Build, Rent and Sell: Options for Commercializing New Technologies Arising from University Research

by

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Author's Declaration for Electronic Submission of a Thesis

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revision, as accepted by my examiners.

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Abstract

This research investigates the strategic governance choices made in commercializing new technologies arising from university research.

Departing from the traditional licensing vs. start-up approach, it is proposed that there are three primary methods of commercializing these technologies: 1) Build – creating a new business based on the technology, 2) Rent – ongoing development and marketing of the technology to established firms that use the technology in their businesses and 3) Sell – disposition of the technology to an established firm.

Using economic theories of the firm, particularly transaction cost economics, it is hypothesized that:

- the build option is positively associated with firms deriving revenue primarily from product market activity (H1a) and expending resources on both technology development activities and production activities (H2a);
- the rent and sell options are positively associated with firms deriving revenue primarily from technology market activity (H1b) and expending resources on technology development activities but not on production activities (H2b).
- the greater the patent or other legal protection (H3), the risk of substitutes (H5) or the dynamism associated with the technology (H8), the greater the likelihood that the technology will be commercialized using the rent option;
- the greater the tacitness and complexity (H4) or the greater the volatility associated with the technology, the greater the likelihood that the technology will be commercialized using the build or sell options; and
- the greater the importance of specialized complementary assets, the greater the likelihood that the technology will be commercialized using the sell option (H6).

Three studies were conducted providing differing perspectives on the research question. Study #1 examines three start-ups based on new technologies arising from research conducted at the University of Waterloo. Study #2 analyzes the business activities of a number of Canadian and U.S. public start-up firms using archival data. Study #3 is a survey

of university faculty members who have had new technologies arising from their academic research put into commercial use.

Hypotheses H1a/b, H2a/b and H3 are supported and Hypothesis H7 received more limited support. Evidence for Hypothesis H5 is in the predicted direction but failed to achieve statistical significance. Hypotheses H4, H5, H6 and H8 are not supported.

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Chapter 1
Introduction

Universities perform 31 percent of Canada's research and development activities (OECD, Main Science and Technology Indicators, 2001, as cited in Industry Canada, 2002). The economic impact of licensing activities by Canadian universities has been estimated at more than $500 million supporting an estimated 4,000 jobs (Gu and Whewell, 1999). In addition, spin-off companies based on university research employ more than 20,000 people and generate $2.5 billion in annual revenue (Read, 2003). Despite these successes, the Government of Canada's Innovation Strategy identifies what it calls the Knowledge Performance Challenge, namely, that "Canadian firms do not reap enough benefits from the commercialization of knowledge" (Industry Canada, 2002, p. 19) and sets as a priority implementing initiatives to "leverage the commercialization of publicly funded academic research" (p. 52). In response, Canadian universities have committed to tripling their commercialization performance by 2010 (AUCC, 2002). While progress has been made in reaching these targets, much remains to be done (AUCC, 2005). Consequently, the commercialization of new technologies arising from university research is an increasingly important issue.

The forms that university research commercialization take are varied and include licensing of patented inventions, collaborative development with industry partners and the creation of start-up ventures. In investigations of these forms, significant variation in the role of patents and the degree of interaction between the researcher and the commercializing firm have been found (Colyvas et al., 2002).

Despite the growing interest in the commercialization of new technologies arising from university research and the suggestion that patents and other characteristics of technologies play a role in the methods used to commercialize these technologies, "scholarly investigation of this phenomenon is virtually non-existent" (Shane, 2004, p. 2).

The research described in this thesis investigates why the transactions involved in commercializing university research take the form they do. Better understanding of the reasons for different forms of commercialization can help inventors and others involved in the commercialization process to select appropriate methods for commercializing new technologies arising from university research.

1.1 Scope of the research

This research focuses on the commercialization of technological innovations arising from university research. “Commercialization is the production, manufacturing, packaging, marketing, and distribution of a product that embodies an innovation” (Rogers, 1995, p. 143). Technological innovation refers to new “theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems. Technology can be embodied in people, materials, cognitive and physical processes, plant, equipment, and tools” (Burgleman, Maidique and Wheelwright, 2001, p. 4).

This research examines the governance structures used in the commercialization of university research. These governance structures can include various forms of licensing, spin-offs and partnerships. Different governance structures are theorized to be efficient in different circumstances. Consequently, it is expected that the choice of an appropriate governance structure can have a significant impact on the success of the commercialization effort.

The research does not examine other issues related to the commercialization of university research. These include how commercializing firms locate specific innovations they wish to commercialize and what motivates researchers to commercialize their innovations.

1.2 Research question

“In a university’s attempt to commercialize a new technology, there is little empirical evidence to suggest which route the university should take” (Gu and Whewell, 1999, p. 73). The research described in this thesis addresses this lack of empirical evidence and asks the research question:

> How do the characteristics of technologies affect the choice of governance structures used to commercialize new technologies arising from university research?

The phrase “characteristics of technologies” in the research question is intended to be interpreted broadly. It includes, for example, characteristics of the technology itself and characteristics of the complementary assets required for the commercialization of the innovation.

The commercialization of new technologies takes different forms for many reasons. For example, the governance structure chosen may be a result of researcher preferences. Some researchers may not be interested in commercial application of their research and may not be willing to participate in activities to transfer the technology. In these circumstances, commercialization may occur through spillover from published papers or through licensing through a university's technology transfer office with little involvement of the researcher. Researchers may have other motives as well. For example, some researchers may be more entrepreneurial and may have a desire to found a start-up venture to commercialize their research. The choice of governance structure may also be affected by financing considerations. For example, new technologies in the pharmaceutical industry may tend to be commercialized by established firms due to the significant costs involved in moving the innovation through the regulatory approval process. In contrast, software innovations often may be commercialized through start-up ventures because of the limited financial capital investments required by these technologies. While many reasons may exist for choosing a particular path to commercialization, the perspective taken in this research is that new technologies with certain attributes align with certain governance structures and that this alignment is primarily based on minimizing the costs of monitoring and managing the relationship between the researcher and the commercializing firm (see section 2.6, Transaction cost economics).

1.3 Outline of this thesis

This thesis is organized as follows. Chapter 2 contains the literature review and consists of two parts. The first deals with the literature related to the commercialization of new technologies arising from university research. The second deals with economic theories of the firm and, in particular, transaction cost economics. Transaction cost economics is the theoretical basis for the governance structures and hypotheses developed in chapters 3 and 4. The literature on the commercialization of university research and the literature on economic theories of the firm suggest a number of implications for the commercialization of new technologies. First, governance structures are important for the successful commercialization of new technologies. However, a focus on governance structures has been absent in the literature on the commercialization of new technologies arising from university research with the exception of a brief mention by Shane (2002). Second, the choice of governance structures is affected by transaction attributes. Under transaction cost economics theory, these attributes are the existence of specialized assets, uncertainty and frequency. Looking more specifically at the commercialization of new technologies, key transaction attributes that have been identified are the ability to exclude others from using the technology and access to specialized complementary assets. Third, in applying transaction cost economics to the commercialization of new technologies, it is important to consider carefully the governance structures that may arise in this specific environment, the specific attributes of new technologies that may affect transaction costs and the ramifications of selecting specific governance structures in light of these specific attributes. That is, it is important to tailor the application of transaction cost economics to the specifics of the situation being considered (Williamson, 2002).

In chapter 3, difficulties with the traditional approach to classifying the methods used to commercialize new technologies arising from university research (licensing vs. start-up) are identified and a proposal is presented for a new method of categorization that is linked to the concept of governance structures discussed in the preceding chapter. It is proposed that there are three primary methods of commercializing new technologies arising from university research: 1) *Build* – creating a new business based on the technology, 2) *Rent* – ongoing development and marketing of the technology to established firms that use the technology in their businesses and 3) *Sell* – disposition of the technology to an established firm. The rationale for the proposed new method is discussed and criteria for the categories are developed. Finally, the benefits of the proposed categorization scheme are presented.

In chapter 4, the hypotheses that will be tested are developed. Two sets of hypotheses are proposed in this chapter. The first set is related to firm characteristics associated with the strategic governance choices of build, rent or sell. The second set of hypotheses relates to the link between certain characteristics of new technologies (i.e., transaction attributes) and the strategic governance choices made in their commercialization.

In chapter 5, the methods used to conduct the research are described. Three studies were conducted in the course of this research. Each of these studies uses different methods. The use of multiple methods, known as triangulation, has the benefit of providing differing perspectives on the research question. Study #1 analyzes three start-ups based on new technologies arising from research conducted at the University of Waterloo. The analyses in this study use archival data related to the three start-ups examined. Study #2 examines the business activities of a number of Canadian and U.S. public start-up firms. This study uses two separate samples of public start-up firms that have commercialized new technologies arising from university research. The first sample is of Canadian companies built on National

Sciences and Engineering Research Council of Canada ("NSERC") funded research. The second sample is of U.S. companies built on research conducted at the Massachusetts Institute of Technology ("MIT"). Study #3 is a survey of university faculty members who have had new technologies arising from their academic research put into commercial use. The population for the survey is faculty members who have had new technologies resulting from their academic research put into commercial use and who are located at one of two of the universities participating in the "C4" consortium of universities located in south-western Ontario.

Chapter 6 contains the results of the analysis of three start-ups based on new technologies arising from research conducted at the University of Waterloo. The primary purpose of these examples is to illustrate the significant differences that exist in the governance structures used to commercialize new technologies. The results support the concerns raised in chapter 3 about the licensing vs. start-up dichotomy for analyzing the commercialization of new technologies arising from university research that has been used in past studies. The results also provide some support for the build, rent and sell classification of governance structures proposed in chapter 3. Further, the findings of this study are consistent with the hypotheses related to firm characteristics associated with the strategic governance choices of build, rent or sell.

Chapter 7 presents the results of the examination of the nature of business activities of a sample of public start-up firms that have been involved in commercializing new technologies arising from university research. The results of this study demonstrate 1) that the criteria identified in chapter 3 can be applied effectively in practice to classify the method used to commercialize a new technology arising from university research, 2) that the build, rent and sell methods are all common approaches to commercialization, and 3) that there are substantive differences in the business activities of firms depending on the method of commercialization used. In doing so, this study provides evidence as to the validity of the build, rent and sell categorization approach. The result of this study also support the hypotheses related to firm characteristics associated with the strategic governance choices of build, rent or sell.

Chapter 8 contains the results of the survey of academic inventors. The primary purpose of this study is to examine the connection between the characteristics of a new technology and the method used to commercialize the technology. This study results in a number of major findings. First, the findings from this study suggest that technology attributes may have an impact on the methods used to commercialize a new technology arising from university research. Specifically, the findings are that, when intellectual property protection for a technology is weak, the build and sell approaches are likely to be more effective than the rent approach. The rent approach requires stronger intellectual property protection to enable the inventor to appropriate gains from the technology since secrecy and other methods of appropriate gains are unlikely to be effective when the rent option is used. Second, the findings help to resolve conflicts in previous research on the role of intellectual property protection. Specifically, the findings imply that there are differences in the importance of intellectual property protection when a technology is licensed to numerous established firms as in the rent approach compared to when a technology is licensed to a single establish firm as in the sell approach. Third, the findings suggest that the build, rent and sell classification scheme proposed in this thesis provides insights into the commercialization process that the licensing vs. start-up approach does not.

