed parameters for real-time estimation of the joint torques (or joint torque differences) in the current state of the machine arm assuming there is no load inside the bucket. Any discrepancy between the "estimated no-load torques" and the "measured joint torques in real-time and in the presence of the payload" is due to the payload mass. Thus, recursive solution of the corresponding equation in real-time is the answer to the challenging problem of dynamic payload monitoring.

Technical Challenges

Both the sensors and the embedded computer could be purchased "off-the-shelf". The innovation was in real-time, intelligent analysis of the sensory data to provide fast and accurate estimation of the bucket payload, without the need to stop the machine links from moving. The major technical challenges that were faced in this project are listed:

- Due to the multi-link structure of these machines, the equations of motion, which are second order, coupled, nonlinear, ordinary differential equations that relate the joint torques to the joint angles are fairly complex and lengthy. Derivation of the complete set of equations and expressing them in a form which is linear in dynamic parameters was previously investigated. There were two challenging issues that needed to be addressed in this regard. The first issue was the simplification of the equations and experimental verification that identification accuracy was not sacrificed by such simplification. The second issue concerned the form of the equations when accelerometers (as indirect position sensors) were used instead of resolvers which are direct joint angle sensors.

- An automated calibration procedure needed to be devised for experimental determination of the dynamic parameters. This required simultaneous movement of the manipulator links and recording of the sensor outputs to be fed to the identification algorithm. This issue had never been addressed before and required elaboration. The calibration process resulted in a set of fixed dynamic parameters which were then used in the payload monitoring algorithm.

- The system design had to comply with the performance specifications listed above. In particular, achieving the required accuracy and speed were challenging tasks. The algorithm had to differentiate between bad data and good data, in order to provide accurate results. Also, it had to be able to reset itself upon sudden changes such as "the excavator bucket hitting the ground" or "the bucket losing part of its payload".

Background – Excavators as Robots

From a robotics perspective, the excavator can be considered as a 4 degree of freedom (4-DOF) manipulator whose links are the cab, boom, stick, and bucket. Unlike the conventional robots (such as PUMA and SCARA) which are controlled by rotary actuators (motors), the excavator links are activated by cylinders which are linear actuators. However, in both cases the manipulator joints are revolute. As a result of using linear actuators the joint angles have limited range of motion. One can consider the excavator (and similar other hydraulic machines) to be formed by a combination of open and closed kinematic chains. However, for simplicity, the closed kinematic part (formed by cylinders and their minor linkages) is ignored here and the schematic diagram shown in Figure 4 is assumed.

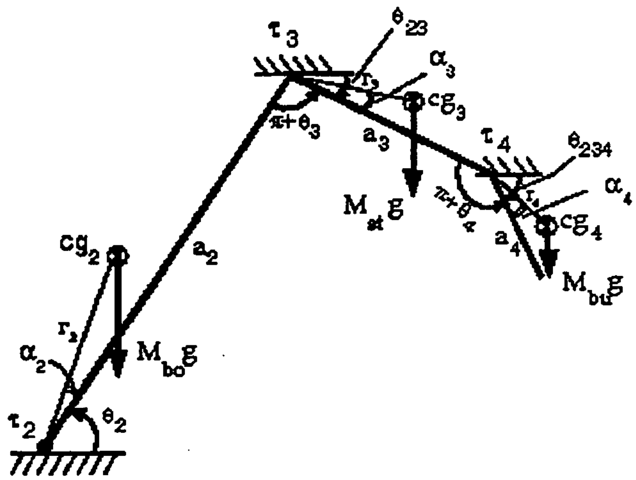
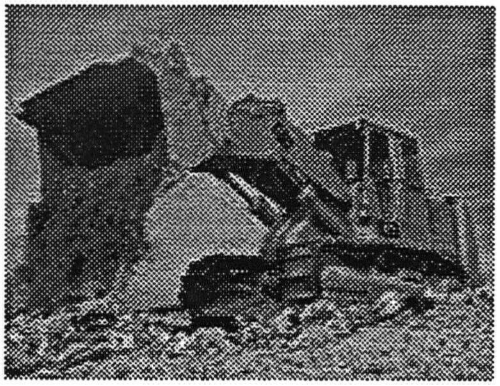


Figure 4. Schematics of the excavator arm as an open kinematic chain, with the gravitational forces.

Appendix B

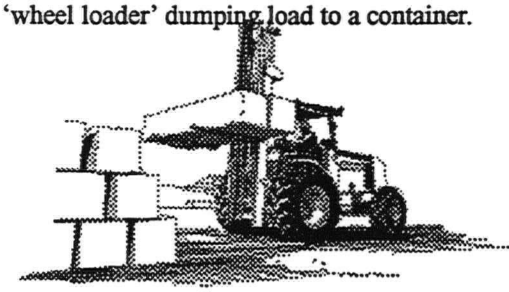
Single-Link VS Multi-Link Machines

Single-Link Machines



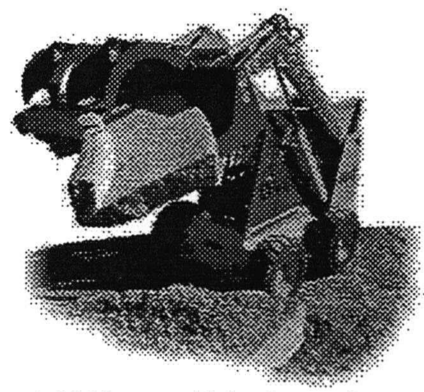
A 'track loader'.

A 'wheel loader' dumping load to a container.



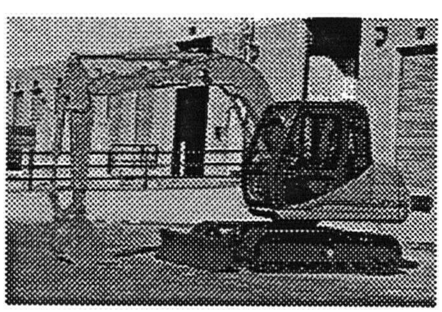
A 'forklift'.

A 'skid steer'.



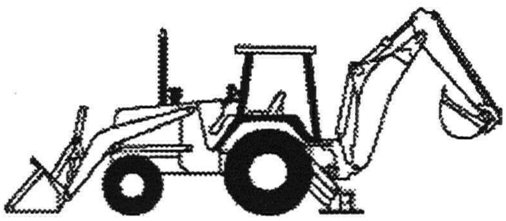
A 'skid steer with loader-arm'.

Multi-Link Machines

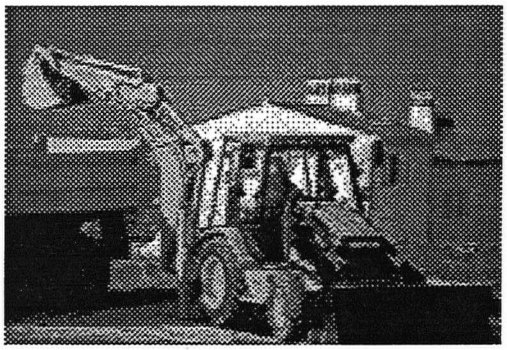


A 'mini-excavator'.

An 'excavator' loading a truck.



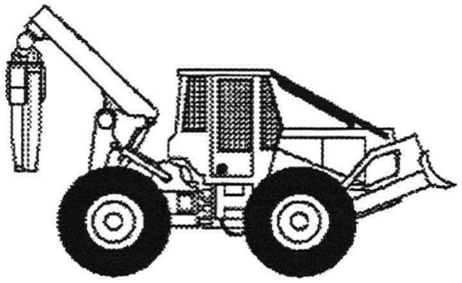
A 'backhoe loader'.



A 'backhoe loader' loading a truck.

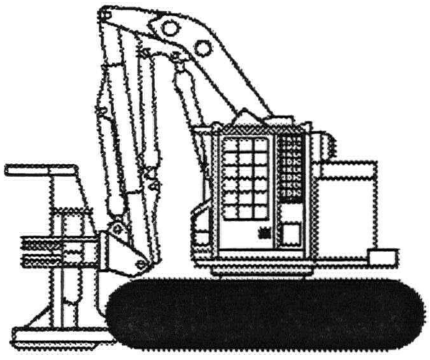
A mining 'face shovel'.

A 'telescopic handler'.



A 'skidder'.

A multi-link 'log loader'.



A 'feller buncher'.

Appendix C

Survey Instrument - Sample

Questionnaire

Name: Erich P Ippen
Phone
Email
Office
Lab
CV
Faculty at MIT since:
Other faculty recommended:

Section 1: Information Transfer from the Inventor to the Licensee Firm

The following questions refer to your patent 'Stretched-Pulse Additive Pulse Mode-Locked Fiber Ring Laser' that has been licensed to XXXX Inc.

1. How did you come into contact with XXXX Inc.?

A. Previously worked there
B. Grad student went to work there after finishing at MIT
C. Firm read one of my publications
D. Our lab initiated contact with them in order to use some of their equipment
E. We met at a conference – they saw me give a presentation
F. We met at a conference – I saw them give a presentation
G. They were involved with someone else at MIT who referred them to me
H. I never had contact with them, the TLO found them as a potential licensee
I. Other (please specify)

2. When did your relationship with XXXX Inc. begin?

- Year:

3. Describe the sponsorship relation with XXXX Inc. before and during the license agreement.

Did they sponsor:	BEFORE		DURING	
you	Yes	No	Yes	No
your lab	Yes	No	Yes	No
MIT	Yes	No	Yes	No

4. Quantify your relationship with XXXX before and during the license agreement.

	BEFORE	DURING
Research Collaboration (#hours):		
Research Collaboration (#co-authored publications):		
Research Collaboration (Equipment sharing – Y/N))		
Consulting (#hours):		
Company affiliation i.e. advisor, board, etc.(months):		
Co-supervise grad student research (months):		
Hire a grad student (months):		
Other (please specify):		

5. **Quantify, in terms of hours, the amount of time you spent working on this invention after it was licensed, but before it began generating revenues (1 person year = 2000 hrs, 1 month = 160 hrs, 1 week = 40 hrs, 1 day = 8 hrs). Only include work that was done in collaboration or close communication with the licensee firm. #hrs__________**

6. **Quantify, in terms of hours, the amount of time graduate students or research scientists from your lab spent working on this invention after it was licensed, but before it began generating revenues (1 person year = 2000 hrs, 1 month = 160 hrs, 1 week = 40 hrs, 1 day = 8 hrs).). Only include work that was done in collaboration or close communication with the licensee firm. #hrs__________**

7. **Describe the process, in terms of your involvement with these firms, leading up to the actual licensing agreement. Include estimates of time (how long things took).**

____

____

____

8. **How were you inspired to begin work on the research question that eventually led to the invention that was licensed? (ie. Was it inspired by these firms, a different company? Currently topical in academic circles?)**

   A. Inspired by these companies
   B. Inspired by industry, but not by these companies
   C. Inspired by a gap in the literature
   D. Other (please specify)

9. **How sure were you that there *might be a patentable outcome* when you began work on the research question that eventually let to the invention that was licensed?**

   A. 75-100%
   B. 50-75%
   C. 25-50%
   D. 0-25%
   E. I had no idea whether this research would lead to a patent

10. How sure were you that the *each of these companies would actually license this invention* when you began work on this research project, given that the research was successful?

A. 75-100%
B. 50-75%
C. 25-50%
D. 0-25%
E. I had no idea whether this firm would be interested

11. List any other companies that you thought might be interested in licensing this technology and also had any relations with.

Company Name	Type and degree of relationship

12. Explain why you think these companies did not take out a license.

____

____

____

Section 2: Personal Characteristics of the Inventor

1. Briefly describe (list) your employment history since grad school

Employer	Years

2. Was your PhD thesis of direct interest to any firms? If so, which ones?

1. ____________________
2. ____________________
3. ____________________

3. List the academic publications you read at least semi-regularly, including title, frequency of publication, and frequency of reading. 'Read' is defined as skimming the titles and reading at least one paper/article.

Title	Publication frequency	Reading frequency

4. **List the non-academic publications you read at least semi-regularly, such as trade journals and popular media, including title, frequency of publication, and frequency of reading.**

Title	Publication frequency	Reading frequency

5. **List the title and location (city, state/country) of academic conferences you attended during 1998.**

Title	Location

6. **List the title and location (city, state/country) of industry conferences or trade shows you attended during 1998.**

Title	Location

7. **How many private affiliations do you currently maintain (advisor, board member, etc.)**

- #________

8. On average, how many calls did you receive from industry per month in 1998?

- #________

9. How many company site visits did you make in 1998?

- #________

10. How many academic presentations did you give in 1998?

- #________

11. How many industry presentations did you give in 1998?

- #________

12. Have you ever attempted to start a hi-tech company?

- Yes No (if 'No', skip to Question 16)

13. If so, how long were you involved in this effort?

- ______ yrs

14. What was/is your role in the company?

- ______________

15. What stage did the company get to (idea, prototype, production, sales)?

- ________________

16. What fraction of your Ph.D. students go on to academic jobs, rather than industry?

- _______%

17. What fraction of the research of your most recent past 5 grads students was of direct interest to industry?

- 0-25% 25-50% 50-75% 75-100%

18. Do you have a web site?

- Yes No

19. How many industry people, if any, contacted you in 1998 as a result of your web site?

- #_______

20. How many academic research faculty, if any, contacted you in 1998 as a result of your web site?

- #_______

21. When people from industry contact you on matters regarding your technical expertise, how have they found out about you? Estimate the fractions.

	%
They read at least one of my publications	
They heard me speak at a conference	
They were referred to me by a grad student	
They were referred to me by an MIT colleague	
They were referred to me by someone who wasn't a grad student or MIT colleague	
They learned about me through my web page	
Other, please specify:	
	100%

22. What fraction of your research funding comes from the private sector?

- ♦ _____%

Section 3: Channels of Knowledge Flow

1. Consider any and all influence your research, *past and present*, has had on industry activities, including research, development and production, during 1998. Estimate the portion of that influence that was transmitted through each of the following channels.