Chapter 9 summarizes the key findings of the research, theoretical and managerial implications, limitations of the research and identifies opportunities for future research. A number of theoretical contributions are identified that help to advance the study of the commercialization of university research. First, the build, rent or sell model provides a theoretical basis for the classification of methods that is lacking in the licensing vs. start-up approach. Second, the build, rent or sell approach reflects the ideas of markets and hierarchies better than does the licensing vs. start-up approach. Third, the focus on governance structures enables researchers to draw on existing literature to study the commercialization of new technologies arising from university research. Fourth, the build, rent or sell approach is easily reconcilable to the broader literature on commercializing innovations. Fifth, the build, rent or sell model captures the governance structure in place at the time when the invention is commercialized. The licensing vs. start-up approach focuses on the point in time when a technology leaves the university. However, there is evidence that a significant amount of time can pass between the time when a technology leaves the university and when it is commercialized and that different approaches may be tried before commercialization actually occurs. Sixth, the build, rent and sell categories capture non-traditional forms of commercialization that are becoming more important due to the emergence of markets for technology. Seventh, the build, rent and sell model has the potential to resolve and explain inconsistent findings in previous research.

The managerial contributions of this research include providing guidance to managers when deciding on a commercialization strategy for a new technology arising from university research. The build, rent and sell model can also help start-up firms to prioritize the activities that they need to undertake in order to commercialize their technology and to avoid wasting valuable resources on activities that are not important to their success. In addition, the model and findings provide resources for individuals in university technology transfer and licensing offices to aid them in determining or advising on commercialization strategies and on development strategies. Further, the existence of novel strategies that may aid universities in the commercialization of new technologies is identified.

Chapter 2
Literature Review

This literature review consists of two parts. The first part deals with the literature related to the commercialization of new technologies arising from university research. The second part addresses economic theories of the firm with an emphasis on transaction cost economics. Transaction cost economics is the theoretical basis for the governance structures and hypotheses developed in chapters 3 and 4.

2.1 The commercialization of new technologies arising from university research

The academic literature on the commercialization of new technologies arising from university research addresses a number of topics. These topics are summarized in Figure 2.1. One area of the literature deals with environmental influences including differences across geographic locations and differences across industries. A second area of the literature deals with university influences including the effects of university institutions, practices and policies and the role of people, particularly inventors, in commercialization. The third area of the literature deals directly with the commercialization of new technologies including identification of the methods available to commercialize a particular new technology, identification of the processes involved, measurement of the extent of commercialization activity and identification of characteristics of technologies that affect the methods used to commercialize the technology.

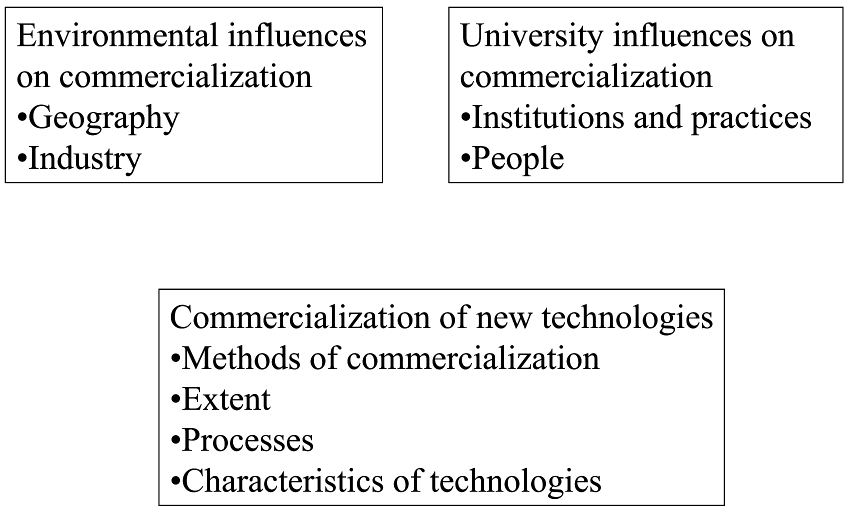
This thesis focuses on the third area of the literature and, particularly, on the literature related to the characteristics of technologies. The following sections provide a brief overview of the literature related to the environmental and university influences on commercialization as they relate to this thesis. A detailed analysis of the literature relating the characteristics of technologies to the methods used to commercialize them follows.

2.2 Environmental influences on commercialization

2.2.1 Differences across geographical locations

Significant differences in the extent of commercialization between different countries have been observed (Unico, 2004). These differences have been attributed to differences in the availability of capital to finance commercialization activities and differences in labour markets affecting the ability of researchers to move between universities and industry (Shane, 2004).

Figure 2.1 Topics in the literature on commercialization of new technologies arising from university research



At a more local level, commercialization success has been found to decline as the geographic distance between the university where the technology was invented and the commercializing firm increases (Agrawal, 2001). This is attributed to a decline in the interaction between the university inventor and the commercializing firm as the distance between them increases.

2.2.2 Differences in industrial environment

Differences in the extent of commercialization related to the local industrial environment have also been observed. In particular, research indicates that the existence of industry clusters affects the extent of commercialization activities (Agrawal, 2001). This effect has been attributed to the benefits of having customers, suppliers and experienced managers in close proximity to the source of the new technology (Shane, 2004).

2.2.3 Implications of environmental differences

The existence of these differences suggests that it is important to account for the effects of geography in research on commercialization. For example, lesser availability of capital to finance commercialization activities in a particular geographic area may reduce the propensity to commercialize new technologies using methods that require greater amounts of capital relative to methods that require lesser amounts of capital. Similarly, the existence of potential customers and suppliers in the geographic area may increase the propensity to commercialize new technologies by methods involving the creation of a new firm as it may make it easier to establish customer and supplier relationships. Section 5.4.2.1 contains a discussion of how environmental differences were controlled for in this research.

2.3 University influences on commercialization

2.3.1 Differences in institutions, practices and policies

A significant amount of research considers the effects of differences between institutions and their policies and practices on the commercialization of new technologies arising from university research (see, for example, Agrawal, 2001; Shane 2004; and Siegel and Phan, 2005 for reviews of this literature). Some of the differences affecting commercialization that have been identified include differences between institutions such as faculty quality (Thursby and Kemp, 2002) and levels of research funding (Carlsson and Fridh, 2002). A second area of identified differences is in university practices such as the size and experience of the university's technology transfer office (Thursby and Kemp, 2002) and the existence of science parks (Link, Scott and Siegel, 2003). A third area of identified differences is in university policies such as whether intellectual property rights to the technology belong to the university or the inventor (Goldfarb and Henrekson, 2003; Hoye and Roe, 2003) and policies regarding the taking of equity in lieu of royalties, the availability of leaves of absence to undertake commercialization activities and the use of university resources (Shane, 2004).

Differences have also been found at the department level. For example, Todorovic (2004) identified differences in entrepreneurial orientation between departments and found that these were related to the commercialization performance of the departments.

2.3.2 Differences in people

Differences in the commercialization of university research due to characteristics of the people involved, particularly researchers, have also been noted. Zucker, Darby and Armstrong (2002) examine the role of “star” scientists in biotechnology related research and found a positive relationship on research productive as measured by the number of patents granted, the number of products in development and the number of products on the market. A positive relationship between an inventor’s prior entrepreneurial experience and commercialization has also been found (Shane and Khurana, 2003).

2.3.3 Implications of university differences

The existence of these differences suggests that it is important to control for the effects of university differences in research on commercialization. For example, differences in the intellectual property policies of universities may affect the incentives to both researchers and universities to expend effort to commercialize new technologies. Similarly, the affiliation of a researcher with a particular department or faculty may affect the method chosen to commercialize a new technology. Section 8.2.2 contains a discussion of how university differences were controlled for in this research.

2.4 Commercialization of new technologies

2.4.1 Methods of commercialization

Knowledge about new technologies is transferred from universities to industry in many ways. These include publications, conferences, consulting, conversations, recruitment of graduates, co-supervising, collaborative research, patents and licenses (Agrawal and Henderson, 2002). Some of these methods involve the transfer of knowledge about new technologies to the economy as a public good (Gu and Whewell, 1999). These methods include publications, conferences, conversations, recruitment of graduates, and co-supervising. Estimates of the relative importance of different knowledge channels suggest that these ‘non-commercial’ methods represent the majority of knowledge transferred from universities to industry (Agrawal and Henderson, 2002).

Commercialization of new technologies involves the direct transfer of knowledge resulting in the introduction of a product in the market incorporating the new technology or the use of the new technology within a production process by one or more firms (Gu and Whewell, 1999; Organisation for Economic Co-operation and Development, 1996). Commercialization of new technologies arising from university research is accomplished primarily through licensing or the creation of start-up firms (see, for example, Association of University Technology Managers, 2004; Gu and Whewell, 1999; and Read, 2003). A key feature of the license vs. start-up dichotomy is the focus on the legal structures used to effect the transfer of the technology from the research environment to the commercial environment.

At a more detailed level, various subcategories have been used or proposed. For licensing, the most common subcategories are exclusive and non-exclusive licenses (see, for example, Association of University Technology Managers, 2004). However, other subcategories have been used. For example, Shane (2002) distinguishes between licensing by inventors and by noninventors in studying who undertakes the commercialization of university research.

Conversely, much of the research on start-ups has failed to distinguish between different types of start-ups (Nicolaou and Birley, 2003a). This despite the fact that "data suggest that rather than representing an undifferentiated outcome driven by a universal process, there are varied types of university-linked new ventures and different processes or fields that give rise to them" (Miner et al., 2001, p. 134). Most researchers assume that start-ups are created for the purpose of developing and selling new products (see, for example, Shane, 2002). However, Wallmark (1997) in looking at start-ups out of Chalmers University of Technology identified a number of cases of firms "with a main interest in developing new patents for sale or licence and only peripheral interest in selling its own products on the market" (p. 134). Some researchers have proposed that different categories of start-ups exist. For example, Nicolaou and Birley (2003b) propose a trichotomous categorization of university spinouts into orthodox, hybrid and technology spinouts. Importantly, however, these categories reflect the relationship between the academic inventor and the firm established to commercialize the technology rather than the method or business model used to commercialize the technology.

Taken together, research on the methods of commercialization suggests that:

- knowledge generated by universities is put into practice in many ways;

- these ways include both spillover of knowledge and commercialization activities;
- many methods of commercialization exist though research primarily focuses on licensing and start-ups; and
- there is much variety within both licensing and start-ups.

There are a number of unanswered questions that arise from this literature. One question is whether the variety within both licensing and start-ups is important. A second question is how to make the choice between licensing and start-ups in the decision to commercialize a technology. Gregory and Sheahen (1991) suggest that creation of spin-off companies is generally a more successful route to commercialization than licensing whereas Shane (2002) argues that, when possible, licensing is the preferred method of commercialization and creation of spin-off companies represents a 'second-best' approach to commercialization. These questions are addressed in chapters 3 and 4.

2.4.2 Extent of commercialization

Research on the extent of commercialization activity has shown that new technologies arising from university research are a significant source of innovative economic activity. Table 2.1 summarizes certain key statistics from the 2002 survey of Canadian and U.S. universities conducted by the Association of University Technology Managers (AUTM, 2003). Research has also shown that returns on the new technologies are highly skewed with a small number of new technologies providing very large returns and a large number of new technologies providing modest returns (AUTM, 2003; Scherer and Harhoff, 2000).

These statistics demonstrate that there is no predominant method of commercialization. Exclusive licensing, non-exclusive licensing and creation of start-ups are all common methods of commercialization.

An important limitation of this research is that it focuses primarily on the point in time when a new technology leaves the university environment and enters the commercial one. However, the fact that a technology leaves the university environment does not necessarily mean that it was put into commercial use. Indirect evidence for this assertion is found in the AUTM data which show that only 47.1% of active licenses yielded any income in 2002 (AUTM, 2003). This issue is addressed in chapter 4 which introduces a method of classifying commercialization methods based on the governance structures in place when the technology is put into commercial use rather than at the point when it leaves the university.

Table 2.1 Statistics on extent of commercialization activity at Canadian and U.S. Universities

Statistic	*Canada*	*U.S.*
Annual total licensing income	C$51.5 million	US$1.337 billion
Start-up companies operation at end of 2002	493	2,236
Proportion of licenses that were exclusive	53.9%	46.5%
Proportion of licenses that were non-exclusive	46.1%	53.5%
Proportion of licenses that were to start-up companies	13.9%	13.6%

Note: Adapted from AUTM Licensing Survey: FY 2002 (AUTM, 2003)

2.4.3 Processes of commercialization

New technologies arising from university research are rarely ready for immediate conversion into commercial products or services (Rogers, 2003). Thursby, Jensen and Thursby (2001) surveyed the technology transfer offices of 62 major U.S. universities. Table 2.2 reports their findings to a question concerning the stage of development of licensed inventions. These data show the early stage of development of most university inventions. Thursby et al. also found that 71% of licensed inventions required inventor cooperation for commercial success.

The conversion of these embryonic technologies into products and services is a difficult process. A transformation process involving the integration of both scientific and market knowledge is needed to develop commercially viable new products and services based on these new technologies (Fontes, 2005). This transformation process involves a number of activities including technology development, product development and business development (Lux and Rorke, n.d.; Shane, 2004). This transformation results in significant reduction in both technical and market uncertainty related to the new technology (Fontes, 2005). The technology development activities often involve significant changes to the technology to improve the performance, robustness, ease of use and other characteristics of the technology

(Shane, 2004). Product development activities involve converting the new technology into a product or service. Customers generally do not buy technology; rather they buy products or services that provide solutions to the problems they face (Shane, 2004). Business development involves acquiring or developing the other capabilities and complementary assets needed to develop, produce and sell products or services based on the technology. These may include manufacturing, distribution, marketing and selling capabilities (Teece, 1986).

Table 2.2 Stage of development of licensed inventions

Stage of development	*Percentage of inventions*
Proof of concept but no prototype	45.1%
Prototype available but only lab scale (further development needed)	37.2%
Some animal data available	26.7%
Some clinical data available	9.5%
Manufacturing feasibility known	15.3%
Ready for practical or commercial use (e.g., software or reagent quality materials)	12.3%

Note: Adapted from Thursby et al., 2001.

This research suggests that there are significant development activities needed between the time a new technology leaves the university setting and when it is commercialized. However, most of the research to date has focused on the technology at the time it leaves the university (either through licensing to commercial firms or the creation of start-ups). Little attention has been focused on the technology, product and business development activities that occur once the technology leaves the university setting. This issue is addressed, in part, in this thesis through the development of a method of classifying commercialization methods based on the governance structures in place when the technology is put into commercial use rather than at the time when it leaves the university (see chapter 4).

2.4.4 Characteristics of technology

A limited amount of research has been conducted relating the characteristics of technologies to the methods used to commercialize them. Table 2.3 summarizes this literature.

Colyvas et al. (2002) considered 11 inventions from Columbia University and Stanford University. Based on their examination of these case studies, they found that inventions that were 'ready to use' out of the laboratory did not require exclusive licenses in order to encourage firms to commercialize the technology and in most cases (three of four instances) were licensed nonexclusively to the commercializing firms. They also found that exclusive licenses were important to encourage firms to undertake the development risks associated with embryonic inventions.

Shane (2002) examined 717 licensed patents from the Massachusetts Institute of Technology and found that when patents are not effective, technologies are likely to be licensed back to the inventors. In another study using the same dataset, Shane (2001) considered the commercialization of technologies through the establishment of a new firm. Based on his examination of these data, Shane concluded that "more important inventions, more radical inventions, and inventions with a broader scope of patent protection were more likely to be commercialized through the creation of new firms" (p. 216). Nerkar and Shane (2003) built on this study by further examining the 128 new firms founded to commercialize new technologies. They found that technology radicalness and patent scope reduce firm failure but only in fragmented industries.

Del Campo, Sparks, Hill and Keller (1999) analyzed the attempt to commercialize superconducting quantum interference devices. They concluded that "licensing may be the best strategy when the proprietary position of the intellectual property is narrow or unpatentable and when the capabilities of the developer are limited" (p. 294). Further, they concluded that start-ups need inventions that represent a core technology with a large market potential and, if possible, multiple product applications to compensate for the high risks involved in creating a start-up firm.

Wright, Vohora and Lockett (2004) examined four high tech start-up firms from universities in the United Kingdom. In each of the four cases, Wright et al. found that the technologies involved could be considered disruptive innovations (Christensen, 1993) suggesting that start-ups are an appropriate method of commercializing such technologies. They also found that licensing was not a viable option in these four cases because potential

Table 2.3 Characteristics of technologies that suggest using licensing or a start-up firm to commercialize the technology

Author	*Method and sample*	*Licensing*	*Start-up*
Colyvas et al., 2002	Qualitative analysis of 11 case studies from Columbia University and Stanford University	Ready to use – nonexclusive licensing Embryonic – exclusive licensing	
Shane, 2002	Regression analysis of 717 licensed patents from the Massachusetts Institute of Technology ("MIT")	Patents are effective	Patents are ineffective
Shane, 2001	Event history analysis of 1,397 patents from MIT		More important inventions More radical inventions Inventions with a broader scope of patent protection
Nerkar and Shane, 2003	Event history analysis of 128 firms founded to exploit new technologies from MIT		Technology radicalness and patent scope reduce firm failure but only in fragmented industries
del Campo et al., 1999	Qualitative analysis of a single case study	Narrow IP protection and researcher lacks core competencies to develop the technology into marketable products	Invention is a core technology with a large market potential and, if possible, multiple product applications
Wright, Vohora and Lockett, 2004	Qualitative analysis of four case studies		Disruptive innovations Technologies involving significant know-how or tacit knowledge
Thursby, Jensen and Thursby, 2001	Survey of technology transfer offices of 62 U.S. universities	Late stage technologies	Early stage technologies
Shane 2004	Multiple sources including many of the above and interviews of people involved in start-ups from MIT	Incremental Codified Late stage Specific-purpose Moderate customer value Minor technical advance Weak IP protection	Radical Tacit Early stage General-purpose Significant customer value Major technical advance Strong IP protection

licensing firms did not have the know-how or tacit knowledge to undertake the required technology development activities.

Thursby, Jensen and Thursby (2001) surveyed 62 technology transfers offices at U.S. universities and found that 60% of the survey respondents indicated that large companies were more likely to take late stage technologies and that small companies were more likely to take early stage technologies.

Using evidence from many of the studies described above and from semi-structured field interviews of people involved in the formation and development of start-ups from the Massachusetts Institute of Technology, Shane (2004) summarized the characteristics of technologies that support commercialization by creation of a start-up vs. commercialization by licensing to an established firm. Shane concluded that start-ups are used to commercialize new technologies that are radical, tacit, early stage, general-purpose, provide significant value to customers, involve major technical advances and have strong intellectual property protection. Licensing to established firms is used to commercialize new technologies that are incremental, codified, late stage, specific-purpose, provide moderate customer value, involve minor technical advance and have weaker intellectual property protection.

Taken together, this research suggests that the characteristics of a technology do affect the choice of method used for commercializing the technology. However, there are important limitations to the evidence obtained. The primary limitation is that the evidence is derived from one large sample from a single university and from a small number of case studies from other universities. There is a need for evidence from additional studies and from universities other than the Massachusetts Institute of Technology.

A number of important issues arise from the research on the characteristics of technology. The first is that there is very limited use of theory in any of these studies linking the characteristics of technology to the method of commercialization. Secondly, Shane's research found conflicting evidence concerning the impact of the strength of intellectual property protection on the choice of method for commercializing the innovation. These issues are addressed in chapters 3 and 4 of this thesis.

2.5 Economic theories of organizations

In order to address the issues raised above, the research described in this thesis draws on the literature on economic theories of organizations to provide a theoretical basis for examining methods of commercializing new technologies arising from university research. Two areas of literature, in particular, are addressed. The first is the transaction cost theory of organizations. The second is the literature on markets for technology.

Neoclassical economic theory views the firm as a 'black-box.' The firm is described as a production function that transforms inputs into outputs. It is assumed that firms operate to maximize profits but, otherwise, little attention is paid to what happens in these firms (Demsetz, 1997; Slater and Spencer, 2000). This view of the firm is useful for studying prices and their impact on firms' outputs and use of resources. It is, however, less useful for understanding why firms exist and how they work (Williamson, 2003). Beginning early in the last century, researchers began to look into the 'black box' of the firm to understand why firms exist and how they operate. For example, Coase (1937) asked the question 'why do firms exist?' and argued that the main reason why firms exist is that there are costs of using the pricing system involved in markets. These include the costs of gathering information about prices and the costs of negotiating contracts. Collectively, Coase refered to these as transaction costs and argued that firms exist because the costs associated with some activities may be lower when they are conducted within a single firm than when they are conducted through markets.

Simon (1947) and Cyert and March (1963) examined how decisions are made within firms. One important result of their work is the suggestion that the concept of rational decision making in neoclassical theory is not feasible. Rational decision-making assumes that the decision maker knows all of the alternatives available to them and all of the consequences of those alternatives. Simon argued that there are limits to decision maker rationality resulting from cognitive limits on the number of alternatives decision makers can consider and uncertainty as to the consequences of those alternatives. Simon proposed instead that decision makers' rationality is bounded. Bounded rationality refers to behaviour that is "intendedly rational but only limitedly so" (Simon, 1961, p. xxiv) due to human limits in processing information and solving complex problems. Penrose (1959) was concerned with the growth of firms and argued that firm growth involves the interaction of management and resources and, consequently, that management capability is a key constraint on firm growth (Mahoney, 2005). This emphasis on the role of management goes beyond the 'black box' view of firms. Together, this research leads to the conclusion that it is a "mistake to confuse the firm of [neoclassical] economic theory with its real world namesake. The chief mission of neoclassical economics is to understand how the price system coordinates the use of resources, not the inner workings of real firms" (Demsetz, 1988, p. 189). Over the past 30 years, a number of theories of the firm have been proposed to explain why firms exist and how they operate. In the sections that follow one of these theories, transaction cost economics theory, is discussed in detail. It is also compared to some of the alternative theories of the firm.

2.6 Transaction cost economics

The theoretical basis of this thesis is the transaction cost theory of organizations. Transaction cost economics is a multidisciplinary approach drawing on economics, organization theory and legal concepts (Mahoney, 2005). The basic premise of transaction cost economics is that the decision to perform an activity inside or outside the firm should be based on the relative efficiency of conducting the activity in these two environments. Transactions should be performed inside the firm when the costs of transacting in the market are higher than the costs of performing the activity internally. The basic concepts involved in transaction cost economics are governance structures, transaction costs and transaction attributes. These are discussed in the following sections.

2.6.1 Governance structures

Transaction cost economics focuses on the issue of governance structures for firms. Initially transaction cost economics dealt primarily with two types of governance structures: markets and hierarchies. Market governance refers to situations where transactions are carried on with third parties outside the firm through the use of contracts. Hierarchies refer to situations where the transactions are internalized so that the economic activities involved in the transaction occur within a single firm. The distinguishing feature of hierarchies is that the activities are integrated under a single common control.

Traditional economic analysis views markets as the most efficient approach. However, a number of reasons have been identified for market failure. Two primary ones are contractual hazards and the needs for adaptation (Mahoney, 2005). Contractual hazards refer to situations that make contracting between separate parties risky for at least one of the parties. Contractual hazards include situations where one or both parties is dependent on the other party and thus in a weak bargaining position (Williamson, 1971) and situations where weak property rights exist resulting in the risk that one party will appropriate use of the property without paying for it (Libecap, 1989). Contractual hazards are reflected in the two behavioural assumptions underlying transaction cost analysis: 1) that decision makers are subject to bounded rationality and 2) that some individuals may act opportunistically (Williamson, 1981). Bounded rationality makes it impossible to anticipate all relevant issues involved in a complex transaction and deal with them in a contract. Thus contracts with outside parties are often incomplete. This incompleteness creates opportunities for the parties to act opportunistically. The problems and hazards of dealing with outside parties through contracts are greatly increased when parties may act opportunistically, particularly, when the parties make "false or empty, that is, self-disbelieved threats or promises" (Goffman, 1969, p. 105).