	Percentage (%)
A. through patents (active license agreements in 1998)	
B. through publications (publications from anytime)	
C. through consulting (anytime)	
D. through informal conversations (anytime)	
E. through co-supervising grad students (during 1998)	
F. through industry hiring your grad students (anytime)	
G. through conference presentations (anytime)	
H. through private presentations to firms (anytime)	
I. other (please specify)	

100%

2. List the firms that you think may have utilized your research output (research conducted at any time) during 1998. Indicate if you have had any direct relationship with any of these firms using the key below.

KEY
A. Collaborative research
B. Consulting
C. Informal conversations
D. Hired grad student
E. Co-supervised grad student
F. Licensed patent
G. Other (please specify)

Firm	Type of contact	Degree of contact (hrs)

Section 4: The Scientific & Economic Importance of Publications

Below (Appendix A) are 8 lists of your *older* publications. Each list contains several publications from one particular year (1989-1996).

1. **Rank the publications (High, Medium, or Low) in terms of the influence you think these publications have had on your field in *academic circles*.**
2. **Rank the publications (High, Medium, or Low) in terms of the influence you think these publications have had on *industry*.**
3. **Economists often use citations as a measure of influence or importance. Appendix B contains the same lists as in Appendix A but include paper rankings by # of citations. Comment on any significant discrepancies between your ranking and the rank by citation count. Why do you think they are different?**

Below (Appendix C) are 2 lists of your *recent* publications. Each list contains several publications from one particular year (1997 and 1998).

4. **Rank the publications (High, Medium, or Low) in terms of the influence you think these publications *will have* on your field in *academic circles*.**
5. **Rank the publications (High, Medium, or Low) in terms of the influence you think these publications *will have* on *industry*.**

Section 5: Network Theory: Origins of Scientific Collaboration

1. **The 39 of your publications listed below (Appendix D) were co-authored with at least one person from industry. Use the key below to indicate how each of these collaborations came about. Also include an estimate (# years) of the duration of the collaborative relationship with this person.**

KEY

A. Co-author was a former grad student who went to that company
B. Used equipment/materials from that company
C. Friend from grad school works at that company
D. Former colleague works at that company
E. Did sabbatical at that company
F. Someone from that company did sabbatical at MIT
G. Company read my papers and was interested to work with me
H. I read their papers and was interested to work with them
I. We work in the same circles – they approached me
J. We work in the same circles – I approached them
K. I was formerly employed with this company
L. I can't remember
M. Other (please specify)
N. Funded by the company
O. Co-op program

Section 6: Disclosing, Patenting and Licensing

The list below contains your invention disclosures to the Technology Licensing Office.

Case	Disclosure Title
1.	Stretched-pulse additive pulse mode-locked fiber ring laser
2.	Modelocking and noise suppression via asynchronous phase modulation

1. **No patent applications were ever filed for the following disclosure #s: 1. Suggest *why no patent application was ever filed.***

Case #	Reason

2. **OMIT Although patent applications were filed, no patents were actually granted for the following disclosure #s: 7 & 8. Select two of these cases and suggest *why no patent was granted.***

Case #	Reason

3. **OMIT Although the following disclosures were awarded a patent, these patents were never licensed: #1,2&3. Suggest *why the patent was never licensed.***

Case #	Reason

4. **What percentage of your colleagues do you think select research questions with the primary reason being:**

	Percentage
A personal history of research on closely related questions	
Greater access to funding for this area of inquiry	
Academically topical	
Commercially applicable	
Other (please specify)	
	100%

5. **On average, what share of royalties do you think faculty in your industry area receive (ie. %net sales of licensee firm)?**

   - ______%

6. **Estimate how much money was distributed to inventors last year in EECS**

   - ______$

7. **Is there a cap on inventor royalties at MIT?**

   - Yes No

8. **Who are the relevant technology licensing officers at the TLO in your field?**

   - ____________
   - ____________

9. **What are the 3 most useful functions performed by the licensing officers relative to licensing faculty inventions?**

   - ______________
   - ______________
   - ______________

10. What do you think is the likelihood of you filing a patent application in the future?

A. 0-25%
B. 25-50%
C. 50-75%
D. 75-100%

11. How much of *your* time do you think would be required to file a patent application for an invention for which you are the primary inventor?

- ______hrs

12. What would be the minimum amount you would expect to receive in royalties over a 10 year period in order to file a patent application?

- ______$

13. Have you ever considered starting a company based on your research area?

- Yes No

14. What do you think is the likelihood of you starting a company in the future?

A. 0-25%
B. 25-50%
C. 50-75%
D. 75-100%

15. What fraction of your time do you think would be required to found a company based on an invention of which you are the primary inventor?

- _______%

16. What are the reasons that would motivate you to start a company?

- ________________________________
- ________________________________

17. What would be the minimum amount you would expect to receive in equity value over 10 years in order to start a company?

- ________$

18. Do you think you would be more likely to have your invention commercialized by starting your own company or licensing your innovations to others?

♦ Start a company	________%
♦ License the invention	________%
	100%

19. What would be the greatest amount of time that you would be willing to postpone the publication of a paper in order to file a patent application?

- ________months

20. In general terms, how many patents in your research area would you consider equal to 3 top tier journal publications (assuming an uncertain value of the patent)?

- ________ patents

21. What would be the minimum amount of royalties that you would expect to receive to make a patent a worthwhile alternative to a top tier journal publication?

- ________ $

22. In the context of a selection committee member for new faculty, rank the following candidate portfolios, *ceteris paribus*:

	Rank
♦ 3 publications, 8 patents	______
♦ 4 publications, 6 patents	______
♦ 6 publications, 4 patents	______
♦ 8 publications, 3 patents	______

23. What do you think would be the effect on your salary from one more publication?

- _____%

24. What do you think would be the effect on your salary from one more patent?

- _____%

APPENDIX A - IPPEN

Annotate the publications listed below (√ = high impact, √√ = 'blockbuster') in terms of the influence you think these publications have had on your field in *academic circles*, and, separately, the influence you think they have had on *industry*.

				Influence in Academic Circles	Influence in Industry
DOUGHERTY, DJ KARTNER, FX HAUS, HA IPPEN, EP	MEASUREMENT OF THE RAMAN GAIN SPECTRUM OF OPTICAL FIBERS	Opt. Lett.	1995		
LENZ, G TAMURA, K HAUS, HA IPPEN, EP	ALL-SOLID-STATE FEMTOSECOND SOURCE AT 1.55 MU-M	Opt. Lett.	1995		
HALL, KL MOORES, JD RAUSCHENBACH, KA WONG, WS IPPEN, EP HAUS, HA	ALL-OPTICAL STORAGE OF A 1.25 KB PACKET AT 10 GB/S	IEEE Photonics Technol. Lett.	1995		
MOORES, JD HALL, KL LEPAGE, SM RAUSCHENBACH, KA WONG, WS HAUS, HA IPPEN, EP	20-GHZ OPTICAL STORAGE LOOP LASER USING AMPLITUDE-MODULATION, FILTERING, AND ARTIFICIAL FAST SATURABLE ABSORPTION	IEEE Photonics Technol. Lett.	1995		
HAUS, HA TAMURA, K NELSON, LE IPPEN, EP	STRETCHED-PULSE ADDITIVE-PULSE MODE-LOCKING IN FIBER RING LASERS - THEORY AND EXPERIMENT	IEEE J. Quantum Electron.	1995		
TAMURA, K IPPEN, EP HAUS, HA	PULSE DYNAMICS IN STRETCHED-PULSE FIBER LASERS	Appl. Phys. Lett.	1995		
NELSON, LE IPPEN, EP HAUS, HA	BROADLY TUNABLE SUB-500 FS PULSES FROM AN ADDITIVE-PULSE MODE- LOCKED THULIUM-DOPED FIBER RING LASER	Appl. Phys. Lett.	1995		
SUN, CK VALLEE, F ACIOLI, LH IPPEN, EP FUJIMOTO, JG	FEMTOSECOND-TUNABLE MEASUREMENT OF ELECTRON THERMALIZATION IN GOLD	Phys. Rev. B-Condens Matter	1994		
TAMURA, K DOERR, CR NELSON, LE HAUS, HA IPPEN, EP	TECHNIQUE FOR OBTAINING HIGH-ENERGY ULTRASHORT PULSES FROM AN ADDITIVE-PULSE MODE-LOCKED ERBIUM-DOPED FIBER RING LASER	Opt. Lett.	1994		
BERGMAN, K HAUS, HA IPPEN, EP SHIRASAKI, M	SQUEEZING IN A FIBER INTERFEROMETER WITH A GIGAHERTZ PUMP	Opt. Lett.	1994		
DOERR, CR HAUS, HA	ASYNCHRONOUS SOLITON MODE-LOCKING	Opt. Lett.	1994		

IPPEN, EP					
DOERR, CR WONG, WS HAUS, HA IPPEN, EP	ADDITIVE-PULSE MODE-LOCKING LIMITING STORAGE-RING	Opt. Lett.	1994		
DOERR, CR HAUS, HA IPPEN, EP SHIRASAKI, M TAMURA, K	ADDITIVE-PULSE LIMITING	Opt. Lett.	1994		
HALL, KL LENZ, G DARWISH, AM IPPEN, EP	SUBPICOSECOND GAIN AND INDEX NONLINEARITIES IN INGAASP DIODE- LASERS	Opt. Commun.	1994		
KHATRI, FI LENZ, G MOORES, JD HAUS, HA IPPEN, EP	EXTENSION OF COUPLED-CAVITY ADDITIVE-PULSE MODE-LOCKED LASER THEORY	Opt. Commun.	1994		
HIRAYAMA, Y SMET, JH PENG, LH FONSTAD, CG IPPEN, EP	FEASIBILITY OF 1.55 MU-M INTERSUBBAND PHOTONIC DEVICES USING INGAAS/ALAS PSEUDOMORPHIC QUANTUM-WELL STRUCTURES	Jpn. J. Appl. Phys. Part 1 - Regul. Pap. Short Notes Rev. Pap.	1994		
KARTNER, FX DOUGHERTY, DJ HAUS, HA IPPEN, EP	RAMAN NOISE AND SOLITON SQUEEZING	J. Opt. Soc. Am. B-Opt. Phys.	1994		
TAMURA, K DOERR, CR HAUS, HA IPPEN, EP	SOLITON FIBER RING LASER STABILIZATION AND TUNING WITH A BROAD INTRACAVITY FILTER	IEEE Photonics Technol. Lett.	1994		
TAMURA, K IPPEN, EP HAUS, HA	OPTIMIZATION OF FILTERING IN SOLITON FIBER LASERS	IEEE Photonics Technol. Lett.	1994		
HAUS, HA IPPEN, EP TAMURA, K	ADDITIVE-PULSE MODELOCKING IN FIBER LASERS	IEEE J. Quantum Electron.	1994		
TAMURA, K NELSON, LE HAUS, HA IPPEN, EP	SOLITON VERSUS NONSOLITON OPERATION OF FIBER RING LASERS	Appl. Phys. Lett.	1994		
IPPEN, EP	PRINCIPLES OF PASSIVE-MODE LOCKING	Appl. Phys. B-Lasers Opt.	1994		
DOERR, CR TAMURA, K SHIRASAKI, M HAUS, HA IPPEN, EP	ORTHOGONAL POLARIZATION FIBER GYROSCOPE WITH INCREASED STABILITY AND RESOLUTION	Appl. Optics	1994		
ULMAN, M BAILEY, DW ACIOLI, LH VALLEE, FG STANTON, CJ IPPEN, EP FUJIMOTO, JG	FEMTOSECOND TUNABLE NONLINEAR ABSORPTION-SPECTROSCOPY IN AL0.1GA0.9AS	Phys. Rev. B-Condens Matter	1993		
SUN, CK VALLEE, F ACIOLI, L IPPEN, EP FUJIMOTO, JG	FEMTOSECOND INVESTIGATION OF ELECTRON THERMALIZATION IN GOLD	Phys. Rev. B-Condens Matter	1993		

TAMURA, K JACOBSON, J IPPEN, EP HAUS, HA FUJIMOTO, JG	UNIDIRECTIONAL RING RESONATORS FOR SELF-STARTING PASSIVELY MODE-LOCKED LASERS	Opt. Lett.	1993		
PAYE, J RAMASWAMY, M FUJIMOTO, JG IPPEN, EP	MEASUREMENT OF THE AMPLITUDE AND PHASE OF ULTRASHORT LIGHT- PULSES FROM SPECTRALLY RESOLVED AUTOCORRELATION	Opt. Lett.	1993		
TAMURA, K IPPEN, EP HAUS, HA NELSON, LE	77-FS PULSE GENERATION FROM A STRETCHED-PULSE MODE-LOCKED ALL- FIBER RING LASER	Opt. Lett.	1993		
IPPEN, E LINDNER, J DITTO, WL	CHAOTIC RESONANCE - A SIMULATION	J. Stat. Phys.	1993		
CHEN, JC HAUS, HA IPPEN, EP	STABILITY OF LASERS MODE-LOCKED BY 2 SATURABLE ABSORBERS	IEEE J. Quantum Electron.	1993		
HIRAYAMA, Y SMET, JH PENG, LH FONSTAD, CG IPPEN, EP	OBSERVATION OF 1.798 MU-M INTERSUBBAND TRANSITION IN INGAAS/ALAS PSEUDOMORPHIC QUANTUM-WELL HETEROSTRUCTURES	Appl. Phys. Lett.	1993		
CHENG, TK ACIOLI, LH VIDAL, J ZEIGER, HJ DRESSELHAUS, G DRESSELHAUS, MS IPPEN, EP	MODULATION OF A SEMICONDUCTOR-TO-SEMIMETAL TRANSITION AT 7-THZ VIA COHERENT LATTICE-VIBRATIONS	Appl. Phys. Lett.	1993		
FLEISCHER, SB IPPEN, EP DRESSELHAUS, G DRESSELHAUS, MS RAO, AM ZHOU, P EKLUND, PC	FEMTOSECOND OPTICAL-DYNAMICS OF C-60 AND M3C-60	Appl. Phys. Lett.	1993		
HALL, KL DARWISH, AM IPPEN, EP KOREN, U RAYBON, G	FEMTOSECOND INDEX NONLINEARITIES IN INGAASP OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1993		
ZEIGER, HJ VIDAL, J CHENG, TK IPPEN, EP DRESSELHAUS, G DRESSELHAUS, MS	THEORY FOR DISPLACIVE EXCITATION OF COHERENT PHONONS	Phys. Rev. B-Condens Matter	1992		
YOKOYAMA, H NISHI, K ANAN, T NAMBU, Y BRORSON, SD IPPEN, EP SUZUKI, M	CONTROLLING SPONTANEOUS EMISSION AND THRESHOLD-LESS LASER OSCILLATION WITH OPTICAL MICROCAVITIES	Opt. Quantum Electron.	1992		
HALL, KL LENZ, G IPPEN, EP RAYBON, G	HETERODYNE PUMP PROBE TECHNIQUE FOR TIME-DOMAIN STUDIES OF OPTICAL NONLINEARITIES IN WAVE-GUIDES	Opt. Lett.	1992		
HALL, KL LENZ, G	FEMTOSECOND TIME DOMAIN MEASUREMENTS OF GROUP-	J. Lightwave	1992		

IPPEN, EP	VELOCITY DISPERSION IN DIODE-LASERS AT 1.5-MU-M	Technol.			
NAGANUMA, K LENZ, G IPPEN, EP	VARIABLE BANDWIDTH BIREFRINGENT FILTER FOR TUNABLE FEMTOSECOND LASERS	IEEE J. Quantum Electron.	1992		
HAUS, HA FUJIMOTO, JG IPPEN, EP	ANALYTIC THEORY OF ADDITIVE PULSE AND KERR LENS MODE-LOCKING	IEEE J. Quantum Electron.	1992		
TAMURA, K HAUS, HA IPPEN, EP	SELF-STARTING ADDITIVE PULSE MODE-LOCKED ERBIUM FIBER RING LASER	Electron. Lett.	1992		
HALL, KL LENZ, G IPPEN, EP KOREN, U RAYBON, G	CARRIER HEATING AND SPECTRAL HOLE BURNING IN STRAINED-LAYER QUANTUM-WELL LASER-AMPLIFIERS AT 1.5-MU-M	Appl. Phys. Lett.	1992		
HULTGREN, CT DOUGHERTY, DJ IPPEN, EP	ABOVE-BAND AND BELOW-BAND FEMTOSECOND NONLINEARITIES IN ACTIVE ALGAAS WAVE-GUIDES	Appl. Phys. Lett.	1992		
KAZEROONIAN, AS CHENG, TK BRORSON, SD LI, Q IPPEN, EP WU, XD VENKATESAN, T ETEMAD, S DRESSELHAUS, MS DRESSELHAUS, G	PROBING THE FERMI LEVEL OF Y1-XPRXBA2CU3O7-DELTA BY FEMTOSECOND SPECTROSCOPY	Solid State Commun.	1991		
HAUS, HA IPPEN, EP	SELF-STARTING OF PASSIVELY MODE-LOCKED LASERS	Opt. Lett.	1991		
NAGAR, R ABRAHAM, D TESSLER, N FRAENKEL, A EISENSTEIN, G IPPEN, EP KOREN, U RAYBON, G	FREQUENCY-MODULATION MODE-LOCKING OF A SEMICONDUCTOR-LASER	Opt. Lett.	1991		
ACIOLI, LH ULMAN, M IPPEN, EP FUJIMOTO, JG KONG, H CHEN, BS CRONINGOLOMB, M	FEMTOSECOND TEMPORAL ENCODING IN BARIUM-TITANATE	Opt. Lett.	1991		
GABETTA, G HUANG, D JACOBSON, J RAMASWAMY, M IPPEN, EP FUJIMOTO, JG	FEMTOSECOND PULSE GENERATION IN TI-AL2O3 USING A MICRODOT MIRROR MODE LOCKER	Opt. Lett.	1991		
MOORES, JD BERGMAN, K HAUS, HA IPPEN, EP	DEMONSTRATION OF OPTICAL SWITCHING BY MEANS OF SOLITARY WAVE COLLISIONS IN A FIBER RING REFLECTOR	Opt. Lett.	1991		
HAUS, HA FUJIMOTO, JG IPPEN, EP	STRUCTURES FOR ADDITIVE PULSE MODE-LOCKING	J. Opt. Soc. Am. B-Opt. Phys.	1991		
MOORES, JD BERGMAN,	OPTICAL SWITCHING USING FIBER RING REFLECTORS	J. Opt. Soc. Am. B-	1991		

K HAUS, HA IPPEN, EP		Opt. Phys.			
FACE, DW BRORSON, SD KAZEROONIAN, A MOODERA, JS CHENG, TK DOLL, GL DRESSELHAUS, MS DRESSELHAUS, G IPPEN, EP VENKATESAN, T WU, XD INAM, A	FEMTOSECOND THERMOMODULATION STUDIES OF LOW AND HIGH-TC SUPERCONDUCTORS	IEEE Trans. Magn.	1991		
HULTGREN, CT IPPEN, EP	ULTRAFAST REFRACTIVE-INDEX DYNAMICS IN ALGAAS DIODE-LASER AMPLIFIERS	Appl. Phys. Lett.	1991		
SUZUKI, M YOKOYAMA, H BRORSON, SD IPPEN, EP	OBSERVATION OF SPONTANEOUS EMISSION LIFETIME CHANGE OF DYE- CONTAINING LANGMUIR-BLODGETT-FILMS IN OPTICAL MICROCAVITIES	Appl. Phys. Lett.	1991		
CHENG, TK VIDAL, J ZEIGER, HJ DRESSELHAUS, G DRESSELHAUS, MS IPPEN, EP	MECHANISM FOR DISPLACIVE EXCITATION OF COHERENT PHONONS IN SB, BI, TE, AND TI2O3	Appl. Phys. Lett.	1991		
SHANK, CV IPPEN, EP	ULTRASHORT PULSE DYE-LASERS	Top. Appl. Phys.	1990		
BRORSON, SD KAZEROONIAN, A FACE, DW CHENG, TK DOLL, GL DRESSELHAUS, MS DRESSELHAUS, G IPPEN, EP VENKATESAN, T WU, XD INAM, A	FEMTOSECOND THERMOMODULATION STUDY OF HIGH-TC SUPERCONDUCTORS	Solid State Commun.	1990		
BRORSON, SD KAZEROONIAN, A MOODERA, JS FACE, DW CHENG, TK IPPEN, EP DRESSELHAUS, MS DRESSELHAUS, G	FEMTOSECOND ROOM-TEMPERATURE MEASUREMENT OF THE ELECTRON-PHONON COUPLING CONSTANT-LAMBDA IN METALLIC SUPERCONDUCTORS	Phys. Rev. Lett.	1990		
IPPEN, EP LIU, LY HAUS, HA	SELF-STARTING CONDITION FOR ADDITIVE-PULSE MODE-LOCKED LASERS	Opt. Lett.	1990		
LIU, LY HUXLEY, JM IPPEN, EP HAUS, HA	SELF-STARTING ADDITIVE-PULSE MODE-LOCKING OF A ND-YAG LASER	Opt. Lett.	1990		

LAI, Y HALL, KL IPPEN, EP EISENSTEIN, G	SHORT PULSE GAIN SATURATION IN INGAASP DIODE-LASER AMPLIFIERS	IEEE Photonics Technol. Lett.	1990		
BRORSON, SD YOKOYAMA, H IPPEN, EP	SPONTANEOUS EMISSION RATE ALTERATION IN OPTICAL WAVE-GUIDE STRUCTURES	IEEE J. Quantum Electron.	1990		
CHENG, TK BRORSON, SD KAZEROONIAN, AS MOODERA, JS DRESSELHAUS, G DRESSELHAUS, MS IPPEN, EP	IMPULSIVE EXCITATION OF COHERENT PHONONS OBSERVED IN REFLECTION IN BISMUTH AND ANTIMONY	Appl. Phys. Lett.	1990		
HALL, KL MARK, J IPPEN, EP EISENSTEIN, G	FEMTOSECOND GAIN DYNAMICS IN INGAASP OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1990		
HALL, KL LAI, Y IPPEN, EP EISENSTEIN, G KOREN, U	FEMTOSECOND GAIN DYNAMICS AND SATURATION BEHAVIOR IN INGAASP MULTIPLE QUANTUM-WELL OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1990		
HUXLEY, JM MATALONI, P SCHOENLEIN, RW FUJIMOTO, JG IPPEN, EP CARTER, GM	FEMTOSECOND EXCITED-STATE DYNAMICS OF POLYDIACETYLENE	Appl. Phys. Lett.	1990		
YOKOYAMA, H NISHI, K ANAN, T YAMADA, H BRORSON, SD IPPEN, EP	ENHANCED SPONTANEOUS EMISSION FROM GAAS QUANTUM-WELLS IN MONOLITHIC MICROCAVITIES	Appl. Phys. Lett.	1990		
HALL, KL IPPEN, EP EISENSTEIN, G	BIAS-LEAD MONITORING OF ULTRAFAST NONLINEARITIES IN INGAASP DIODE-LASER AMPLIFIERS	Appl. Phys. Lett.	1990		
MARK, J LIU, LY HALL, KL HAUS, HA IPPEN, EP	FEMTOSECOND PULSE GENERATION IN A LASER WITH A NONLINEAR EXTERNAL RESONATOR	Opt. Lett.	1989		
IPPEN, EP HAUS, HA LIU, LY	ADDITIVE PULSE MODE-LOCKING	J. Opt. Soc. Am. B-Opt. Phys.	1989		
KESLER, MP IPPEN, EP	FEMTOSECOND TIME-DOMAIN MEASUREMENTS OF GROUP-VELOCITY DISPERSION IN ALGAAS DIODE-LASERS	Electron. Lett.	1989		
NELSON, KA IPPEN, EP	FEMTOSECOND COHERENT SPECTROSCOPY	Adv. Chem. Phys.	1989		
IPPEN, EP	RECENT ADVANCES IN FEMTOSECOND PULSE GENERATION	Abstr. Pap. Am. Chem. Soc.	1989		
SCHOENLEIN, RW LIN, WZ BRORSON, SD	FEMTOSECOND HOT CARRIER ENERGY REDISTRIBUTION IN GAAS AND ALGAAS	Solid-State Electron.	1988		

IPPEN, EP FUJIMOTO, JG					
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HARTER, DJ BAND, YB IPPEN, EP	THEORY OF MODE-LOCKED LASERS CONTAINING A REVERSE SATURABLE ABSORBER	IEEE J. Quantum Electron.	1985		
DESILVESTRI, S FUJIMOTO, JG IPPEN, EP GAMBLE, EB WILLIAMS, LR NELSON, KA	FEMTOSECOND TIME-RESOLVED MEASUREMENTS OF OPTIC PHONON DEPHASING BY IMPULSIVE STIMULATED RAMAN-SCATTERING IN ALPHA- PERYLENE CRYSTAL FROM 20-K TO 300-K	Chem. Phys. Lett.	1985		
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FUJIMOTO, JG IPPEN, EP	TRANSIENT 4-WAVE MIXING AND OPTICAL PULSE-COMPRESSION IN THE FEMTOSECOND REGIME	Opt. Lett.	1983		
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IPPEN, EP	INTRODUCTION TO THE SPECIAL ISSUE ON PICOSECOND PHENOMENA	IEEE J. Quantum Electron.	1983		
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APPENDIX B - IPPEN

Appendix B contains the same lists as in Appendix A but includes paper rankings by # of citations. Comment on any significant discrepancies between your ranking and the rank by citation count. (Write comments in space provided in Section 4.) Why do you think they are different?