The need for adaptation also creates issues in operating through markets. Some adaptation occurs as a result of changes in prices. For example, when gasoline costs increase, a manufacturing firm may adapt by changing its distribution methods from truck to rail. This type of adaptation, sometimes referred to as autonomous adaptation, is handled well by markets (Hayek, 1945). Other types of adaptation involve intended cooperation between parties "that kind of cooperation among men that is conscious, deliberate, purposeful" (Barnard, 1938, p. 4). This type of adaptation, sometimes referred to as cooperation adaptation, is difficult to achieve through market structures (Williamson, 1991). The existence of contractual hazards and the need for adaptation suggest that markets are not always the most effective approach and that hierarchy governance structures may be more appropriate in some circumstances.

Each of these governance structures has different attributes. Market governance structures provide strong incentives to the individual firms to minimize costs and to adapt quickly to changing circumstances in order to maximize their income. These structures are very good at adapting to situations where coordination between the parties is not necessary and each can act autonomously (i.e., autonomous adaptation). Hierarchies have much weaker incentives but have greater administrative controls over activities providing greater abilities to adapt to situations requiring coordination between activities (i.e., cooperation adaptation) (Williamson, 1991).

Subsequent to its initial formulation, hybrid forms of governance have been introduced into transaction cost theory (Williamson, 1991). Williamson (1991) describes hybrids as follows:

> The hybrid mode is located between market and hierarchy with respect to incentives, adaptability, and bureaucratic costs. As compared with the market, the hybrid sacrifices incentives in

> favor of superior coordination among the parts. As compared with the hierarchy, the hybrid sacrifices cooperativeness in favor of greater incentive intensity." (p. 283)

Examples of hybrid governance structures include joint ventures (Klein, Frazier and Roth, 1990) and a variety of other inter-firm alliances (Oxley, 1999).

The choice of governance structure has consequences for the firm. A firm that adopts a hierarchy structure when a market approach is more appropriate will invest resources in activities but receive no strategic benefit for doing so. A firm that adopts a market structure when a hierarchy structure is more appropriate may find itself in a weak bargaining position with another firm that controls certain critical activities or assets with the result that its profitability is diminished. In some cases, it may even find that its survival is threatened (Teece, 2000).

2.6.2 Transaction costs

"A transaction occurs when a good or service is transferred across a technologically separable interface. One stage of activity terminates and another begins" (Williamson, 1985, p. 1). Transaction costs result from the need to manage these transfers and include the costs of negotiating, monitoring and enforcing contracts with outside parties and the costs of managing internally governed exchanges (Coase, 1937; Poppo and Zenger, 1998).

While transaction costs represent real economic costs, it is difficult to estimate these costs reliably in advance of choosing a governance structure and, even after a governance structure has been chosen, it is difficult to allocate the costs incurred by the firm to specific transactions. Consequently, transaction cost economics focuses on a number of transaction attributes that affect transaction costs.

2.6.3 Transaction attributes

Transaction cost economics identifies three principal dimensions affecting transaction costs. "These key attributes are the frequency with which transactions recur, the uncertainty (disturbances) to which transactions are subject, and the degree to which transactions are supported by transaction specific assets. A good deal of the explanatory power of transaction cost economics turns on this last" (Williamson, 1999, p. 1089).

Asset specificity refers “to the degree to which an asset can be redeployed to alternative uses and by alternative users without sacrifice of productive value” (Williamson, 1996a, p. 59). Asset specificity can take a variety of forms including site-specific, physical, human, dedicated assets, brand name capital and temporal (Williamson, 1996a). According to transaction cost economics, market governance has high transaction costs when dealing with assets of high specificity due to the difficulties resulting from small numbers bargaining (Williamson, 1975). “Specific assets trigger a threat of opportunistic behavior that requires costly contractual safeguards to deter” (Poppo and Zenger, 1998, p. 853). Thus, it is argued that in situations of high asset specificity, more integrated governance forms are preferred as they have the lower transaction costs (Poppo and Zenger, 1998).

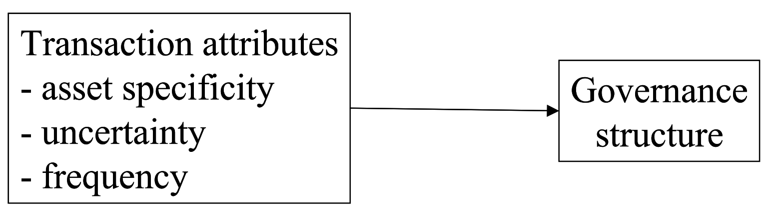
Uncertainty is the second key factor affecting governance approaches in transaction cost economics. Uncertainty makes it difficult to contract in the market and increases market transaction costs in two ways. Transaction costs are increased as a result of the costs of trying to anticipate uncertain events and writing these into the contract. Secondly, costs arise because the transactions are maladapted to the environment while the parties adjust to the changed circumstances (Poppo and Zenger, 1998; Williamson, 1991). Thus, in highly uncertain environments, transaction cost economics predicts that more integrated forms of governance will be more efficient. Empirical support for this view of uncertainty has been mixed. For example, Walker and Weber (1984) found in their study of make or buy decisions in the U.S. automotive industry that volume uncertainty was positively related to integrated forms of governance while technological uncertainty was negatively (though not significantly) related to integrated forms of governance. Klein, et al. (1990) argued that this is because uncertainty has a number of dimensions that may impact governance structures differently. The two dimensions of uncertainty identified by Klein et al. are volatility and diversity. Volatility reflects the speed of change in the environment and diversity reflects the number of sources of uncertainty in the environment. Klein et al. argued that higher levels of volatility create problems in writing contracts and higher transaction costs for market governance structures thus encouraging more integrated forms of governance. Klein et al. argued that diversity leads to a desire for flexibility and that market governance structures provide this flexibility. Research by Klein et al. (1990) and McNaughton and Bell (2000) found some evidence supporting the diversity effect on governance structures but was inconclusive on the effect of volatility.

The frequency of interaction between parties is the third key factor identified in transaction cost economics. The argument is that parties that transact frequently have incentives to work more cooperatively and less opportunistically than parties that do not expect to have future dealings with each other. Transaction cost economics argues that market contracting is thus most efficient when higher frequencies of transactions are expected.

2.6.4 Discriminating alignment hypothesis

The concepts of governance structures, transaction costs and transaction attributes are brought together in the discriminating alignment hypothesis. “Transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and competencies, in a discriminating (mainly, transaction-cost-economizing) way” (Williamson, 1991, p. 277). The discriminating alignment hypothesis is the basis for most of the empirical research on transaction cost economics. Figure 2.2 illustrates this hypothesis.

Figure 2.2 Discriminating alignment hypothesis



2.6.5 Evidence supporting transaction cost economics

Macher and Richman (2005) identified over 600 empirical studies of aspects of transaction cost economics. These studies covered a broad variety of fields and specific applications. In evaluating the results of these studies, Macher and Richman concluded the following:

> Taken together, the papers surveyed provide considerable support for the main propositions derived from transaction cost economic theory. The central hypothesis that governance

> choice is largely determined by the cost of transacting and that these costs are influenced by observable characteristics of the underlying transactions receives overwhelming support in our assessment. There is also considerable support for many of the specific transaction-level factors identified in the theory as influencing contracting costs. (p. 35)

Studies of transaction cost economics involve numerous methodological approaches. Common approaches that have been used include focused case studies and studies of contracts, statistical analysis of secondary data and statistical analysis using field data (Mahoney, 2005).

The subject areas covered by these studies are quite broad. Vertical integration and long-term contracting are the subject of many studies. Distribution networks in marketing, diversification and the choice of debt versus equity financing in finance have also been studied using transaction cost economics (Macher and Richman, 2005). However, little research has been done in the application of transaction cost economics to innovation in general and the commercialization of university research in particular. The one instance identified in the literature where transaction cost economics was applied to the issue of the commercialization of new technologies arising from university research is Shane (2002). In this study, Shane argued that licensing to noninventors represents a market form of governance and that licensing to inventors represents a hierarchy form of governance. This study is described in further detail in sections 2.4.4 and 3.4.

2.6.6 Criticism of transaction cost economics

Two major themes recur in the criticisms of transaction cost economics. One theme is that the focus on transaction costs is too limited (Grant, 2001). For example, Zajac and Olsen (1993) argued that maximizing the total *value* of the transaction to both participants is a more appropriate focus than minimizing the transaction *costs* to the individual participants. Transaction cost economics does emphasize transaction costs over other costs (e.g., differences in production costs) and other sources of value (e.g., strategic and learning gains). Nonetheless, the empirical evidence discussed above demonstrates that a focus on transaction costs can go a long way towards understanding governance structures. Similarly, Holmstron and Roberts argued "the theory of the firm … has become too narrowly focused on the hold-up problem and the role of asset specificity" (1998, p. 91). Much of the empirical testing of hypotheses based on transaction cost economics does focus on asset specificity. However, transaction cost economics does not suggest that asset specificity is the only source of transaction costs, only that it is an important one (Williamson, 1985). This thesis considers sources of transaction costs beyond asset specificity consistent with this criticism (see chapter 4).

The second major criticism of transaction cost economics relates to the underlying behavioural assumption of opportunism. Critics argue that, as a result, transaction cost economics places too large an emphasis on contractual controls and management fiat and underemphasizes the role of trust, social controls and other features of organizations (Connor and Prahalad, 1996; Ghoshal and Moran, 1996). Responses to this criticism are two-fold. First, transaction cost economics does not require that all individuals act opportunistically all of the time. Rather, it assumes that some individuals will act opportunistically some of the time (Ghoshal and Moran, 1996). Secondly, as stated by Williamson (1996b):

> The main purposes served by invoking opportunism are these: (a) it avoids the contractual naivete that arises when contract as mere promise (unsupported by credible commitments) is invoked and (b) it invites the identification, explication, and mitigation of hazards that have their origins in opportunism. Neither of these require scholars to regard economic agents as mean spirited or to behave in a manner unconstrained by morality. (p. 50)

In summary, while there are numerous valid criticisms of transaction cost economics, it has remained “a predominant theoretical explanation of boundary choice” (Poppo and Zenger, 1998, p. 853).

2.7 Comparison to related theories

Transaction cost economics is closely related to property rights theory, agency theory and the resource-based view of the firm. Table 2.4 provides a brief comparison of some of the major features these theories.