				# Citatns
Winn, JN Fan, SH Joannopoulos, JD Ippen, EP	Interband transitions in photonic crystals	Phys. Rev. B-Condens Matter	1999	0
Little, BE Chu, ST Pan, W Ripin, D Kaneko, T Kokubun, Y Ippen, E	Vertically coupled glass microring resonator channel dropping filters	IEEE Photonics Technol. Lett.	1999	0
Jones, DJ Chen, Y Haus, HA Ippen, EP	Resonant sideband generation in stretched-pulse fiber lasers	Opt. Lett.	1998	0
Yu, CX Margalit, M Ippen, EP Haus, HA	Direct measurement of self-phase shift due to fiber nonlinearity	Opt. Lett.	1998	0
Jones, DJ Hall, KL Haus, HA Ippen, EP	Asynchronous phase-modulated optical fiber-ring buffer	Opt. Lett.	1998	2
Margalit, M Yu, CX Ippen, EP Haus, HA	Cross phase modulation squeezing in optical fibers	Opt. Express	1998	0
Wong, WS Hansen, PB Nielsen, TN Margalit, M Namiki, S Ippen, EP Haus, HA	In-band amplified spontaneous emission noise filtering with a dispersion-imbalanced nonlinear loop mirror	J. Lightwave Technol.	1998	0
Jones, DJ Haus, HA Nelson, LE Ippen, EP	Stretched-pulse generation and propagation	IEICE Trans. Electron.	1998	0
Little, BE Haus, HA Foresi, JS Kimerling, LC Ippen, EP Ripin, DJ	Wavelength switching and routing using absorption and resonance	IEEE Photonics Technol. Lett.	1998	3
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Margalit, M Yu, CX Namiki, S Ippen, EP Haus, HA	Harmonic mode-locking using regenerative phase modulation	IEEE Photonics Technol. Lett.	1998	0
Jones, DJ Namiki, S Barbier, D Ippen, EP Haus, HA	116-fs soliton source based on an Er-Yb codoped waveguide amplifier	IEEE Photonics Technol. Lett.	1998	0
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Wong, WS Namiki, S Margalit, M Haus, HA Ippen, EP	Self-switching of optical pulses in dispersion-imbalanced nonlinear loop mirrors	Opt. Lett.	1997	5
Foresi, JS Villeneuve, PR Ferrera, J Thoen, ER Steinmeyer, G Fan, S Joannopoulos, JD Kimerling, LC Smith, HI Ippen, EP	Photonic-bandgap microcavities in optical waveguides	Nature	1997	17
Namiki, S Ippen, EP Haus, HA Yu, CX	Energy rate equations for mode-locked lasers	J. Opt. Soc. Am. B-Opt. Phys.	1997	3
Jones, DJ Nelson, LE Haus, HA Ippen, EP	Diode-pumped environmentally stable stretched-pulse fiber laser	IEEE J. Sel. Top. Quantum Electron.	1997	1
Dougherty, DJ Fleischer, SB Warlick, EL House, JL Petrich, GS Kolodziejski, LA Ippen, EP	Ultrafast carrier dynamics and intervalley scattering in ZnSe	Appl. Phys. Lett.	1997	0
Fleischer, SB Pevzner, B Dougherty, DJ Ippen, EP Dresselhaus, MS Hebard, AF	Phototransformation in visible and near-IR femtosecond pump- probe studies of C-60 films - Response	Appl. Phys. Lett.	1997	0
Fleischer, SB Pevzner, B Dougherty, DJ Zeiger, HJ Dresselhaus, G Dresselhaus, MS Ippen, EP Hebard, AF	Coherent phonons in alkali metal-doped C-60	Appl. Phys. Lett.	1997	0
Nelson, LE Jones, DJ Tamura, K Haus, HA Ippen, EP	Ultrashort-pulse fiber ring lasers	Appl. Phys. B-Lasers Opt.	1997	5
Zeiger, HJ Cheng, TK Ippen, EP Vidal, J Dresselhaus, G Dresselhaus, MS	Femtosecond studies of the phase transition in Ti2O3	Phys. Rev. B-Condens Matter	1996	2
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Lenz, G Gellermann, W Dougherty, DJ Tamura, K Ippen, EP	Femtosecond fiber laser pulses amplified by a KCl:Tl+ color- center amplifier for continuum generation in the 1.5-mu m region	Opt. Lett.	1996	5
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House, JL Dougherty, DJ Petrich, GS Kolodziejski, LA Ippen, EP Hua, GC	Growth and characterization of ZnSe/GaAs single quantum well structures	Appl. Surf. Sci.	1996	0
Darwish, AM Ippen, EP Le, HQ Donnelly, JP Groves, SH Swanson, EA	Short-pulse wavelength shifting by four wave mixing in passive InGaAsP/InP waveguides	Appl. Phys. Lett.	1996	3
Namiki, S Ippen, EP Haus, HA Tamura, K	Relaxation oscillation behavior in polarization additive pulse mode-locked fiber ring lasers	Appl. Phys. Lett.	1996	4
Fleischer, SB Pevzner, B Dougherty, DJ Ippen, EP Dresselhaus, MS Hebard, AF	Phototransformation in visible and near-IR femtosecond pump- probe studies of C-60 films	Appl. Phys. Lett.	1996	9
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LENZ, G TAMURA, K HAUS, HA IPPEN, EP	ALL-SOLID-STATE FEMTOSECOND SOURCE AT 1.55 MU-M	Opt. Lett.	1995	14
HALL, KL MOORES, JD RAUSCHENBACH, KA WONG, WS IPPEN, EP HAUS, HA	ALL-OPTICAL STORAGE OF A 1.25 KB PACKET AT 10 GB/S	IEEE Photonics Technol. Lett.	1995	17
MOORES, JD HALL, KL LEPAGE, SM RAUSCHENBACH, KA WONG, WS HAUS, HA IPPEN, EP	20-GHZ OPTICAL STORAGE LOOP LASER USING AMPLITUDE-MODULATION, FILTERING, AND ARTIFICIAL FAST SATURABLE ABSORPTION	IEEE Photonics Technol. Lett.	1995	12
HAUS, HA TAMURA, K NELSON, LE IPPEN, EP	STRETCHED-PULSE ADDITIVE-PULSE MODE-LOCKING IN FIBER RING LASERS - THEORY AND EXPERIMENT	IEEE J. Quantum Electron.	1995	53

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HULTGREN, CT IPPEN, EP	ULTRAFAST REFRACTIVE-INDEX DYNAMICS IN ALGAAS DIODE-LASER AMPLIFIERS	Appl. Phys. Lett.	1991	49
SUZUKI, M YOKOYAMA, H BRORSON, SD IPPEN, EP	OBSERVATION OF SPONTANEOUS EMISSION LIFETIME CHANGE OF DYE- CONTAINING LANGMUIR-BLODGETT-FILMS IN OPTICAL MICROCAVITIES	Appl. Phys. Lett.	1991	43
CHENG, TK VIDAL, J ZEIGER, HJ DRESSELHAUS, G DRESSELHAUS, MS IPPEN, EP	MECHANISM FOR DISPLACIVE EXCITATION OF COHERENT PHONONS IN SB, BI, TE, AND TI2O3	Appl. Phys. Lett.	1991	32
SHANK, CV IPPEN, EP	ULTRASHORT PULSE DYE-LASERS	Top. Appl. Phys.	1990	0
BRORSON, SD KAZEROONIAN, A FACE, DW CHENG, TK DOLL, GL DRESSELHAUS, MS DRESSELHAUS, G IPPEN, EP VENKATESAN, T WU, XD INAM, A	FEMTOSECOND THERMOMODULATION STUDY OF HIGH-TC SUPERCONDUCTORS	Solid State Commun.	1990	51
BRORSON, SD KAZEROONIAN, A MOODERA, JS FACE, DW CHENG, TK IPPEN, EP DRESSELHAUS, MS DRESSELHAUS, G	FEMTOSECOND ROOM-TEMPERATURE MEASUREMENT OF THE ELECTRON-PHONON COUPLING CONSTANT-LAMBDA IN METALLIC SUPERCONDUCTORS	Phys. Rev. Lett.	1990	99
IPPEN, EP LIU, LY HAUS, HA	SELF-STARTING CONDITION FOR ADDITIVE-PULSE MODE-LOCKED LASERS	Opt. Lett.	1990	54
LIU, LY HUXLEY, JM IPPEN, EP HAUS, HA	SELF-STARTING ADDITIVE-PULSE MODE-LOCKING OF A ND-YAG LASER	Opt. Lett.	1990	67
LAI, Y HALL, KL IPPEN, EP EISENSTEIN, G	SHORT PULSE GAIN SATURATION IN INGAASP DIODE-LASER AMPLIFIERS	IEEE Photonics Technol. Lett.	1990	27
BRORSON, SD YOKOYAMA, H IPPEN, EP	SPONTANEOUS EMISSION RATE ALTERATION IN OPTICAL WAVE-GUIDE STRUCTURES	IEEE J. Quantum Electron.	1990	60
CHENG, TK BRORSON, SD KAZEROONIAN, AS	IMPULSIVE EXCITATION OF COHERENT PHONONS OBSERVED IN REFLECTION IN BISMUTH AND ANTIMONY	Appl. Phys. Lett.	1990	32

MOODERA, JS DRESSELHAUS, G DRESSELHAUS, MS IPPEN, EP				
HALL, KL MARK, J IPPEN, EP EISENSTEIN, G	FEMTOSECOND GAIN DYNAMICS IN INGAASP OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1990	111
HALL, KL LAI, Y IPPEN, EP EISENSTEIN, G KOREN, U	FEMTOSECOND GAIN DYNAMICS AND SATURATION BEHAVIOR IN INGAASP MULTIPLE QUANTUM-WELL OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1990	39
HUXLEY, JM MATALONI, P SCHOENLEIN, RW FUJIMOTO, JG IPPEN, EP CARTER, GM	FEMTOSECOND EXCITED-STATE DYNAMICS OF POLYDIACETYLENE	Appl. Phys. Lett.	1990	22
YOKOYAMA, H NISHI, K ANAN, T YAMADA, H BRORSON, SD IPPEN, EP	ENHANCED SPONTANEOUS EMISSION FROM GAAS QUANTUM-WELLS IN MONOLITHIC MICROCAVITIES	Appl. Phys. Lett.	1990	96
HALL, KL IPPEN, EP EISENSTEIN, G	BIAS-LEAD MONITORING OF ULTRAFAST NONLINEARITIES IN INGAASP DIODE-LASER AMPLIFIERS	Appl. Phys. Lett.	1990	12
MARK, J LIU, LY HALL, KL HAUS, HA IPPEN, EP	FEMTOSECOND PULSE GENERATION IN A LASER WITH A NONLINEAR EXTERNAL RESONATOR	Opt. Lett.	1989	158
IPPEN, EP HAUS, HA LIU, LY	ADDITIVE PULSE MODE-LOCKING	J. Opt. Soc. Am. B-Opt. Phys.	1989	136
KESLER, MP IPPEN, EP	FEMTOSECOND TIME-DOMAIN MEASUREMENTS OF GROUP-VELOCITY DISPERSION IN ALGAAS DIODE-LASERS	Electron. Lett.	1989	4
NELSON, KA IPPEN, EP	FEMTOSECOND COHERENT SPECTROSCOPY	Adv. Chem. Phys.	1989	41
IPPEN, EP	RECENT ADVANCES IN FEMTOSECOND PULSE GENERATION	Abstr. Pap. Am. Chem. Soc.	1989	0
SCHOENLEIN, RW LIN, WZ BRORSON, SD IPPEN, EP FUJIMOTO, JG	FEMTOSECOND HOT CARRIER ENERGY REDISTRIBUTION IN GAAS AND ALGAAS	Solid-State Electron.	1988	9
LIN, WZ SCHOENLEIN, RW FUJIMOTO, JG IPPEN, EP	FEMTOSECOND ABSORPTION SATURATION STUDIES OF HOT CARRIERS IN GAAS AND ALGAAS	IEEE J. Quantum Electron.	1988	115
KESLER, MP IPPEN, EP	SUBPICOSECOND SPECTRAL GAIN DYNAMICS IN ALGAAS LASER-DIODES	Electron. Lett.	1988	18
BRORSON, SD FUJIMOTO, JG IPPEN, EP	FEMTOSECOND ELECTRONIC HEAT-TRANSPORT DYNAMICS IN THIN GOLD- FILMS	Phys. Rev. Lett.	1987	116
NAKAZAWA, M STIX, MS IPPEN, EP HAUS, HA	THEORY OF THE SYNCHRONOUSLY PUMPED FIBER RAMAN LASER WITH SELF- PHASE MODULATION	J. Opt. Soc. Am. B-Opt. Phys.	1987	4
WINTNER, E CHEN, DP MELNGAILIS, J IPPEN, EP	OPTICAL-GENERATION AND PHASE-SENSITIVE DETECTION OF SURFACE ACOUSTIC-WAVES ON INP	IEEE Trans. Ultrason.	1987	2

		Ferroelectr. Freq. Control		
IPPEN, EP	ULTRASHORT PULSE GENERATION AND MEASUREMENT TECHNIQUES	Hyperfine Interact.	1987	0
WILLIAMS, LR GAMBLE, EB NELSON, KA DESILVESTRI, S WEINER, AM IPPEN, EP	FEMTOSECOND TIME-RESOLVED MEASUREMENTS OF ELECTRONIC EXCITED- STATE RELAXATION IN PYRENE EXCIMER-FORMING CRYSTALS	Chem. Phys. Lett.	1987	14
KESLER, MP IPPEN, EP	SUBPICOSECOND GAIN DYNAMICS IN GAALAS LASER-DIODES	Appl. Phys. Lett.	1987	126
KUZNETSOV, M TSANG, DZ WALPOLE, JN LIAU, ZL IPPEN, EP	MULTISTABLE MODE-LOCKING OF INGAASP SEMICONDUCTOR-LASERS	Appl. Phys. Lett.	1987	9
SCHOENLEIN, RW LIN, WZ IPPEN, EP FUJIMOTO, JG	FEMTOSECOND HOT-CARRIER ENERGY RELAXATION IN GAAS	Appl. Phys. Lett.	1987	43
LIN, WZ FUJIMOTO, JG IPPEN, EP LOGAN, RA	FEMTOSECOND DYNAMICS OF HIGHLY EXCITED CARRIERS IN ALXGA1-XAS	Appl. Phys. Lett.	1987	41
LIN, WZ FUJIMOTO, LG IPPEN, EP LOGAN, RA	FEMTOSECOND CARRIER DYNAMICS IN GAAS	Appl. Phys. Lett.	1987	61
FUJIMOTO, JG DESILVESTRI, S IPPEN, EP PULIAFITO, CA MARGOLIS, R OSEROFF, A	FEMTOSECOND OPTICAL RANGING IN BIOLOGICAL-SYSTEMS	Opt. Lett.	1986	60
LIN, WZ FUJIMOTO, JG IPPEN, EP LOGAN, RA	FEMTOSECOND STUDIES OF ABSORPTION SATURATION DYNAMICS IN GAAS	J. Opt. Soc. Am. B-Opt. Phys.	1986	0
GABRIEL, MC HAUS, HA IPPEN, EP	THERMAL INDEX CHANGES BY OPTICAL-ABSORPTION IN GROUP-III-V SEMICONDUCTOR WAVE-GUIDES	J. Lightwave Technol.	1986	8
ISLAM, MN IPPEN, EP BURKHARDT, EG BRIDGES, TJ	PICOSECOND STUDY OF NEAR-BAND-GAP NONLINEARITIES IN GAINASP	J. Appl. Phys.	1986	15
NAKAZAWA, M KUZNETSOV, M IPPEN, EP	THEORY OF THE SYNCHRONOUSLY PUMPED FIBER RAMAN LASER	IEEE J. Quantum Electron.	1986	5
STIX, MS KESLER, MP IPPEN, EP	OBSERVATIONS OF SUBPICOSECOND DYNAMICS IN GAALAS LASER-DIODES	Appl. Phys. Lett.	1986	50
WEINER, AM FUJIMOTO, JG IPPEN, EP	FEMTOSECOND TIME-RESOLVED REFLECTOMETRY MEASUREMENTS OF MULTIPLE-LAYER DIELECTRIC MIRRORS	Opt. Lett.	1985	23
WEINER, AM DESILVESTRI, S IPPEN, EP	3-PULSE SCATTERING FOR FEMTOSECOND DEPHASING STUDIES - THEORY AND EXPERIMENT	J. Opt. Soc. Am. B-Opt. Phys.	1985	157
FUJIMOTO, JG LIN, WZ IPPEN, EP PULIAFITO, CA STEINERT, RF	TIME-RESOLVED STUDIES OF ND-YAG LASER-INDUCED BREAKDOWN - PLASMA FORMATION, ACOUSTIC-WAVE GENERATION, AND CAVITATION	Invest. Ophthalmol. Vis. Sci.	1985	51
HARTER, DJ BAND, YB	THEORY OF MODE-LOCKED LASERS CONTAINING A REVERSE	IEEE J.	1985	16

IPPEN, EP	SATURABLE ABSORBER	Quantum Electron.		
DESILVESTRI, S FUJIMOTO, JG IPPEN, EP GAMBLE, EB WILLIAMS, LR NELSON, KA	FEMTOSECOND TIME-RESOLVED MEASUREMENTS OF OPTIC PHONON DEPHASING BY IMPULSIVE STIMULATED RAMAN-SCATTERING IN ALPHA- PERYLENE CRYSTAL FROM 20-K TO 300-K	Chem. Phys. Lett.	1985	75
WEINER, AM IPPEN, EP	FEMTOSECOND EXCITED-STATE RELAXATION OF DYE MOLECULES IN SOLUTION	Chem. Phys. Lett.	1985	82
SHAHIDI, GG IPPEN, EP MEINGAILIS, J	SUBMICRON-GAP HIGH-MOBILITY SILICON PICOSECOND PHOTODETECTORS	Appl. Phys. Lett.	1985	3
ISLAM, MN IPPEN, EP BURKHARDT, EG BRIDGES, TJ	PICOSECOND NONLINEAR ABSORPTION AND 4-WAVE MIXING IN GAINASP	Appl. Phys. Lett.	1985	7
FUJIMOTO, JG SHEVEL, SG IPPEN, EP	FEMTOSECOND TIME-RESOLVED EXCITON DYNAMICS IN CDSE	Solid State Commun.	1984	18
FUJIMOTO, JG LIU, JM IPPEN, EP BLOEMBERGEN, N	FEMTOSECOND LASER INTERACTION WITH METALLIC TUNGSTEN AND NONEQUILIBRIUM ELECTRON AND LATTICE TEMPERATURES	Phys. Rev. Lett.	1984	127
WEINER, AM IPPEN, EP	NOVEL TRANSIENT SCATTERING TECHNIQUE FOR FEMTOSECOND DEPHASING MEASUREMENTS	Opt. Lett.	1984	47
YORZ, J IPPEN, E SHEVEL, SG	PICOSECOND LASER ACTION IN MIXED ZNXCD1-XS SINGLE-CRYSTALS IN AN EXTERNAL CAVITY	Kvantovaya Elektron.	1984	0
FUJIMOTO, JG WEINER, AM IPPEN, EP	COMPRESSION AND PARAMETRIC SCATTERING WITH FEMTOSECOND PULSES	J. Opt. Soc. Am. B-Opt. Phys.	1984	0
WEINER, AM FUJIMOTO, JG IPPEN, EP	FEMTOSECOND REFLECTOMETRY STUDIES OF BROAD-BAND DIELECTRIC MIRROR COATINGS	J. Opt. Soc. Am. A-Opt. Image Sci. Vis.	1984	0
DESILVESTRI, S WEINER, AM FUJIMOTO, JG IPPEN, EP	FEMTOSECOND DEPHASING STUDIES OF DYE MOLECULES IN A POLYMER HOST	Chem. Phys. Lett.	1984	34
WINTNER, E IPPEN, EP	NONLINEAR CARRIER DYNAMICS IN GAXIN1-XASYP1-Y COMPOUNDS	Appl. Phys. Lett.	1984	47
FUJIMOTO, JG WEINER, AM IPPEN, EP	GENERATION AND MEASUREMENT OF OPTICAL PULSES AS SHORT AS 16 FS	Appl. Phys. Lett.	1984	93
MOLLENAUER, LF WIESENFELD, JM IPPEN, EP	PICOSECOND MEASUREMENT OF RELAXATION IN COLOR-CENTERS	Radiat. Eff. Defects Solids	1983	3
FUJIMOTO, JG IPPEN, EP	TRANSIENT 4-WAVE MIXING AND OPTICAL PULSE-COMPRESSION IN THE FEMTOSECOND REGIME	Opt. Lett.	1983	16
YORSZ, J SHEVEL, SG IPPEN, EP	OPTICALLY PUMPED ZNXCD1-XS PLATELET LASERS	Opt. Commun.	1983	3
STIX, MS IPPEN, EP	PULSE SHAPING IN PASSIVELY MODE-LOCKED RING DYE-LASERS	IEEE J. Quantum	1983	58

		Electron.		
IPPEN, EP	INTRODUCTION TO THE SPECIAL ISSUE ON PICOSECOND PHENOMENA	IEEE J. Quantum Electron.	1983	0
LATTES, A HAUS, HA LEONBERGER, FJ IPPEN, EP	AN ULTRAFAST ALL-OPTICAL GATE	IEEE J. Quantum Electron.	1983	111
WINTNER, E FUJIMOTO, JG IPPEN, EP	PICOSECOND AND FEMTOSECOND DIAGNOSTICS OF SEMICONDUCTORS	1984	452	0

APPENDIX C - IPPEN

Annotate the publications listed below (√ = high impact, √√ = 'blockbuster') in terms of the influence you think these publications will have on your field in *academic circles*, and, separately, the influence you think they will have on *industry*.

				Influence on Academic Circles	Influence in Industry
Winn, JN Fan, SH Joannopoulos, JD Ippen, EP	Interband transitions in photonic crystals	Phys. Rev. B-Condens Matter	1999		
Little, BE Chu, ST Pan, W Ripin, D Kaneko, T Kokubun, Y Ippen, E	Vertically coupled glass microring resonator channel dropping filters	IEEE Photonics Technol. Lett.	1999		
Jones, DJ Chen, Y Haus, HA Ippen, EP	Resonant sideband generation in stretched-pulse fiber lasers	Opt. Lett.	1998		
Yu, CX Margalit, M Ippen, EP Haus, HA	Direct measurement of self-phase shift due to fiber nonlinearity	Opt. Lett.	1998		
Jones, DJ Hall, KL Haus, HA Ippen, EP	Asynchronous phase-modulated optical fiber-ring buffer	Opt. Lett.	1998		
Margalit, M Yu, CX Ippen, EP Haus, HA	Cross phase modulation squeezing in optical fibers	Opt. Express	1998		
Wong, WS Hansen, PB Nielsen, TN Margalit, M Namiki, S Ippen, EP Haus, HA	In-band amplified spontaneous emission noise filtering with a dispersion-imbalanced nonlinear loop mirror	J. Lightwave Technol.	1998		
Jones, DJ Haus, HA Nelson, LE Ippen, EP	Stretched-pulse generation and propagation	IEICE Trans. Electron.	1998		
Little, BE Haus, HA Foresi, JS Kimerling, LC Ippen, EP Ripin, DJ	Wavelength switching and routing using absorption and resonance	IEEE Photonics Technol. Lett.	1998		
Little, BE Foresi, JS Steinmeyer, G Thoen, ER Chu, ST Haus, HA Ippen, EP Kimerling, LC Greene, W	Ultra-compact Si-SiO2 microring resonator optical channel dropping filters	IEEE Photonics Technol. Lett.	1998		
Margalit, M Yu, CX Namiki, S Ippen, EP Haus, HA	Harmonic mode-locking using regenerative phase modulation	IEEE Photonics Technol. Lett.	1998		
Jones, DJ Namiki, S Barbier, D Ippen, EP Haus, HA	116-fs soliton source based on an Er-Yb codoped waveguide amplifier	IEEE Photonics Technol. Lett.	1998		
Thoen, ER Steinmeyer, G	Coherent acoustic phonons in PbTe quantum dots	Appl. Phys.	1998		

Langlois, P Ippen, EP Tudury, GE Cruz, CHB Barbosa, LC Cesar, CL		Lett.			
Ippen, E	Ippen will lead OSA in 2000	Phys. Today	1997		
Wong, WS Namiki, S Margalit, M Haus, HA Ippen, EP	Self-switching of optical pulses in dispersion-imbalanced nonlinear loop mirrors	Opt. Lett.	1997		
Foresi, JS Villeneuve, PR Ferrera, J Thoen, ER Steinmeyer, G Fan, S Joannopoulos, JD Kimerling, LC Smith, HI Ippen, EP	Photonic-bandgap microcavities in optical waveguides	Nature	1997		
Namiki, S Ippen, EP Haus, HA Yu, CX	Energy rate equations for mode-locked lasers	J. Opt. Soc. Am. B-Opt. Phys.	1997		
Jones, DJ Nelson, LE Haus, HA Ippen, EP	Diode-pumped environmentally stable stretched-pulse fiber laser	IEEE J. Sel. Top. Quantum Electron.	1997		
Dougherty, DJ Fleischer, SB Warlick, EL House, JL Petrich, GS Kolodziejski, LA Ippen, EP	Ultrafast carrier dynamics and intervalley scattering in ZnSe	Appl. Phys. Lett.	1997		
Fleischer, SB Pevzner, B Dougherty, DJ Ippen, EP Dresselhaus, MS Hebard, AF	Phototransformation in visible and near-IR femtosecond pump- probe studies of C-60 films - Response	Appl. Phys. Lett.	1997		
Fleischer, SB Pevzner, B Dougherty, DJ Zeiger, HJ Dresselhaus, G Dresselhaus, MS Ippen, EP Hebard, AF	Coherent phonons in alkali metal-doped C-60	Appl. Phys. Lett.	1997		
Nelson, LE Jones, DJ Tamura, K Haus, HA Ippen, EP	Ultrashort-pulse fiber ring lasers	Appl. Phys. B-Lasers Opt.	1997		
Zeiger, HJ Cheng, TK Ippen, EP Vidal, J Dresselhaus, G Dresselhaus, MS	Femtosecond studies of the phase transition in Ti2O3	Phys. Rev. B-Condens Matter	1996		
Jones, DJ Haus, HA Ippen, EP	Subpicosecond solitons in an actively mode-locked fiber laser	Opt. Lett.	1996		
Cundiff, ST Knox, WH Ippen, EP Haus, HA	Frequency-dependent mode size in broadband Kerr-lens mode locking	Opt. Lett.	1996		
Lenz, G Gellermann, W Dougherty, DJ Tamura, K Ippen, EP	Femtosecond fiber laser pulses amplified by a KCl:Tl+ color- center amplifier for continuum generation in the 1.5-mu m region	Opt. Lett.	1996		
Nelson, LE Fleischer, SB Lenz, G Ippen, EP	Efficient frequency doubling of a femtosecond fiber laser	Opt. Lett.	1996		

Haus, HA Jones, DJ Ippen, EP Wong, WS	Theory of soliton stability in asynchronous modelocking	J. Lightwave Technol.	1996		
Donnelly, JP Le, HQ Swanson, EA Groves, SH Darwish, A Ippen, EP	Nondegenerate four-wave mixing wavelength conversion in low- loss passive InGaAsP-InP quantum-well waveguides	IEEE Photonics Technol. Lett.	1996		
Barry, RA Chan, VWS Hall, KL Kintzer, ES Moores, JD Rauschenbach, KA Swanson, EA Adams, LE Doerr, CR Finn, SG Haus, HA Ippen, EP Wong, WS Haner, M	All-optical network consortium - Ultrafast TDM networks	IEEE J. Sel. Areas Commun.	1996		
Haus, HA Khatri, FI Wong, WS Ippen, EP Tamura, KR	Interaction of soliton with sinusoidal wave packet	IEEE J. Quantum Electron.	1996		
House, JL Dougherty, DJ Petrich, GS Kolodziejski, LA Ippen, EP Hua, GC	Growth and characterization of ZnSe/GaAs single quantum well structures	Appl. Surf. Sci.	1996		
Darwish, AM Ippen, EP Le, HQ Donnelly, JP Groves, SH Swanson, EA	Short-pulse wavelength shifting by four wave mixing in passive InGaAsP/InP waveguides	Appl. Phys. Lett.	1996		
Namiki, S Ippen, EP Haus, HA Tamura, K	Relaxation oscillation behavior in polarization additive pulse mode-locked fiber ring lasers	Appl. Phys. Lett.	1996		
Fleischer, SB Pevzner, B Dougherty, DJ Ippen, EP Dresselhaus, MS Hebard, AF	Phototransformation in visible and near-IR femtosecond pump- probe studies of C-60 films	Appl. Phys. Lett.	1996		
Darwish, AM Ippen, EP Le, HQ Donnelly, JP Groves, SH	Optimization of four-wave mixing conversion efficiency in the presence of nonlinear loss	Appl. Phys. Lett.	1996		
Lenz, G Ippen, EP Wiesenfeld, JM Newkirk, MA Koren, U	Femtosecond dynamics of the nonlinear anisotropy in polarization insensitive semiconductor optical amplifiers	Appl. Phys. Lett.	1996		

APPENDIX D - IPPEN

Below is a list of your publications that include at least one private sector co-author. Please indicate how this collaboration came about (see legend in Section 5 for categories) and the duration (# years) of this relation.

							KEY	#YRS
Wong, WS Hansen, PB Nielsen, TN Margalit, M Namiki, S Ippen, EP Haus, HA	In-band amplified spontaneous emission noise filtering with a dispersion-imbalanced nonlinear loop mirror	J. Lightwave Technol.	1998	AT&T Bell Labs	AT&T Bell Labs	MIT		
Little, BE Foresi, JS Steinmeyer, G Thoen, ER Chu, ST Haus, HA Ippen, EP Kimerling, LC Greene, W	Ultra-compact Si-SiO2 microring resonator optical channel dropping filters	IEEE Photonics Technol. Lett.	1998	MIT	Hewlett Packard Co	Univ Maryland		
Jones, DJ Namiki, S Barbier, D Ippen, EP Haus, HA	116-fs soliton source based on an Er-Yb codoped waveguide amplifier	IEEE Photonics Technol. Lett.	1998	MIT	MIT	Furukawa Elect Co Ltd		
Jones, DJ Nelson, LE Haus, HA Ippen, EP	Diode-pumped environmentally stable stretched-pulse fiber laser	IEEE J. Sel. Top. Quantum Electron.	1997	MIT	MIT	AT&T Bell Labs		
Fleischer, SB Pevzner, B Dougherty, DJ Ippen, EP Dresselhaus, MS Hebard, AF	Phototransformation in visible and near-IR femtosecond pump- probe studies of C-60 films - Response	Appl. Phys. Lett.	1997	UNIV CALIF SANTA BARBARA	MIT	AT&T BELL LABS		
Fleischer, SB Pevzner, B Dougherty, DJ Zeiger, HJ Dresselhaus, G Dresselhaus, MS Ippen, EP Hebard, AF	Coherent phonons in alkali metal-doped C-60	Appl. Phys. Lett.	1997	UNIV CALIF SANTA BARBARA	MIT	AT&T BELL LABS		
Nelson, LE Jones, DJ Tamura, K Haus, HA Ippen, EP	Ultrashort-pulse fiber ring lasers	Appl. Phys. B-Lasers Opt.	1997	AT&T BELL LABS	MIT	MIT		
Cundiff, ST Knox, WH Ippen, EP Haus, HA	Frequency-dependent mode size in broadband Kerr-lens mode locking	Opt. Lett.	1996	BELL LABS	MIT	MIT		
Barry, RA Chan, VWS Hall, KL Kintzer, ES Moores, JD Rauschenbach,	All-optical network consortium - Ultrafast TDM networks	IEEE J. Sel. Areas Commun.	1996	MIT	AT&T BELL LABS	#VALUE!		