Property rights theory is based on the idea that a transaction involves the exchange of property rights (Demsetz, 1967). These property rights include the right to use an asset, the right to appropriate returns from an asset and the right to change the form or substance of an asset. Under property rights theory, the economic problem is to ensure property rights are allocated between firms appropriately in order to maximize wealth (Mahoney, 2005). The

Table 2.4 Comparison of transaction cost economics, property rights theory, agency theory and the resource based view of the firm

	Transaction cost economics	*Property rights theory*	*Agency theory*	*Resource-based view*
Basic question addressed by theory	How to get the governance right to minimize costs?	How to get the property rights well defined and correctly allocated to create wealth?	How to get the incentives right to minimize the agency loss?	How to choose the right resources to generate and sustain wealth?
Key idea	Transactions with different attributes align with governance structures that differ in their costs and competencies in a cost minimizing way	Property rights need to be well defined and properly allocated to create and allocate wealth	Principal-agent relationships should reflect efficient organization of information and risk-bearing costs	Maximizing long-run profits through exploiting and developing firm resources
Unit of analysis	Transaction	Institution	Contract between principal and agent	Routines
Human assumptions	Bounded rationality Opportunism	Bounded rationality Opportunism	Self-interest Bounded rationality Risk aversion	Bounded rationality
Key variables	Asset specificity Uncertainty Frequency	Control rights Sunk cost investments Complementarity of assets	Goal conflict Risk preferences Measurement difficulty	VRIN attributes (valuable, rare, inimitable, and nonsubstitutable) of resources
Implications for choice of firm boundaries / governance structures	Minimize transaction costs	Optimally allocate control rights between parties	Minimize agency costs	Maximize profit through developing and exploiting firm specific VRIN resources

Note: Derived in part from Eisenhardt (1989), Eisenhardt and Martin (2000), Mahoney (2005), Tsang (2000) and Williamson (1999).

unit of analysis in property rights theory is the institution or firm. Property rights theory is based on the same human assumptions as transaction cost economics but emphasizes different key variables. In property rights theory, these key variables are control rights to the property, the extent of sunk cost investments and the complementarity between different assets (Hart 1995; Joskow, 1985). Applying property rights theory to the question of how the boundaries of a firm should be determined, Hart (1995) argues that firm boundaries are chosen to optimally allocate control rights over the property between the parties to the transaction.

Agency theory focuses on the relationship between principals and agents. Agency relationships arise when one individual depends on the actions of another. The agent is the one taking action and the principal is the individual depending on the agent. Under agency theory, the economic problem is to structure the agency relationship to minimize agency costs (Pratt and Zeckhauser, 1985). Agency costs include the costs of monitoring the agent, bonding expenditures incurred to reassure the principal and the costs resulting from conflicts of interest between the principal and agent (Jensen and Meckling, 1976). The unit of analysis in agency theory is the contract between the principal and agent. The key variables in agency theory are goal conflict, differences in risk preferences between principal and agent, and measurement difficulties related to the effort of the agent. Agency theory is focused on the separation of ownership and control (Williamson, 1996a). Its indirect application to the question of firm boundaries focuses on minimizing agency costs related to the transaction.

The resource-based view of the firm is based on the idea that competitive advantage is derived from the possession of valuable, rare, inimitable and nonsubstitutable (“VRIN”) resources (Eisenhardt and Martin, 2000). The unit of analysis in the resource-based view is routines and bounded rationality is an underlying human assumption. The key variables in the resource-based view are the VRIN attributes of resources. Applied to the question of firm boundaries, the resource-based view focuses on the acquisition of those resources that are needed to support a firm’s competence and strategic direction and the disposition of those resources that are not needed even though the resulting governance choices may not be the most efficiency when viewed on a transaction by transaction basis (Tsang 2000). A closely related theory to the resource-based view is the dynamic capabilities view. It builds on the resource-based view and focuses on the ability of firms to generate new capabilities or resources that have the VRIN attributes. Specifically, dynamic capabilities are defined as “the firm’s ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments” (Teece, Pisano and Shuen, 1997, p. 516).

2.7.1 Competing or complementary theories

Much of the literature on theories of the firms views these theories as competing theories where one is correct and the others incorrect (see, for example, the debates in Connor and Prahalad, 1996; Foss, 1996; Ghoshal and Moran, 1996; Kogut and Zander, 1992; Perrow, 1986; Williamson, 1996b). In recent years, a number of researchers have begun to look at the theories of the firm as complementary rather than as competing (Schilling and Steensma, 2002; Silverman, 1999; Steensma and Corley, 2001). Steensma and Corley (2001) characterized this view as asking 'when does each theory apply?' rather than 'which theory is correct?' Silverman (1999) integrated ideas from transaction cost economics with the resource-based view in looking at decisions of firms to diversify into other industries and concluded that "while conflicts between the two theories do exist, the strong complementarities between them should not be ignored" (p. 1123). Steensma and Corley (2001) and Schilling and Steensma (2002) looked at technology-sourcing decisions and found that transaction cost economics, the resource-based view and an options perspective play complementary roles in the choice of firm boundaries. This view that different theories of the firm are complementary is the one adopted in this thesis. While transaction cost economics is the primary lens used to view boundary choice decisions, other lenses are considered where they are helpful in understanding the specific circumstances of commercializing new technologies arising from university research.

2.7.2 Basis for choice of transaction cost economics

This thesis addresses the issue of how new technologies arising from university research are commercialized. More specifically, it is concerned with the question of how the activities involved in commercializing a new technology should be organized. Transaction cost economics was selected as the primary theoretical basis for this research because it most directly relates to the choice of firm boundaries. Boundary choice "focuses on the operating parts and asks which activities should be performed within the firm, and which outside it, and why" (Williamson, 1981, p. 549). The other theories discussed above have implications for the choice of firm boundaries but are primarily focused on other issues. The unit of analysis in transaction cost economics, the transaction, is also well suited to the study of the commercialization of new technologies arising from university research. Commercializing a new technology involves technology development, product development (Shane, 2004) and supporting activities such as manufacturing, distribution and marketing. Thus, there are a number of distinct activities that need to be coordinated either through markets or hierarchies (i.e., we have transactions). Nonetheless, as indicated earlier, insights from other theories will be considered in developing the hypotheses tested in this thesis.

2.8 Special issues related to commercializing new technologies

2.8.1 The nature of innovation

Due to issues of potentially weak property rights and the need for responsiveness to changing conditions, Williamson (1991) suggests that transaction cost economics not be applied uncritically to the special issues of commercializing new technologies though he suggests that the general framework is applicable. The work of Teece has been particularly important in looking at governance structures involving the commercialization of new technologies. Teece (1986) identifies the appropriability of a technology and the requirement for specialized complementary assets, such as manufacturing capabilities and distribution networks, as two key factors in the choice of governance structures for commercializing new technologies. The work of Teece and others also suggests that the need to coordinate various tasks in the innovation process can result in significant transaction costs if a market governance structure is adopted (Teece, 1996, Arora et al., 2001). Teece (1986) suggests that the choice of governance structure is a critical factor in determining how much of the profit from a new technology is captured by the inventor.

Teece (2000) also specifically considers the issues facing an individual inventor. These situations are similar to that facing an academic researcher/university in commercializing a new technology arising from university research since universities are not in the business of producing commercial goods or services and lack the complementary assets needed to commercialize the new technologies developed through university research (Shane, 2004b). Teece (2000) identifies the following alternatives open to the individual inventor:

> (1) licensing the technology to incumbent firms who already have the necessary complementary assets in place; (2) using intellectual property as collateral to raise debt funds to establish an organization to exploit the technology; (3) exchanging the patent for equity in a new venture-funded firm; (4) exchanging the intellectual property for cash or equity in an established firm. (p. 55)

The first of these options represents a market governance structure while the other three represent hierarchy governance structures (see section 2.6.1).

2.8.2 Markets for technology

The discussion on governance structures presumes the existence of effective markets. In the case of the commercialization of new technologies arising from university research, this means effective markets for technology. Markets for technology are markets for "intellectual property that is licensed and its close substitutes" (U.S. Department of Justice, 1995, p. 8). Markets for technology represent a method for firms to acquire the right to use a new technology and are an alternative to developing the new technology in house. In the case of commercializing new technologies arising from university research, markets for technology allow the university/researcher to sell certain rights to a new technology to firms that will put the technology into use by producing new products or services based on the innovation or by using the technology in their production or other processes.

A number of difficulties to having effective markets for technology have been identified (Teece, 1986). These difficulties are the result of information asymmetry and uncertainty (Shane, 2003). The nature of information creates problems in transferring information between parties that do not exist in transferring goods or services. In the absence of intellectual property protection, if an owner of information discloses that information to a prospective buyer, the buyer now knows the information and no longer has a need to bargain for access to it. But if the owner of the information does not disclose it, the potential buyer cannot evaluate the value of it and, consequently, will not be willing to pay for information which may turn out to be worthless to him (Arrow, 1962). Arrow's paradox of disclosure results from the combined effect of information asymmetry and the difficulties in protecting intellectual property and implies that information that lacks legal protection cannot be sold through markets.

The high level of uncertainty related to new technologies also creates problems in the market. One source of this uncertainty relates to the technical development of the technology. The research by Thursby, Jensen and Thursby (2001) discussed earlier in this chapter (see section 2.4.3) shows the early stage of development of most university inventions. A second source of uncertainty relates to whether markets exist for products or services derived from the technology (Shane, 2004). These high levels of uncertainty make it difficult for prospective buyers to evaluate the technology. The uncertainties also create bargaining problems as the seller of the technology will often have a significantly different view of the value of the technology than a potential buyer (Shane, 2003).

Despite the challenges of transacting through markets for technology, there is evidence that markets for technology exist and are becoming increasing important. Chesbrough (2003) argues that we have entered a world of ‘open innovation’ where firms increasingly look outside the boundaries of the firm to acquire new technologies from other firms and to transfer to other firms technologies they have invented that do not fit their business plans. One of the reasons Chesbrough cites for this change is the emergence of external options for ideas that are not commercialized by the firm where they are invented (i.e., the emergence of markets for technology).

Arora et al. (2001) argue that markets for technology improve the efficency of the innovation process by allowing for the division of innovative labour. Firms can specialize in whatever components of the innovation process they have comparative advantage in. For some, this may be research and development activities that lead to the invention and development of new technologies. For others, this may be in the production and sale of goods and services derived from these new technologies. Arora et al. found evidence that markets for technology do, in fact, exist and are growing in importance. The worldwide market for technologies is estimated at US$35-50 billion annually and is growing (Arora et al., 2001).

Gans and Stern (2003) examined how the emergence of markets for technology affects the commercialization strategies available to technology entrepreneurs. They argue that inventors have two strategic options available to them. They can compete in the product market by developing, producing and selling goods or services based on the technology or they can compete in the ‘market for ideas’ by transferring rights to their technology to established firms who operate in the product market selling products or services based on the technology. Gans and Stern argue that the two key factors affecting this strategic choice are the ability of the firm to exclude others from copying the technology and the firm’s position relative to any specialized complementary assets needed to commercialize the technology.

2.9 Summary

The literature on the commercialization of university research and the literature on economic theories of the firm suggest a number of implications for the commercialization of new technologies. First, governance structures seem to be important for the successful commercialization of new technologies. Nonetheless, a focus on governance structures has been absent in the literature on the commercialization of new technologies arising from university research with the exception of a brief mention by Shane (2002).

Second, the choice of governance structures is affected by transaction attributes. Under transaction cost economics theory, these attributes are the existence of specialized assets, uncertainty and frequency. Looking more specifically at the commercialization of new technologies, key transaction attributes that have been identified are the ability to exclude others from using the technology and access to specialized complementary assets.

Third, in applying transaction cost economics to the commercialization of new technologies, it is important to consider carefully the governance structures that may arise in this specific environment, the specific attributes of new technologies that may affect transaction costs and the ramifications of selecting specific governance structures in light of these specific attributes. That is, it is important to tailor the application of transaction cost economics to the specifics of the situation being considered (Williamson, 2002).

Chapter 3

Build, Rent and Sell – Governance Structures for Commercializing New Technologies

In this chapter, difficulties with the traditional approach to classifying the methods used to commercialize new technologies arising from university research (licensing vs. start-up) are identified and a proposal for a new method of categorization that links to the concept of governance structures discussed in the preceding chapter is presented.

This chapter is organized as follows. First, problems with the licensing vs. start-up dichotomy are identified. Then, a new method of categorization is proposed. The rationale for the proposed new method is discussed and criteria for the categories are developed. Finally, the benefits of the proposed categorization scheme are presented.