KA Swanson, EA Adams, LE Doerr, CR Finn, SG Haus, HA Ippen, EP Wong, WS Haner, M								
Namiki, S Ippen, EP Haus, HA Tamura, K	Relaxation oscillation behavior in polarization additive pulse mode-locked fiber ring lasers	Appl. Phys. Lett.	1996	MIT	MIT	FURUKAWA ELECT CORP LTD		
Fleischer, SB Pevzner, B Dougherty, DJ Ippen, EP Dresselhaus, MS Hebard, AF	Phototransformation in visible and near-IR femtosecond pump- probe studies of C-60 films	Appl. Phys. Lett.	1996	MIT	MIT	AT&T BELL LABS		
Lenz, G Ippen, EP Wiesenfeld, JM Newkirk, MA Koren, U	Femtosecond dynamics of the nonlinear anisotropy in polarization insensitive semiconductor optical amplifiers	Appl. Phys. Lett.	1996	MIT	AT&T BELL LABS	#VALUE!		
DOERR, CR HAUS, HA IPPEN, EP SHIRASAKI, M TAMURA, K	ADDITIVE-PULSE LIMITING	Opt. Lett.	1994	MIT	MIT	FUJITSU LABS LTD		
HIRAYAMA, Y SMET, JH PENG, LH FONSTAD, CG IPPEN, EP	FEASIBILITY OF 1.55 MU-M INTERSUBBAND PHOTONIC DEVICES USING INGAAS/ALAS PSEUDOMORPHIC QUANTUM-WELL STRUCTURES	Jpn. J. Appl. Phys. Part 1 - Regul. Pap. Short Notes Rev. Pap.	1994	TOSHIBA CO LTD	HARVARD UNIV	MIT		
DOERR, CR TAMURA, K SHIRASAKI, M HAUS, HA IPPEN, EP	ORTHOGONAL POLARIZATION FIBER GYROSCOPE WITH INCREASED STABILITY AND RESOLUTION	Appl. Optics	1994	MIT	MIT	FUJITSU LABS LTD		
HALL, KL DARWISH, AM IPPEN, EP KOREN, U RAYBON, G	FEMTOSECOND INDEX NONLINEARITIES IN INGAASP OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1993	MIT	MIT	AT&T BELL LABS		
YOKOYAMA, H NISHI, K ANAN, T NAMBU, Y BRORSON, SD IPPEN, EP SUZUKI, M	CONTROLLING SPONTANEOUS EMISSION AND THRESHOLD-LESS LASER OSCILLATION WITH OPTICAL MICROCAVITIES	Opt. Quantum Electron.	1992	NEC CORP LTD	MIT	MIT		
HALL, KL LENZ, G IPPEN, EP KOREN, U RAYBON, G	CARRIER HEATING AND SPECTRAL HOLE BURNING IN STRAINED-LAYER QUANTUM-WELL LASER-AMPLIFIERS AT 1.5-MU-M	Appl. Phys. Lett.	1992	MIT	MIT	AT&T BELL LABS		
NAGAR, R ABRAHAM, D TESSLER, N FRAENKEL, A EISENSTEIN, G IPPEN, EP KOREN, U RAYBON,	FREQUENCY-MODULATION MODE-LOCKING OF A SEMICONDUCTOR-LASER	Opt. Lett.	1991	TECHNION ISRAEL INST TECHNO	MIT	AT&T BELL LABS		

G				L				
FACE, DW BRORSON, SD KAZEROONIAN, A MOODERA, JS CHENG, TK DOLL, GL DRESSELHAUS, MS DRESSELHAUS, G IPPEN, EP VENKATESAN, T WU, XD INAM, A	FEMTOSECOND THERMOMODULATION STUDIES OF LOW AND HIGH-TC SUPERCONDUCTORS	IEEE Trans. Magn.	1991	MIT	MIT	BELLCORE		
SUZUKI, M YOKOYAMA, H BRORSON, SD IPPEN, EP	OBSERVATION OF SPONTANEOUS EMISSION LIFETIME CHANGE OF DYE- CONTAINING LANGMUIR-BLODGETT-FILMS IN OPTICAL MICROCAVITIES	Appl. Phys. Lett.	1991	NEC CORP LTD	NEC CORP LTD	MIT		
BRORSON, SD KAZEROONIAN, A FACE, DW CHENG, TK DOLL, GL DRESSELHAUS, MS DRESSELHAUS, G IPPEN, EP VENKATESAN, T WU, XD INAM, A	FEMTOSECOND THERMOMODULATION STUDY OF HIGH-TC SUPERCONDUCTORS	Solid State Commun.	1990	MIT	MIT	BELLCORE		
HALL, KL LAI, Y IPPEN, EP EISENSTEIN, G KOREN, U	FEMTOSECOND GAIN DYNAMICS AND SATURATION BEHAVIOR IN INGAASP MULTIPLE QUANTUM-WELL OPTICAL AMPLIFIERS	Appl. Phys. Lett.	1990	MIT	MIT	AT&T BELL LABS		
YOKOYAMA, H NISHI, K ANAN, T YAMADA, H BRORSON, SD IPPEN, EP	ENHANCED SPONTANEOUS EMISSION FROM GAAS QUANTUM-WELLS IN MONOLITHIC MICROCAVITIES	Appl. Phys. Lett.	1990	NEC CORP LTD	MIT	#VALUE!		
NAKAZAWA, M STIX, MS IPPEN, EP HAUS, HA	THEORY OF THE SYNCHRONOUSLY PUMPED FIBER RAMAN LASER WITH SELF- PHASE MODULATION	J. Opt. Soc. Am. B-Opt. Phys.	1987	NIPPON TELEGRAPH & TEL PUBL CORP	MIT	MIT		
LIN, WZ FUJIMOTO, JG IPPEN, EP LOGAN, RA	FEMTOSECOND DYNAMICS OF HIGHLY EXCITED CARRIERS IN ALXGA1-XAS	Appl. Phys. Lett.	1987	MIT	MIT	AT&T BELL LABS		
LIN, WZ FUJIMOTO, LG IPPEN, EP LOGAN, RA	FEMTOSECOND CARRIER DYNAMICS IN GAAS	Appl. Phys. Lett.	1987	MIT	MIT	AT&T BELL LABS		
LIN, WZ FUJIMOTO, JG IPPEN, EP LOGAN, RA	FEMTOSECOND STUDIES OF ABSORPTION SATURATION DYNAMICS IN GAAS	J. Opt. Soc. Am. B-Opt. Phys.	1986	ZHONGSHAN	MIT	AT&T BELL LABS		

				UNIV				
ISLAM, MN IPPEN, EP BURKHARDT, EG BRIDGES, TJ	PICOSECOND STUDY OF NEAR-BAND-GAP NONLINEARITIES IN GAINASP	J. Appl. Phys.	1986	MIT	MIT	AT&T BELL LABS		
NAKAZAWA, M KUZNETSOV, M IPPEN, EP	THEORY OF THE SYNCHRONOUSLY PUMPED FIBER RAMAN LASER	IEEE J. Quantum Electron.	1986	MIT	NIPPON TELEGRAPH & TEL PUBL CORP	#VALUE!		
HARTER, DJ BAND, YB IPPEN, EP	THEORY OF MODE-LOCKED LASERS CONTAINING A REVERSE SATURABLE ABSORBER	IEEE J. Quantum Electron.	1985	ALLIED CORP	BEN GURION UNIV NEGEV	MIT		
WEINER, AM IPPEN, EP	FEMTOSECOND EXCITED-STATE RELAXATION OF DYE MOLECULES IN SOLUTION	Chem. Phys. Lett.	1985	RES LAB ELECTR	MIT	#VALUE!		
ISLAM, MN IPPEN, EP BURKHARDT, EG BRIDGES, TJ	PICOSECOND NONLINEAR ABSORPTION AND 4-WAVE MIXING IN GAINASP	Appl. Phys. Lett.	1985	MIT	MIT	AT&T BELL LABS		
MOLLENAUER, LF WIESENFELD, JM IPPEN, EP	PICOSECOND MEASUREMENT OF RELAXATION IN COLOR-CENTERS	Radiat. Eff. Defects Solids	1983	BELL TEL LABS INC	MIT	#VALUE!		

Appendix D

Table of Interviews Conducted

Table of Interviews Conducted[1]

Name	Title	Institution	Date
Dr. Peter Lawrence	Professor of Electrical Engineering	University of British Columbia	May 26, 1998; Mar. 30, 1999
Dr. Shahram Tafazoli	President/Doctoral Student	MotionMetrics Inc./University of British Columbia	June 1998; Jan, Mar, May, 1999
Dr. Charles Sodini	Professor EECS, Associate Director Microsystems Lab	MIT	Feb. 22, 1999
Dr. Jesus del Alamo	Professor, EECS	MIT	Feb. 18, 1999
Dr. Hermann Haus	Institute Professor, EECS	MIT	Feb. 17, 1999
Dr. Michael Dertouzos	Professor, EECS, Director, Lab for Computer Science	MIT	Mar. 1, 1999
Dr. Anant Agarwal	Professor of Computer Science, EECS	MIT	Mar. 3, 1999
Dr. Erich Ippen	Elihu Thomson Professor of Electrical Engineering, EECS	MIT	Feb. 24, 1999
Dr. Tom Leighton	Professor, Mathematics/Chief Scientist	MIT/Akamai	Mar. 12, 1999
Dr. Dimitri Antoniadis	Professor, EECS	MIT	Mar. 11, 1999
Dr. David Forney	Adjunct Professor, EECS	MIT	Mar. 3, 1999
Dr. Jerry Sussman	Matsushita Professor of Electrical Engineering, EECS	MIT	Mar. 2, 1999
Dr. William Schreiber	Professor of Electrical Engineering, Emeritus, Sr. Lecturer, EECS	MIT	Feb. 25, 1999
Dr. David Gifford	Professor, EECS	MIT	Feb. 25, 1999
Dr. Markus Zahn	Professor, EECS, Director, Vi-A	MIT	Mar. 29,

[1] A number of professors (32) agreed to be interviewed under the condition that they remain anonymous. The number of professors who requested anonymity increased significantly following the publication of two articles that were published on the front page of the Wall Street Journal during the summer of 1999 concerning controversy over the commercialization of MIT inventions. ('MIT Students, Lured to New Tech Firms, Get Caught in a Bind – They Work for Professors Who May Also Oversee Their Academic Careers – Homework as Nondisclosure', June 24, 1999, p. A1; 'MIT Seeds Inventions But Wants a Nice Cut of Profits they Yield', July 20, 1999, p. A1) I have respected the wishes of these professors and although they are not acknowledged in this list, I am grateful for the generous amounts of time each spent with me.

	Program		1999
Dr. Joel Moses	Dugald C Jackson Professor of Computer Science and Engineering, former Provost	MIT	Mar. 30, 1999
Dr. Jeffrey H Shapiro	Professor, EECS, Associate Department Head, Elec Eng	MIT	Mar. 31, 1999
Dr. Gill Pratt	Assistant Professor, EECS	MIT	April 1, 1999
Dr. Richard Larson	Professor/Director, Center for Advanced Education Services	MIT	April 2, 1999
Dr. Mildred Dresselhaus	Institute Professor, EECS	MIT	April 5, 1999
Dr. Roger Mark	Distinguished Professor in Health Science and Technology	Harvard/MIT	April 6, 1999
Arvind	Charles W & Jennifer C Johnson Professor in Computer Science and Engineering	MIT	April 6, 1999
Dr. Jack Dennis	Professor of Electrical Engineering, Emeritus, Sr. Lecturer	MIT	April 8, 1999
Dr. Thomas Magnanti	Institute Professor, School of Management	MIT	April 9, 1999
Dr. Jeffrey Lang	Professor EECS, Associate Director L E E S	MIT	April 12, 1999
Haig Farris	President	Fractal Capital	June 14, 1998; Jan 6, 1999
Ed Roberts	David Sarnoff Prof. of Mgmnt of Technology; Chairman MIT Entrepreneurship Ctr, Co-Chairman Intl Center for Research on the Mgmnt of Tech.	MIT	May 19, 1998
Harris A. Fishman	CPA, CFO	Self-employed	July 16, 1999
Rick Langhans	VP Research (satellite communications)	GE	Jan. 22, 28 1999
Dr. Ray Jakubek	Research Director	Bell Labs/AT&T/ Lucent	Dec. 23, 1998
Jerry Agi	President, Engineer	AGI Engineering	May 10, May 25, June 12, July 6, 1998
Angus Livingston	Licensing Officer, University-Industry Liason Office	University of British Columbia	July 14, 1998
Lori Pressman	Assistant Director, Technology	MIT	Nov.

	Licensing Office		1998; Jan. 20, June 8, 1999
Lita Nelson	Director, Technology Licensing Office	MIT	Jan 20, June 8, 1999
Dr. Clayton Christenson	Professor of Technology and Operations Management	Harvard Business School	Jan. 19, 1999
Dr. Ernesto Blanco	Adjunct Professor, Mechanical Engineering	MIT	June 29, 1999
Dr. Woodie Flowers	Pappalardo Professor of Mechanical Engineering	MIT	June 29, 1999
Dr. Hae-Seung Lee	Professor, EECS	MIT	June 29, 1999
Dr. Borivoje Mikic	Professor, Mechanical Engineering	MIT	June 29, 1999
Dr. Anthony Patera	Professor, Mechanical Engineering	MIT	June 30, 1999
Dr. Robert Mann	Mechanical Engineering, Whitaker Professor Emeritus of Biomedical Engineering, Sr.Lecturer	MIT	July 1, 1999
Dr. David E. Hardt	Professor, Mechanical Engineering	MIT	July 1, 1999
Dr. Nam Pyo Suh	Department Head and Ralph E & Eloise F Cross Professor of Mechanical Engineering	MIT	July 2, 1999
Dr. Hermano Igo Krebs	Research Scientist, Mechanical Engineering	MIT	July 6, 1999
Dr. Mark Johnson	Principal Research Engineer, Mechanical Engineering	MIT	July 7, 1999
Dr. Ronald Probstein	Professor of Mechanical Engineering	MIT	July 21, 1999
Dr. Warren Seering	Professor of Mechanical Engineering/Director Center Innov Prod Dev	MIT	July 29, 1999

Appendix E

MIT University Licensing in the News - 1999

Class Struggle:
MIT Students, Lured
To New Tech Firms,
Get Caught in a Bind

They Work for Professors
Who May Also Oversee
Their Academic Careers

Homework as `Nondisclosure'
By Amy Dockser Marcus
06/24/1999
The Wall Street Journal
Page A1

CAMBRIDGE, Mass. -- William Koffel, a junior at the Massachusetts Institute of Technology, was among the brightest students in his 6.033 Computer System Engineering course last spring. But he couldn't handle one of the homework assignments from Prof. M. Frans Kaashoek.

It wasn't that the assignment, to design a new system to speed up delivery of Web pages, was too complex. Actually, it was easy, because Mr. Koffel already had been working on just such a project -- not as a student, but as an employee, at a company co-founded by a different MIT professor. And Mr. Koffel was bound by a nondisclosure agreement, or an NDA, not to reveal his work for the company.

"At first I thought, 'What a boring project if I have to write about something I already understand,' " recalls Mr. Koffel, 21 years old. "Then I thought about the nondisclosure agreement I signed and wondered if I could do my homework at all."

Three other students who live in Mr. Koffel's dorm and work at Akamai Technologies Inc. were in the same fix. So Mr. Koffel poured out his predicament to F. Thomson Leighton, the MIT professor who helped found Akamai. After the two professors conferred, the students sent an e-mail to Mr. Kaashoek asking for a new homework assignment.

He agreed -- but reluctantly. "I felt the students were getting a bad deal. The students should be able to do any assignment at MIT ," Mr. Kaashoek says. "I'm not going to let it happen again. It's ridiculous that an NDA is going to set the content of my course. In the future, my policy is going to be, 'If you sign an NDA, you take this class at your own risk.' "

Mr. Leighton realizes the situation was awkward, but says the issue isn't simple. He says Mr. Kaashoek has started his own company, SightPath Inc., that is attempting to do work similar to Akamai's. Indeed, Mr. Leighton wonders if his fellow professor gave that assignment as a way to learn more about Akamai's progress.

Mr. Kaashoek insists it was homework, not espionage: "There's tons of companies in that space." But Mr. Leighton isn't so sure. "Frans was aware of exactly what we are doing," he says. "If Akamai didn't exist, would he have thought of this question? It's not clear."

What is clear is that on many campuses, student jobs have come a long way from the days of busing tables in the cafeteria or checking the footnotes in a professor's research project. And as the payouts at Internet start-ups skyrocket, some of the conflicts these jobs present are as cutting-edge as the technology they develop.

High-tech launches from universities frequently can't get off the ground without a steady supply of students, who are often the most talented and the most willing to toil around the clock. But intense schedules on the job can keep students from doing their best academic work. And when both student and teacher share a huge financial incentive to make a company a success, some professors might be tempted to look the other way when studies slip or homework gets in the way.

Other universities with top-notch engineering programs, such as Stanford or Cal Tech, are also grappling with the phenomenon, but nowhere are the dilemmas more intense than at MIT , the school responsible for such pioneering innovations as commercial spreadsheet programs and encryption for secure online transactions. MIT actively encourages professors and students to turn university-developed technologies into businesses, which often results in a return to the school in licensing fees, royalties or stock. The MIT Technology Licensing Office coaches students and faculty on how to set up companies and connects them with venture capitalists. The office has helped create about 150 companies that are still in business; MIT holds equity in about a third of them.

MIT official policy requires professors to disclose any situation that might pose a conflict; potential problems are then worked out with the department heads on a case-by-case basis. But the number of students working at start-ups has soared so quickly that issues like the homework problem have taken the school by surprise. "We're making up policy as we go along," says John Guttag, head of MIT 's Department of Electrical Engineering and Computer Science.

He sometimes turns down faculty who ask for leaves to start companies; otherwise he wouldn't have enough professors to teach courses. Meanwhile, some professors note that students are more frequently missing assignments and getting poorer grades because of work commitments at start-ups.

A walk down the main hallway of the computer-science department shows how close the academia-business relationship has become. Prof. Stephen Ward is on leave getting his technology company, Curl Corp., off the ground. David Gifford helped set up e-commerce pioneer Open Market Inc. and is now working on SightPath with Mr. Kaashoek. Mr. Guttag himself says he may sign on as an adviser to Vanu Inc., an Internet company based on Ph.D. research by one of his graduate students.

Mr. Guttag often sees students wondering whether they should stay in school or work for Vanu. "I'd start to tell them, `No, don't go, stay at MIT and do research for me,' and realized that I had a conflict too."

Such problems required Mr. Guttag to weigh in with faculty earlier this month. "My perception is that an increasing number of our students are being hired to work at companies in which MIT faculty members play a significant role," he wrote to professors. That raises "some serious issues with respect to potential conflicts of interest, and has already put some of our students in difficult situations."

Mr. Guttag mandated that from now on, when a professor wants to hire an MIT student for his company, the student must first meet with another faculty member for counseling. After that, it's up to the student, but at least he or she will have had the benefit of some impartial advice.

And starting in the fall, students who sign nondisclosure agreements will not be given alternative homework, Mr. Guttag says. To Mr. Kaashoek, that means students who won't do their work because they've signed an agreement will flunk the assignment. To Mr. Leighton, that means a student who works at Akamai might have to let his company "review a homework assignment before it was turned in."

Such arrangements can stifle the very openness so important to higher education, says Mr.

Gifford, the computer-science and engineering professor. "Part of academic life is to write papers and have them judged by others," he says. Students who sign nondisclosure agreements "are now cut out of a lot of academic discourse."

And the impact can go deeper, some fear. "I think someone should be asking these students, 'Will you be sorry 15 years from now that you were too busy in college to have a boyfriend or a girlfriend? That you didn't play a sport, or act in a play? Are you going to be sorry you didn't take your studies seriously?' " says Mr. Guttag. He notes there is "an inherent conflict of interest" for entrepreneurial professors: "Once you've started a company . . . you're in sell mode, and it's hard not to be in that mode when talking to students, too."

Still, Akamai is the talk of MIT these days. The company just unveiled a board of advisers that includes Tim Berners-Lee, director of the World Wide Web Consortium, and Peter Solvik, Cisco Systems Inc.'s chief information officer. Akamai recently closed a second round of financing for $35 million, and last month it won the 1999 MIT Sloan eCommerce Award for Rookie of the Year -- given to the start-up most likely to dominate its field.

No company has been more closely tied to MIT . The firm has its roots in a research project directed by Mr. Leighton about three years ago. Daniel Lewin, one of Mr. Leighton's graduate students, came up with a key idea for how to apply algorithms, or numerical instructions for computers, to Internet congestion problems. He and some fellow students worked on the issue for a year, then published a paper in May 1997.

That fall, Mr. Lewin talked to Mr. Leighton about joining a student-run team for an MIT entrepreneurship contest -- grand prize, $50,000. Mr. Leighton signed on.

Their team didn't win the contest, but no matter. By mid-1998, Mr. Leighton and Mr. Lewin were on the entrepreneur's road, looking for financing. Battery Ventures, a venture-capital firm based in Wellesley, Mass., along with Polaris Venture Partners, based in Boston and Seattle, put up $8.4 million.

They hired 15 undergraduates to code the algorithms. They bought computers and started to build a prototype for their new network system. Akamai, Hawaiian for intelligent, clever and cool, was born.

Messrs. Lewin and Leighton struggled to keep their MIT and Akamai responsibilities separate. Mr. Lewin had completed his master's thesis, which inspired Akamai's technology, in May 1998. Mr. Leighton told Mr. Lewin to have a second professor co-sign the thesis, to certify that the quality of the work met rigorous academic standards. Mr. Leighton says he wanted a second signer because he worried about the appearance of conflict in his supervising Mr. Lewin's academic work while also pursuing a business venture with him.

Mr. Lewin got a co-signer: David Karger, who was involved in Mr. Lewin's original research project and would later become a part-time research scientist at Akamai. Mr. Leighton says he now wishes that someone completely outside the group had co-signed the thesis, but he didn't think much of it at the time because Mr. Karger hadn't played an active role in the entrepreneurship competition.

Since its founding, Akamai has aggressively used its MIT connections. Of the firm's 104 employees, 20 were students in the last semester, including 16 who were undergraduates or enrolled in a joint bachelor's-master's degree program. Ten more students have been hired to work for the summer.

"This company exists because of students," says Paul Sagan, the company's president. MIT , plus its faculty and students, now have about 40% of the company's shares.

But to maintain good ties with the school, Akamai has had to negotiate some tricky policy

positions.
For one, the company voices a strong stance against students dropping out. Early on, Mr. Sagan says, some students approached him about going full time. "I told them that if they drop out of college before completing their undergraduate degree because they want to work full time at Akamai, we won't offer them a full-time job," says Mr. Sagan.
Akamai also faced a problem over stock options. At most companies, options expire once an employee is no longer working there full time. But at Akamai, graduate students' options continue to vest as long as the students work an average of 20 hours a week while completing their degrees.
For undergraduates, the Akamai experience can be heady stuff. Luke Matkins had just finished his sophomore year when he joined the Akamai team for a summer job. He would spend all night programming; then, "in the morning, the guys from the venture-capital funds would come by, and I'd be in charge of leading the demo," says Mr. Matkins. Soon, he found himself in charge of a group of four to eight programmers.
Mr. Matkins began working 70 to 80 hours a week on top of his classes. Now, at the age of 21, he earns a salary of $75,000 -- more, he says, than his schoolteacher father makes. He was given 60,000 options, a stake now worth over $1 million based on the latest price venture capitalists paid per share.
His grades weren't as high as they would have been had he spent more time on homework. In his computer-systems class, he got a B because he was too busy to complete all of his assignments. He sometimes skipped lectures. The work at Akamai, he says, was far more compelling.
Mr. Matkins says the prospect of being a millionaire by his senior year is "very cool." He loves MIT , but in many ways, he says, Akamai has become his real university. "There are different ways to learn stuff," he says. "I've learned more at Akamai than I would in a classroom."
Meanwhile, Mr. Lewin, 29, is taking a year off from his coursework toward a Ph.D. so he can concentrate on his duties as chief technology officer at Akamai. He plans to use his work as the basis of his doctoral dissertation, but says he'll probably need permission from the Akamai board of directors -- on which he sits. He will also probably need approval from Akamai's chief scientist, Mr. Leighton, who, it turns out, is his Ph.D. adviser.

Bose and Arrows:
MIT Seeds Inventions
But Wants a Nice Cut
Of Profits They Yield

It Is Jousting With a Son
Of Audio-Making Family
Over the Use of a Patent

Income Source for University
By Amy Dockser Marcus
07/20/1999
The Wall Street Journal
Page A1

CAMBRIDGE, Mass. -- Vanu Bose grew up at the Massachusetts Institute of Technology. His father, Amar, founded sound-system maker Bose Corp. at MIT and is an MIT professor. Vanu went to MIT summer day camps, spent Sundays in the university gym watching his dad play badminton, and later earned bachelor's, master's and doctoral degrees at the university.

But Vanu Bose, 34 years old, isn't feeling very grateful toward his alma mater these days. For more than a year, he has been embroiled in negotiations with MIT 's Technology Licensing Office over rights to a pending patent based on technology he devised for his Ph.D. Since that work was done at the university, it will own the patent, with Vanu listed as inventor.

Now he wants MIT to give his start-up company, Vanu Inc., exclusive rights to the patent. MIT wants a cut of the company in exchange. They haven't been able to come to terms.

At first, MIT demanded $1.25 million over the next eight years in licensing fees, along with royalties of 10% on licensed services, 10% on software the firm developed, 4% on computer hardware and 6% on "firmware," which is software embedded in hardware. And MIT asked to be made a 6% owner of the company.

"I have to confess to being astounded" at the proposal from MIT 's Technology Licensing Office, or TLO, wrote back John Guttag, an MIT professor who negotiated on behalf of Vanu Inc. "It certainly gave more the appearance of trying to put funds in the TLO's coffers than of trying to help us commercialize the technology."

Lita L. Nelsen, director of the TLO, shrugs off the criticism. Technology developed at MIT belongs to MIT , she says, and her office is out to make sure MIT gets a fair deal. "We have a large fan club," Ms. Nelsen says. "The gripers are the exceptions."

Things weren't so contentious 35 years ago, when Amar Bose started Bose Corp. with technology he developed at the university. MIT let him have the rights to the patent for nothing. Mr. Bose, now 68, eventually got rich off the closely held company, with a net worth now estimated at $550 million. He says his Bose Foundation has since donated more than $6 million to MIT .

But times have changed. MIT doesn't just want generous alumni, the lifeblood of most private universities. If it has had a hand in their commercial success, it also wants a slice of their companies.

Government funds to the university have dropped off, and even with a $1.2 billion budget, MIT , like most research universities, feels squeezed. The technology office in recent years has become an important income source. Its gross revenue was $18.6 million in fiscal 1998, ended in June. And that doesn't include the value of stock MIT has obtained in companies started by its professors and students, a figure the university won't disclose.