3.1 Limitations of the licensing vs. start-up approach for analyzing methods of commercialization

Section 2.4.1 describes the existing literature on the use of licensing and start-ups as categories for analyzing the methods used to commercialize new technologies arising from university research. In this section, some of the more significant limitations of this system for categorizing the methods used to commercialize university research are described and why these limitations are important is indicated.

The primary limitation of the licensing vs. start-up system is that it reflects the legal form rather than the substance of the method used to commercialize the technology. Licenses represent an "agreement … between two parties, where the owner of the technology (licensor) permits the other party (licensee) to *share* the rights to use the technology" (AUTM, 2004, p. 42, emphasis added). The extent of the sharing of these rights to use the technology can vary widely. Licensing a technology on a non-exclusive basis to a number of firms with the researcher/university continuing to develop and market the technology represents a limited form of sharing. In these cases, the researcher/university retains the majority of the risks and benefits of ownership of the technology. These benefits include the ability to benefit from future development of the technology and the risks include the risk of technological obsolescence. Licensing the technology on an exclusive basis to an established firm for substantially all of the economic life of the technology with the researcher/university retaining no rights to ownership of improvements in the technology represents a very different form of sharing of the rights to the technology. In these cases, the researcher/university transfers the majority of the risks and benefits of ownership of the technology to the licensee. It is the licensee who benefits from future development of the technology and incurs the risk of technological obsolescence. In these cases, the researcher/university has, in substance, sold the technology to the licensee. This discussion demonstrates that the license vs. start-up classification scheme, by focusing on the legal form of the transaction, fails to capture the substance of the method used to commercialize the technology. Shane (2002) recognizes this limitation, in part, when he identifies that licensing to inventors typically represents, in substance, the creation of a start-up company.

A second limitation of the licensing and start-up categories is that they are not distinct. For example, a start-up firm founded by a researcher may need to license the technology from his or her university if the university holds the intellectual property rights to the technology. This situation involves both creation of a start-up firm and licensing.

Third, the categories are not comprehensive. Most of the discussion of start-ups focuses on start-ups that develop new products or services based on the technology. As indicated in section 2.8.2, this is not the only way that start-ups can commercialize an invention. Start-ups can commercialize new technologies either through the product market or the market for technologies. The product market refers to situations where the start-up launches a product based on the technology. The market for technologies refers to situations where the start-up commercializes the technology by “identifying and executing agreements with other firms – usually incumbents – who serve as conduits for commercializing technology to the product market” (Gans and Stern, 2003, p. 336). These agreements often take the form of licensing arrangements. Arora, Fosfuri and Gambardella (2001) emphasize the emergence in recent years of markets for technologies as an important method of commercializing new technologies. However, little attention has been paid in the literature on university technology transfer to start-ups that compete through the market for technologies. These start-ups face a different set of risks than do start-ups in the product market. Specifically, they do not face the risks associated with acquiring the skills and complementary assets, such as manufacturing capabilities and distribution networks, needed to commercialize the technology but face the contracting hazards that exist in markets for technologies (Arora, Fosfuri and Gambardella, 2001; Gans and Stern, 2003). These start-ups face risks similar to those faced by university technology transfer offices attempting to license new technologies to existing firms and very different from those faced by start-ups in the product market.

Rambus Inc. is a firm founded by two university professors that "designs, develops and markets chip-to-chip interface solutions that enhance the performance and cost-effectiveness of its customers' chip and system products" (Rambus, 2002, p. 1). Rambus does not manufacture chips rather it "sell[s] licenses to semiconductor and system companies who then incorporate our interface products into their chips and systems" (Rambus, 2002, p. 2). Rambus is an example of a start-up that operates in the market for technologies rather than in the product market. Certicom and Senesco, described in the chapter 6, are also examples of start-ups that operate in the market for technologies. The licensing vs. start-up approach does not recognize the differences in start-ups that operate in markets for products compared to those that operate in markets for technology.

An objective of this thesis is to better understand which methods of commercialization are appropriate for a particular new technology. Is there a free choice as to how to commercialize (i.e., are all choices equal?) or do certain methods suit certain technologies? If the latter is the case, it is important to understand and recognize the substance of these methods. As illustrated above, the licensing vs. start-up system of diverse, indistinct and non-comprehensive categories does not do this. Therefore, there is a need for a comprehensive framework that 1) reflects the substance rather than the legal form of commercialization activities, 2) reflects the variety of approaches to commercializing university research (e.g., creation of new firms, sale of technology to existing firms), and 3) reflects multiple methods of commercialization (i.e., does not just subdivide either the start-up or licensing categories). In the next section, a classification approach that attempts to address these issues is proposed.

3.2 Build, rent or sell: A proposed categorization scheme

To address the issues identified above, the following typology for categorizing the methods used to commercialize new technologies arising from university research is proposed. The descriptions that follow are from the perspective of the university/researcher rather than from the perspective of the firm that commercializes the technology. It is proposed that there are three primary methods of commercializing new technologies arising from university research: 1) *Build* – creating a new business based on the technology, 2) *Rent* – ongoing development and marketing of the technology to established firms that use the technology in their businesses and 3) *Sell* – disposition of the technology to an established firm.

The build option involves the creation of a new business based on the technology and reflects situations where the technology forms the basis for the development of a new firm to exploit the invention. This new firm acquires or develops the complementary assets needed to commercialize the technology.

The rent option involves ongoing development and marketing of the technology to firms that use the technology in their business and reflects situations where the right to use technology is ‘rented,’ typically through a licensing arrangement, to firms to use in their businesses for a fee. The university/researcher retains ownership of the technology and is often involved in enhancing the technology so that it can continue to mine the technology for additional revenues. Often, the technology is rented to more than one firm.

The sell option involves disposition of the technology to an established firm and reflects situations where the technology is ‘sold’ to an existing firm. The established firm typically has the complementary assets needed to commercialize the technology. The technology may be sold outright or licensed on an exclusive basis so that the licensee obtains substantially all of the risks and benefits of ownership of the technology. The university/research typically retains no ongoing rights to the technology or its future enhancements.

The build option differs from the rent option in that building involves developing and selling products or services based on the technology while renting involves selling rights to use the technology to others who develop and sell products based on the technology (i.e., the build option operates through the product market while the rent option operates through the market for technologies). The build option differs from the sell option in that, in the build option, the technology forms the core around which a *new* business is formed while, in the sell option, the technology supplements an *existing* business. The difference between the rent option and the sell option is analogous to selling the fruit of a tree versus selling the tree. The rent option is similar to selling the fruit of a tree. The technology (the tree) continues to be grown and harvested by the university/researcher while limited rights to use the technology (the fruit) are sold to one or more firms. The sell option is similar to selling the tree. The university/researcher retains no ongoing economic interest in the technology.

3.3 Examples of build, rent and sell approaches to commercialization

Each of the build, rent and sell options can be implemented using various legal structures such as licensing arrangements and the creation of start-up companies. For example, the Association of University Technology Manager’s Licensing Survey for 2003 indicates that 12.9% of licenses were to start-up firms (AUTM, 2004). A large of number of these start-ups are likely to be involved in developing new products or services based on the technologies (i.e., they are commercializing the technology using the build option). DALSA, described in chapter 6, is an example of a start-up using the build option.

The rent option may be implemented through non-exclusive licensing such as with the Waterloo Emitter™ for the bio-enhanced remediation of contaminated groundwater (University of Waterloo, 2005) but also may involve the use of intermediaries (Arora et al., 2001) and start-up companies. Rambus, described in section 3.1, and Certicom, described in chapter 6, are examples of such start-up companies.

An example of the sell option involving licensing is Florida State University's exclusive license of a patented process for the synthesis of the anticancer drug Taxol to Bristol-Myers Squibb (Eisenstein and Resnick, 2001). Genetech Inc., a start-up company founded in 1976, operated using a sell model in its early years though it has since become a fully integrated pharmaceutical company. Genentech's first two discoveries, human insulin and Factor VIII, were licensed to pharmaceutical companies who manufactured and marketed drugs based on these discoveries (Genentech, 2005). Senesco, described in chapter 6, is also an example of a start-up using the sell option.

These examples illustrate that the build, rent and sell options can be implemented in a variety of legal forms and, therefore, reaffirm the importance of having a categorization scheme that reflects the economic substance of these transactions rather than their legal form. Table 3.1 summarizes the characteristics of the build, rent and sell options; and the examples described in this section.

3.4 Rationale for build, rent and sell categories

The rationale for the build, rent and sell categories is based on the application on the concept of governance structures discussed in section 2.6.1 to the specific circumstances of the commercialization of university research.

In applying transaction cost economics to the commercialization of university research, it is necessary to identify the transaction involved and the possible governance structures. "A transaction occurs when a good or service is transferred across a technologically separable interface. One stage of activity terminates and another begins" (Williamson, 1985, p. 1). In the commercialization of university research, the transaction is the transfer of a new technology from a research setting to a commercialization setting. This transaction involves two groups of related activities and their supporting assets. One activity is the development of the technology and the assets supporting this activity include codified information concerning the innovation, related intellectual property rights and the tacit know-how of the researcher. The other activity is the production and delivery of products based on the technology. The operating assets for this activity consist of the complementary assets needed to commercialize the technology. Manufacturing capabilities and distribution networks are examples of the other complementary assets needed to put technological innovations into commercial use (Teece, Pisano and Shuen, 1997).

Table 3.1 Descriptions, characteristics and examples of the build, rent and sell options

	Build	*Rent*	*Sell*
Description	Create a new business based on the invention	Market the technology to other firms who will use it in their business	Dispose of the technology to a firm who will use it in its business
Characteristics	Technology is the key source of competitive advantage for the new business. Complementary assets need to be acquired or developed	Technology is made available through the markets for technology to established firms that develop new products or services based on the technology	The acquiring firm incorporates the technology into its existing business
Examples:	Many of the 12.9% of all licenses that go to start-up firms Dalsa Corporation	Waterloo Emitters™ for groundwater remediation Certicom Rambus Inc.	Process for the synthesis of Taxol Genentech Inc. early years Senesco

The build, rent and sell categories reflect differences in organizational form. Market governance refers to situations where transactions are carried on with third parties outside the firm through the use of contracts and, in this case, reflects situations where the university/researcher, who retains ownership of the technology, and third parties, who own the complementary assets needed to produce products and services based on the technology, transact through the use of contracts, often non-exclusive licensing arrangements. The rent option represents a market form of governance. Hierarchies refer to situations where the transactions are internalized so that the economic activities involved in the transaction occur within a single firm. In both the build and sell options, the technology and the complementary assets required to commercialize the technology are brought together in a single firm. In the build option, they are brought together in a newly created firm while in the sell option they are brought together in an established firm. Figure 3.1 depicts the differing organizational structures involved in the build, rent and sell options.

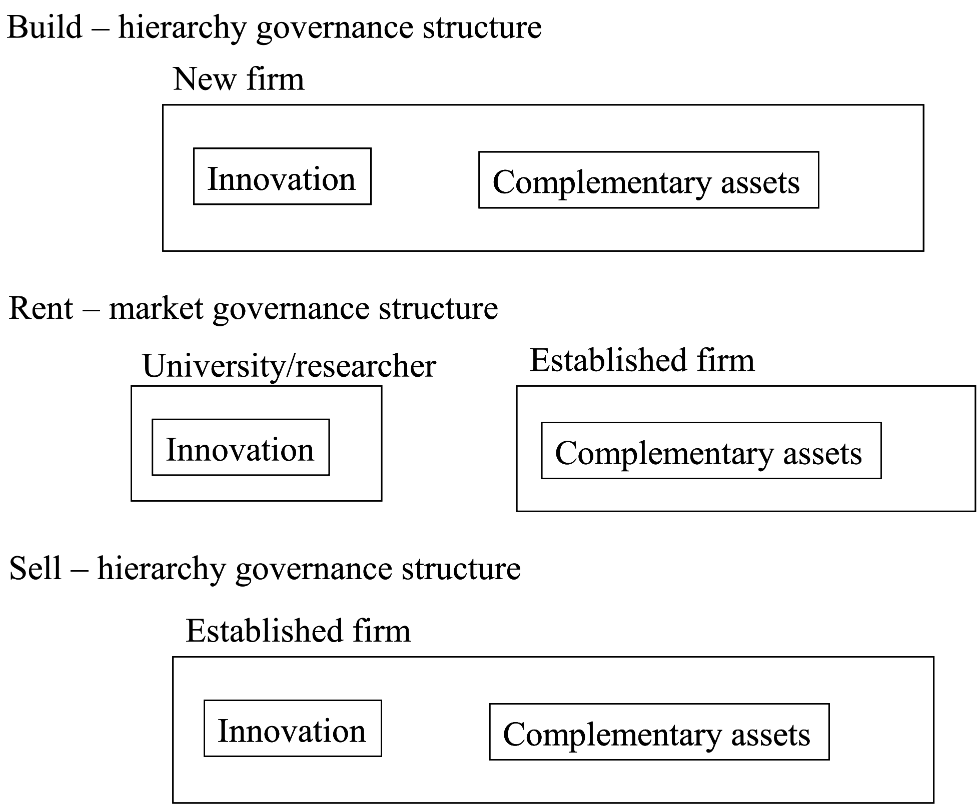
This examination of governance structures reinforces the concerns with the licensing vs. start-up view of the methods of commercialization. It is difficult to link the licensing vs. start-up dichotomy to the literature on markets and hierarchies. These difficulties relate primarily to the fact that the licensing and start-up categories do not align well with the market and hierarchy governance structures. Shane (2002) recognizes this difficulty by arguing that licensing to firms founded by inventors represents, in substance, a hierarchy governance structure rather than a market one (i.e., that licensing cannot always be equated with a market governance structure). Similarly, Rambus and Certicom are start-up firms but ones that operate through a market governance structure with the established firms that put their technologies into use. In these cases, commercialization by a start-up firm cannot be equated with a hierarchy governance structure. In summary, these examples show that a simple ‘licensing = market, start-up = hierarchy’ model does not adequately reflect the complexities that exist in the business models used to commercialize new technologies arising from university research.

3.5 Criteria distinguishing the build, rent and sell categories

For the build, rent and sell categories to be useful, it must be possible to uniquely place the commercialization of a particular technology into one of these categories. Two criteria are proposed for doing so. The first criterion is whether a new firm or an established firm commercializes the technology. Commercialization by a new firm involves a different set of risks than those faced by an established firm commercializing a technology (Teece, 1996).

These risks include the problems of acquiring the skills (Shane, 2002) and complementary assets (Teece, 1986) necessary to commercialize the technology.

Figure 3.1 Governance structures of the build, rent and sell options



The second criterion relates to the ownership of the property rights to the technology. The ownership of the property rights can be evaluated based on “three elements: (a) the right to use the asset …, (b) the right to appropriate returns from the asset …, and (c) the right to change the asset’s form and/or substance” (Williamson, 1991, p. 287). Some rights to use the technology will always be held by the commercializing firm. Otherwise, it would be unable to commercialize the technology. The right to use a technology also implies the right to exclude others from using the technology. A firm that controls ownership of a technology has the right to exclude others from using the technology. Thus the right to exclude others from using the technology is an important consideration in assessing the ownership of the property rights to the technology. The right to appropriate returns from the technology will be shared in some form between the university/researcher and the commercializing firm. This sharing may take the form of fixed payments, payments dependent on use of the technology (e.g., running royalties), equity in the commercializing firm or some combination of these. This sharing varies in nature from fixed contractually determined amounts though to residual returns (i.e., the profit resulting from the sale of the products after all expenses). Retention of residual returns by the university/researcher suggests that they have retained the majority of the rights to appropriate returns while fixed returns suggest that they have transferred the majority of the rights to appropriate returns to the commercializing firm. The right to change the technology's form and/or substance reflects the university's/researcher's rights to benefit from further enhancements of the technology. (e.g., to develop and patent improvements or enhancements to the technology). If the university/researcher retains the rights to benefit from future enhancements of the technology, this is evidence that they have retained ownership of the property rights to the technology. An overall evaluation of these three elements leads to an assessment of whether the university/research, or a firm created by them to market the technology to established firms, have retained the majority of the property rights to the technology or whether they have transferred the majority of the property rights to the commercializing firm.

Table 3.2 summarizes how these criteria relate to the three proposed categories of commercialization. The table also makes clear that each proposed category represents a unique combination of the three criteria.

Together these criteria specify three distinct governance structures for commercializing technologies. The build model reflects a hierarchy governance structure where the technology forms the core of the business and the complementary assets needed to commercialize the technology are acquired by the new business. The rent model reflects a market governance structure where the technology and the complementary assets needed to commercialize it are held in two (or more) separate firms transacting through markets for technology. The sell model reflects a hierarchy structure where the technology is sold to and incorporated into an existing firm that has the complementary assets needed to commercialize the technology.

Table 3.2 Criteria for the build, rent and sell options

	Build	*Rent*	*Sell*
Criteria:			
1) Firm that commercializes the technology	New firm	Established firm(s)	Established firm
2) Ownership of property rights to the technology	New firm	Majority retained by inventor/university or a firm created by them to market the technology to established firms	Established firm
Governance structure	Hierarchy	Market	Hierarchy

3.6 Implications and benefits of the build, rent or sell approach

The build, rent or sell approach has a number of implications and benefits for understanding the commercialization of new technologies arising from university research. First, the approach is easily reconcilable to the broader literature on commercializing innovations. For example, Teece (2000) identifies the following four options available to independent inventors and stand-alone laboratories:

> (1) licensing the technology to incumbent firms who already have the necessary complementary assets in place; (2) using intellectual property as collateral to raise debt funds to establish an organization to exploit the technology; (3) exchanging the patent for equity in a new venture-funded firm; (4) exchanging the intellectual property for cash or equity in an established firm. (p. 55)

The first of these options is comparable to the rent option; the second and third options are comparable to the build option and the fourth option is comparable to the sell option. Teece argues that appropriability conditions and control of complementary assets are the key factors in determining which of these options is preferable in a particular circumstance.

The build, rent or sell approach also better reflects the ideas of markets and hierarchies than does the licensing vs. start-up approach. The focus on governance structures enables researchers to draw on the extensive literature on markets and hierarchies and on the literature on markets for technology (see sections 2.6.5 and 2.8.2) to study the commercialization of new technologies arising from university research. This is done in chapter 4 where transaction cost economics theory is used to develop hypotheses related to the methods of commercializing university research. It is significant to note that the hypotheses developed from the proposed approach differ in important ways from those developed using the licensing vs. start-up dichotomy. For example, there are a significant number of licensing arrangements that will be identified as hierarchy governance structures using the proposed approach. The Association of University Technology Manager's Licensing Survey for 2003 indicates that 87% of licenses were to existing companies (52.5% of licenses were to small companies and 34.5% of licenses were to large companies). A significant number of these licenses (35% of licenses to large companies and 43% of licenses to small companies) are exclusive (AUTM, 2004). Many of these licenses will be classified as sell transactions resulting in a hierarchy governance structure using the proposed approach. These licenses are grouped with other licensing arrangements and considered market governance structures under the licensing vs. start-up approach.

An important third benefit of the proposed approach is that it captures the governance structure in place at the time when the invention is commercialized. The licensing vs. start-up approach focuses on the point in time when a technology leaves the university. However, there is evidence that significant time can pass between the point when a technology leaves the university and when it is commercialized (see section 2.4.3). The licensing vs. start-up approach fails to take into account the significant changes that can occur between the time a technology leaves the university setting and when it is put into commercial use.

3.7 Conclusion

In this chapter, difficulties with the licensing vs. start-up dichotomy were identified and a proposal for a new method of categorization that takes into account the variety of methods of commercialization was developed. In the next chapter, this approach is used to generate a number of hypotheses relating the characteristics of new technologies arising from university research to the governance structures used to commercialize them.

Chapter 4
Hypotheses

In this chapter, the hypotheses that will be tested are developed. Two sets of hypotheses are proposed in this chapter. The first set is related to firm characteristics associated with the strategic governance choices of build, rent or sell. The second set of hypotheses relate to the link between certain characteristics of new technologies (i.e., transaction attributes) and the strategic governance choices made in their commercialization.

4.1 Hypotheses related to governance choices and firm characteristics

The build, rent and sell typology of governance choices proposed in chapter 3 is derived from theory related to the concepts of markets and hierarchies. While this typology has a strong theoretical basis, it must also be anchored in empirical experience to be useful (Meyer, Tsui and Hinings, 1993). Accordingly, hypotheses are derived that link the theoretical classifications to specific firm characteristics. These characteristics relate to the markets the firms derive their revenue from and how they allocate their resources.

4.1.1 Revenue sources

As discussed in section 2.8.2, firms may operate in markets for products or markets for technology (Arora et al., 2001; Gans and Stern, 2003; Giuri and Luzzi, 2005). It is expected that the strategic governance choice made in commercializing a new technology will affect the extent to which a firm operates in each of these markets. When the build option is used to commercialize a technology, a new firm is created to produce goods or services based on the new technology. Therefore, it is expected that the new firm will derive its revenue primarily from product market activities. Revenue from product market activity includes revenue from sales of products; long-term contracts for the provision of products or services; services and support; and software products. When the rent option is used to commercialize a technology, the technology is marketed to established firms who use it in their business. Similarly, when the sell option is used to commercialize a technology, the technology is disposed of to an established firm that uses it in its business. In both the rent and sell situations, the established firm(s) that commercialize the technology are expected to derive their revenue primarily from the product market while the university/inventor, or a firm created by them for the purpose of marketing the technology to other firms, is expected to derive its revenue primarily from technology market activity. Revenue from technology market activity is revenue that is derived from intellectual property (U.S. Department of Justice, 1995). This leads to the following hypotheses:

> H1a: The build option is positively associated with new firms created to commercialize technologies deriving revenue primarily from product market activity.
>
> H1b: The rent and sell options are positively associated with new firms created to commercialize technologies deriving revenue primarily from technology market activity.

4.1.2 Allocation of resources

The allocation of internal resources between different business activities is a critical element in implementing a firm's strategy (Porter, 1980). Therefore, it is expected that a firm's strategic governance choice will affect the allocation of resources to certain business activities. As discussed in section 2.4.3, most new technologies arising from university research are at an early stage. Consequently, technology development and follow-on product development are important activities in commercializing a new technology (Shane, 2004). Technology development activity is reflected in a firm's spending on research and development activities. Once products have been developed, they need to be produced and sold in product markets. Consequently, the production of goods and services based on the new technology is another significant business activity involved in the commercialization of a new technology.

The build option involves a hierarchy governance structure where both the technology development activities and production activities are expected to be performed by the new firm created to commercialize the technology. The rent option involves a market governance structure where the technology development activities are expected to be performed by the university/inventor, or a firm created by them for the purpose of marketing the technology to other firms, and the production activities are expected to be performed by the established firms that produce goods or services based on the technology. When the sell option is used to commercialize a new technology, the university/inventor, or a firm created by them for the purpose of marketing the technology to other firms, is expected to perform the technology development activities up to the point when the technology is disposed of to an established firm. The established firm is expected to perform any subsequent technology development activity and the production activity. This analysis leads to the following hypotheses:

> H2a: The build option is positively associated with new firms created to commercialize technologies expending resources on both technology development activities and production activities.
>
> H2b: The rent and sell options are positively associated with new firms created to commercialize technologies expending resources on technology development activities but not on production activities.