This kind of success comes at a price. In the exchanges between Vanu Inc. and the licensing office, the two sides keep arguing not only over the deal but also over who has the best interest of the school in mind. Is it MIT 's higher responsibility to make sure that useful technology is disseminated, or to earn money for the school? Should MIT be fighting for spin-off business profits or giving its faculty and students good deals in hopes of donations when they get rich? (MIT has built a $4.3 billion endowment with the help of such largess.)

These are tensions that more universities are facing these days. In the past, academic inventors and their schools were typically working together to sell the technology to interested companies outside. Now they sometimes find themselves on opposite sides of the negotiating table, as more professors and students try to start companies themselves.

Both sides agree that the negotiations started off amicably enough. Vanu Bose came to the TLO offices in Cambridge with his Ph.D. adviser, Mr. Guttag, for a brief meeting to explain the company plan in March 1998. "I said, 'I've been around MIT all my life. I just want a deal where if I do well, MIT does well too,'" Mr. Bose recalls telling Ms. Nelsen. She responded that the TLO shared the sentiment and that she'd send along a contract.

When it arrived, amity dissipated. "This proposal is not viable for my startup," Mr. Bose wrote in a letter rejecting MIT 's terms, which he said would hurt chances of a business success. "My greater concern, however, is that the TLO's licensing policy places an unreasonable burden on any start-up."

From there, suspicions grew. The TLO offered the company a seven-year exclusive license, saying that renegotiating later on was in Mr. Bose's best interest, since the company's needs would change. He balked. As he saw it, if the company did do well, " MIT would have me over a barrel in the new negotiations." As bargaining dragged on, Mr. Guttag threatened to put the technology in the public domain or investigate the legality of patenting some of the ideas outside of MIT .

The TLO sent a scaled-down proposal in May 1998, nearly halving its request for licensing fees over eight years. It now sought 4% equity instead of 6%. The other requests were reduced, too: 3% royalties on hardware, 7% on software, 4% on firmware and 10% on licensed services. Better, but still too high, Mr. Bose and his partners said.

Vanu Inc. is living off research contracts while it tries to create a prototype for a "software radio" that would allow users to run all their wireless gadgets, from cellular telephones to baby monitors and garage-door openers, on one device. "We want to stay private," says Andrew Beard, a vice president. "If we immediately have to pinch pennies to pay MIT , then the first thing to go is our ability to fund research."

Responding to the second proposal, Mr. Guttag argued that the TLO's primary mission is to benefit the public by commercializing MIT -developed technology. "Your proposal seems to place the highest priority on the one benefit that does not follow from your mission statement, making money for the MIT ," he wrote.

Ms. Nelsen quickly replied: "We are, of course, well aware of our mission statement. You should also be aware that the TLO has an obligation to MIT to make a fair deal whereby MIT benefits in return for the resources it has provided to enable our inventions to occur."

Amar Bose has watched his son's battle with MIT with increasing dismay. The senior Mr. Bose says he owes MIT a great debt. He earned a doctorate in electrical engineering at MIT in 1956 and never left. When his company was just getting off the ground, MIT said it could use the MIT labs rent-free until permanent offices were found. MIT was an early investor in Bose Corp. and remains one. "What MIT did for me is unbelievable," he says. "What's happening now is painful."

Prof. Bose says he wants to change the TLO policies in order to help all MIT students, not just his son. "The students are no match for the technology licensing staffs of the institutions," he says, suggesting that MIT ought to advise students not to enter TLO offices without a lawyer by their side.

Calling the TLO's mission statement "window dressing," he says that "the bottom line is they want to make money." Yet "any university that tries to earn money from its students' inventions will inevitably have a conflict between their interests and those of the student," he contends.

In his son's case, Mr. Bose has worked to give the student-inventor every advantage. A Bose Corp. patent attorney advised Vanu Bose on signing documents, reviewed the proposed patent application and has continued to offer informal counsel throughout the negotiations. When they stalled, father told son to try to find a way around the MIT patent. Then in January, the senior Mr. Bose went to talk to the MIT provost about the case and TLO policies.

It didn't take long for Ms. Nelsen to hear about that. The attempt to intercede was "upsetting" and disappointing to her, says the TLO director, whose husband is a former student of Prof. Bose and an ex-employee of Bose Corp. "People throw their weight around when they can, but the institution is supportive of us," she says. Someone from the provost's office inquired as to the kind of deal Vanu Bose had been offered, but she says she simply replied that it was "the generous low end," compared with similar start-ups, and that was the end of the discussion.

Provost Robert A. Brown won't comment except to say that sentiment shouldn't have a role. "This is a fairness issue," he says. "Internal MIT people can't take a different negotiation path than outsiders."

Ms. Nelsen concedes terms of the first proposal were too tough, something she attributes to the inexperience of the initial licensing officer. "We don't think we need to do penance for a mistake," she says.

Ms. Nelsen says the negotiations have taken a long time not because her office wants to make Vanu sweat but because it is overwhelmed with more-pressing deals with companies that must settle terms with MIT to get venture capital. "No one asked us to hurry it up, including Vanu," she says. As to the charge the TLO takes advantage of students, Ms. Nelsen bristles. "We bend over backward to help students," she says.

Her office's latest offer is $70,000 in licensing fees from Vanu Inc. over eight years -- only about 5% of its original demand. MIT nows seeks 3% equity in Vanu, plus 1% royalties on hardware, 5% on software, 2% on firmware and 3% on licensed services. It's a fair deal that won't hurt a new company, she says, adding: "We shouldn't give the technology away just because someone yells a lot."

Her technology office has its fans. It has helped student entrepreneurs find business advisers and funding sources. But even its supporters say that it thinks like a company, with an eye to improving its bottom line.

Mr. Guttag says maximizing the MIT technology office's revenue isn't the same as maximizing MIT 's. "One might say that much more important than the revenue from the licensing is earning the long-term goodwill of our students," he observes. "They might make more in charitable contributions to MIT than we'd get from a licensing deal."

On a recent afternoon, Vanu Bose walks around the MIT campus, retracing the geography of his childhood. There is the MIT pool, and the gym where he waited in the bleachers on Sundays to get some time alone with his father. He stops in front of a sign announcing the spot as the future site of the Ray and Maria Stata Center, thanks to a $25 million gift from the founder of Analog Devices Inc. and his wife. "Now there's a very happy alum," he muses.

After four months of silence, another meeting with the TLO is scheduled to take place this week to discuss the last offer. Mr. Bose looks at the Stata Center sign again. " MIT is like my second home. I love this place," he says. "But right now I don't plan to donate a cent."

Appendix F

Sample Contract to Illustrate 'Use-it-or-Lose-It' Clause

Following is an example of the 'diligence' terms included in an invention licensing agreement. These terms are commonly referred to as the 'use-it-or-lose-it' terms and are employed to prevent the strategic (mis)use of university intellectual property by purposefully keeping an invention dormant. In other words, these terms are included to prevent firms from keeping university inventions as 'sleeping patents'. This appendix also includes two letters from the licensee firm addressed to the Technology Licensing Office which discuss milestone updates in light of these diligence terms.

3 – Diligence

3.1 LICENSEE shall use its best effort to bring one or more LICENSED PRODUCTS or LICENSED PROCESSES to market through a program that meets or exceeds the milestones as set forth in this agreement for exploitation of the PATENT RIGHTS and to continue active, diligent marketing efforts for one or more LICENSED PRODUCTS or LICENSED PROCESSES throughout the life of this Agreement.

3.2 In addition, LICENSEE shall adhere to the following milestones:

a. LICENSEE shall deliver to M.I.T. on or before January 1, 1996 a business plan showing the amount of money, number and kind of personnel and time budgeted and planned for each phase of development of the LICENSED PRODUCTS and LICENSED PROCESSES and shall provide similar reports to M.I.T on or before January 1 of each year.

b. LICENSEE shall develop a working model on or before June 1, 1996 and permit an in-plant inspection by M.I.T. on or before June 1, 1996, and thereafter permit in-plant inspections by M.I.T. at regular intervals with at least twelve (12) months between each inspection.

c. LICENSEE shall make a first commercial sale of a LICENSED PRODUCT and/or a first commercial use of a LICENSED PROCESS on or before January 1, 1997.

d. LICENSEE shall make NET SALES according to the following schedule:

1997	5 UNITS
1998	10 UNITS
1999 and each year thereafter	20 UNITS

3.3(a) In the event that M.I.T. or LICENSEE receives written request from a capable third party for a license or a sublicense to use the PATENT RIGHTS in a field of use which does not compete with the LICENSED PRODUCTS already offered for sale by LICENSEE or in the process of being developed so as to be available for sale within one (1) year as demonstrated by LICENSEE's written business plans, then LICENSEE agrees to enter into good faith negotiations with said third party to grant sublicenses to said third party.

3.3(b) If the negotiations referred to in 3.3 (a) have not been completed within four (4) months from the date LICENSEE first receives such written request, then M.I.T. shall have the right to negotiate a non-exclusive license to said third party for the appropriate subfield of use under substantially similar, or, at M.I.T.'s discretion, less favorable (to said third party) terms than those contained in this Agreement.

3.3(c) Paragraph 3.3(b) shall apply only for four (4) months after M.I.T. is first informed in writing that the third party wishes to enter into good faith negotiations with M.I.T., according to their rights under paragraph 3.3(b).

3.3(d) LICENSEE grants M.I.T. permission to inform the third party of the term of subparagraphs 3.3(a), (b), (c), and (d).

3.3(e) If M.I.T. grants a license under paragraph 3.3(b), M.I.T. agrees to credit to LICENSEE twenty-five percent (25%) of M.I.T.'s net royalties and net license fees.

3.4 LICENSEE's failure to perform in accordance with either Paragraph 3.1, 3.2, or 3.3 above shall be grounds for M.I.T. to terminate this Agreement pursuant to Paragraph 13.3 hereof.

January 1, 1996

Director
Technology Licensing Office
Massachusetts Institute of Technology
77 Massachusetts Ave., Room E32-300
Cambridge, Massachusetts 02139

Re: M.I.T. Case ####

Pursuant to Section 3.2a of the PATENT LICENSE AGREEMENT between MASSACHUSETTS INSTITUTE OF TECHNOLOGY and #### the following is our business plan for the development and commercialization of the LICENSED PRODUCT.

To date #### Inc. has spent approximately $65,000.00 and about 2 man months on the development of a prototype of LICENSED PRODUCT for the purpose of understand the various aspects of device fabrication. Approximately $50,000.00 of these funds have come from a Phase 1 SBIR grant from the National Institute of Science and Technology, with another approximately $10,000.00 coming from a Phase II, DoD SBIR. The balance of $5,000.00 has come from operating revenues of the company.

We are pleased with the performance of the prototype - in fact, so pleased that our current plan is to make this product the focus of a series of major trade shows that occur this Spring and Summer (the #### Show in Anaheim, CA in June and the #### Show in Tokyo in July). We anticipate that we will begin to accept orders for LICENSED PRODUCT in the late Summer or early Fall, with actual product delivery to begin shortly after January 1, 1997.

We anticipate spending about $70,000.00 for equipment needed to assemble LICENSED PRODUCT ($50,000.00 for a fusion splicer). Approximately another $50,000 in parts is budgeted to develop the first commercial prototypes that will be exhibited at the above mentioned trade shows. One senior scientist will be assigned to the program to develop and characterize the commercial prototypes. When we transfer the LICENSED PRODUCT to production at least one and probably two technicians will be trained to assemble and test the commercial device before shipment.

We plan on submitting a proposal for Phase II SBIR funding to NIST and a Phase I SBIR proposal to DoD in 1996 to further develop the technology. In both proposals we will be collaborating with Professor ####'s group at M.I.T. We are very optimistic that the NIST Phase II proposal will be funded based on the work done in Phase I.

Thus, we have high expectations for the successful commercialization of the LICENSED PRODUCT, and look forward to a rewarding relationship for both of us.

Sincerely,
####

December 28, 1996

Lita L. Nelson,
Director
Technology Licensing Office
Massachusetts Institute of Technology
77 Massachusetts Avenue, Room E32-300
Cambridge, Massachusetts 02139

Re: MIT Case #### License Agreement

Dear Ms. Nelson:

Pursuant to our License Agreement with M.I.T. and my discussions with Ms. Lori Pressman, this letter is intended to fulfill the reporting requirements of section 3 of the above referenced License Agreeement.

Re: 3.2a, #### has completed the development of a LICENSED PRODUCT as per the terms of the License Agreement with M.I.T. (please see copy of #### data sheet enclosed). To date, the company has expended $303,000.00 in its effort to commercialize the licensed technology. This includes not only extensive design and redesign to optimize the performance of the final product, but also promotion at trade shows, #### Meeting, #### Meeting, #### USA, #### Europe, ####), advertisements (see for example the attached from the 1997 issue of ####), and promotion on our web site (####). We have dedicated the equivalent of 2 Ph.D.'s and 2 staff people to our commercialization efforts over the past year.

Re: 3.2b., a prototype product was developed well before the June 1, 1996 deadline – in time to exhibit the product at the #### USA show in May of 1996.

Re: 3.2c., the company has sold 2 licensed products in 1996, fulfilling its obligation to make a first commercial sale of LICENSED PRODUCT before January 1, 1997.

Over the next year(s) we plan on making further investments in the LICENSED PRODUCT to evolve the technology in ways that reduce cost and increase its utility in many varied applications. We are exploring its use in conjunction with an SBIR that is aimed at proof-of-concept of a ####. We anticipate that, as the #### gains acceptance in the marketplace over the next few years, we will see additional applications emerge in science, medicine, and industrial process and quality control.

Our work over the past year with this superb technology invented by Professors #### and #### has confirmed our high hopes for its future. In fact, we have become so enamored with it that our objective is now to make it the keystone of our product line and its future development.

On the downside, there seems to be some confusion at #### about whether or not we currently owe you any payments per the terms of the License Agreement. Unfortunately, ####, our bookkeeper, is out of the office until January 13th, so I cannot determine what has been paid until she gets back.

Can you have whoever is responsible for this call me at #### so I can get involved in straightening out this issue?

Sincerely,
####