4.2 Hypotheses related to transaction attributes

The basic premise of transaction cost economics is that the decision to perform an activity inside or outside the firm should be based on the relative efficiency of conducting the activity in these two environments. Transactions should be performed inside the firm when the costs of transacting in the market are higher than the costs of performing the activity internally. These transaction costs include the costs of negotiating, monitoring and enforcing contracts with outside parties and the costs of managing internally governed exchanges (Coase, 1937; Poppo and Zenger, 1998). Transaction cost economics identifies three principal dimensions affecting transaction costs. These are the extent to which the transaction involves transaction specific assets, uncertainty related to the transaction and the frequency with which transactions recur (Williamson, 1999).

Asset specificity refers “to the degree to which an asset can be redeployed to alternative uses and by alternative users without sacrifice of productive value” (Williamson, 1996a, p. 59). According to transaction cost economics, market governance has high transaction costs when dealing with assets of high specificity (Williamson, 1975). “Specific assets trigger a threat of opportunistic behavior that requires costly contractual safeguards to deter” (Poppo and Zenger, 1998, p. 853). Thus, in situations of high asset specificity, more integrated governance forms are preferred as they have the lower transaction costs (Poppo and Zenger, 1998). In the commercialization of new technologies arising from university research, the two primary issues of asset specificity relate to the appropriability of the technology and the requirement for specialized complementary assets.

4.2.1 Appropriability of the technology

Appropriability relates to how easily and quickly potential competitors can imitate a technology. Winter (2000) identifies four mechanisms of appropriability: 1) patents and related legal protection, 2) secrecy, 3) lead time and 4) control of complementary assets. Strong intellectual property protection makes it more difficult to imitate an innovation (Teece, 1986; Williamson, 1991). “When … poorly protected intellectual capital … [is] at issue, pure market arrangements expose the parties to recontracting hazards or appropriability hazards. In such circumstances, hierarchical control structures may work better than pure arms-length contracts” (Teece, Pisano and Shuen, 1997, p. 522). Where patents and related legal protection are strong, the legal safeguards provided mitigate the threat of opportunistic behavior. This suggests that strong patents or other legal protection support the commercialization of technologies using a market governance structure (i.e., the rent option). Empirical support for this relationship was found by Oxley (1999) who examined technology transfer alliances between U.S. and non-U.S. firms and found that, when intellectual property protection was weak, firms adopted more hierarchical governance structures. This leads to the following hypothesis.

> H3: The greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option.

Secrecy is another method of keeping others from appropriating the benefits of the technology. Secrecy requires that information about the technology be kept secret and, therefore, opportunities for trading in markets for technologies are limited if secrecy is to be maintained. Two elements that make it easier to maintain secrecy and more difficult for other firms to transfer and imitate a technology are high levels of tacitness and complexity in the knowledge inherent in the technology (Teece, Pisano and Shuen, 1997). Tacit knowledge refers to knowledge that cannot be easily communicated and shared (Simonin, 1999). “Complexity is usually defined according to dimensions that increase the difficulty of comprehending how a system (i.e., an organization, organism, device) functions or produces some outcome. Simon (1962) defines a complex system as one that consists of *many unique* and *interacting* elements, which have *equally important* effects on the outcomes produced by the system." (McEvily and Chakravarthy, 2002, p. 289). Complexity requires coordination to enable rapid adjustment as components change over time. This is facilitated by hierarchical governance structures better than by market governance structures (Chesbrough and Kusonoki, 2001). Therefore, high levels of tacitness and complexity suggest that the technology be commercialized through a hierarchical governance structure (i.e., either the build or sell options).

> H4a: The greater the tacitness of the knowledge inherent in a technology, the greater the likelihood that the technology will be commercialized using the build or sell options.

> H4b: The greater the complexity of the knowledge inherent in a technology, the greater the likelihood that the technology will be commercialized using the build or sell options.

Lead time reflects the fact that the threat of appropriability can be reduced even without patent or other legal protection or secrecy if there exists a lead time before substitute technologies can be developed. However, because lead times before substitutes appear are limited in duration, it is important to maximize the returns from the technology in the time before substitutes appear. A market governance structure facilitates this by making the technology available to multiple established firms who have the manufacturing and distribution capabilities to bring products based on the technology to market quickly.

> H5: The greater the risk of substitutes, the greater the likelihood that the technology will be commercialized using the rent option.

4.2.2 Complementary assets

The complementary assets needed to commercialize the technology may be generic or specialized to the invention (Teece, 1986). Assets that are specialized to the technology increase the transaction costs of market governance. Therefore, the rent option is likely to be less effective when specialized complementary assets are needed to commercialize the technology as it involves a market governance structure. Furthermore, Teece (1986) and Gans and Stern (2003) suggest that situations where specialized complementary assets are required to commercialize the technology pose significant hazards to new firms attempting to compete with the existing firms that control these specialized complementary assets. This is the situation faced when the build option is used to commercialize a new technology. This suggests that the sell option is likely to be most effective when specialized complementary assets are required to commercialize the technology.

> H6: The greater the importance of specialized complementary assets, the greater the likelihood that the technology will be commercialized using the sell option.

4.2.3 Uncertainty

Uncertainty is the second key dimension affecting transaction costs. Uncertainty makes it difficult to contract in markets for technology and increases market transaction costs in two ways. Transaction costs are increased as a result of the costs of trying to anticipate uncertain events and writing these into the contract. Secondly, costs arise because the transactions are maladapted to the environment while the parties adjust to the changed circumstances (Poppo and Zenger, 1998; Williamson, 1991). Empirical studies of the effect of uncertainty on the choice of governance structures have produced contradictory evidence (Sutcliffe and Zaheer, 1998). Klein et al. (1990) argue that uncertainty has a number of dimensions that may impact governance structures differently. The two dimensions of uncertainty identified by Klein et al. are volatility and diversity. Volatility reflects the speed of change in the environment and diversity reflects the number of sources of uncertainty in the environment. Klein et al. argue that higher levels of volatility create problems in writing contracts and higher transaction costs for market governance structures thus encouraging more integrated forms of governance. Klein et al. argue that diversity leads to a desire for flexibility and that market governance structures provide this flexibility.

Two important sources of uncertainty that have been identified are technical and market uncertainty (Schilling and Steensma, 2002; Walker and Weber, 1984). Thus, it is hypothesized that greater volatility related to technical and market uncertainty increases the likelihood that technologies will be commercialized using the build or sell options and that greater dynamism related to technical and market uncertainty increases the likelihood that technologies will be commercialized using the rent option.

> H7a: The greater the volatility relating to technical uncertainty associated with the technology, the greater the likelihood that

the technology will be commercialized using the build or sell options.

H7b: The greater the volatility relating to market uncertainty associated with the technology, the greater the likelihood that the technology will be commercialized using the build or sell options.

H8a: The greater the dynamism relating to technical uncertainty associated with the technology, the greater the likelihood that the technology will be commercialized using the rent option.

H8b: The greater the dynamism relating to market uncertainty associated with the technology, the greater the likelihood that the technology will be commercialized using the rent option.

4.2.4 Frequency

The third dimension affecting transaction costs is the frequency with which transactions recur. The commercialization of new technologies arising from university research is an environment where transactions between a specific researcher and a specific commercializing firm are expected to be infrequent. Thus, it is expected that frequency of interaction will not be a distinguishing feature in this environment and, therefore, no hypotheses related to frequency are proposed.

4.3 Summary of hypotheses tested

Table 4.1 summarizes the hypotheses tested in this thesis. For the reasons set out in section 8.2, Hypotheses 3a and 3b related to tacitness and complexity are combined into a single hypothesis. Likewise, Hypotheses 7a and 7b related to volatility and Hypotheses 8a and 9b related to dynamism are combined into single hypotheses related to volatility and dynamism respectively.

Table 4.1 Summary of hypotheses tested

Hypotheses	
Firm characteristics associated with the strategic governance choices of build, rent or sell:	
H1a	The build option is positively associated with new firms created to commercialize technologies deriving revenue primarily from product market activity.
H1b	The rent and sell options are positively associated with new firms created to commercialize technologies deriving revenue primarily from technology market activity.
H2a	The build option is positively associated with new firms created to commercialize technologies expending resources on both technology development activities and production activities.
H2b	The rent and sell options are positively associated with new firms created to commercialize technologies expending resources on technology development activities but not on production activities.
Transaction attributes and the strategic governance choices made in their commercialization:	
H3	The greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option.
H4	The greater the tacitness and complexity of the knowledge inherent in a technology, the greater the likelihood that the technology will be commercialized using the build or sell options.
H5	The greater the risk of substitutes, the greater the likelihood that the technology will be commercialized using the rent option.
H6	The greater the importance of specialized complementary assets, the greater the likelihood that the technology will be commercialized using the sell option.
H7	The greater the volatility associated with the technology, the greater the likelihood that the technology will be commercialized using the build or sell options.
H8	The greater the dynamism associated with the technology, the greater the likelihood that the technology will be commercialized using the rent option.

Chapter 5
Methods

Three studies were conducted in the course of this research. Study #1 analyzes three start-ups based on new technologies arising from research conducted at the University of Waterloo. Study #2 examines the business activities of a number of Canadian and U.S. public start-up firms. Study #3 is a survey of university faculty members who have had new technologies arising from their academic research put into commercial use. Each of these studies uses different methods. The use of multiple methods, known as triangulation, has the benefit of providing differing perspectives on the research question.

This chapter is organized as follows. First the concept of triangulation is discussed and its advantages and disadvantages for this particular research are discussed. This is followed by detailed descriptions of the methods used in each of the three studies.

5.1 Triangulation

Triangulation is "the combination of methodologies in the study of the same phenomenon" (Denzin, 1978, p. 291). Each of the three studies in this research uses different methods. Study #1, the tale of the three start-ups, involves the detailed *qualitative* analysis of data gathered from a variety of archival data sources. Study #2, the examination of public start-up firms, involves the *quantitative* analysis of data gathered from archival data sources. Study #3, the study of academic researchers involved in commercialization, involves the quantitative analysis of data gathered using a survey document. Focused case studies and studies of contracts, statistical analysis of secondary data and statistical analysis using field data have all been used in the study of transaction cost economics (Mahoney, 2005). However, they have rarely been used together as complementary sources of evidence.

The primary advantage attributed to triangulation is that the strengths of one method can compensate for weaknesses in the other methods (Baumard and Ibert, 2001; Jick, 1979). When two or more methods support the same result, this "enhances our belief that the results are valid and not a methodological artifact" (Bouchard, 1976, p. 268). The primary weakness attributed to triangulation is that, in general, there are no reliable methods for combining the results of the various tests (Jick, 1979).

Study #1, the tale of three start-ups, has the advantage of providing an in-depth analysis of the three firms examined. This allows for an understanding of some of the subtleties of the commercialization process that are difficult to capture through quantitative means. However, Study #1 involves the study of a very limited number of firms selected for their differences rather than for their representativeness. Thus, Study #1 has weak external validity. Study #2, the examination of public company start-up firms, is quantitative in nature and provides greater objectivity in its findings that Study #1. Study #2 involves both Canadian and U.S. firms and uses secondary data from reliable sources. Study #2 provides strengths related to the reliability and external validity of the overall research. Study #3, the survey of academic researchers, has strengths related to the internal validity of the overall research. The survey is designed to specifically measure the variables of interest whereas Studies #1 and #2 use secondary data that was originally prepared for other purposes. Enhanced internal validity is an attribute commonly attributed to primary data such as that collected in Study #3 (Baumard and Ibert, 2001). Studies #1 and #2 also focus on instances of commercialization that involved a start-up firm that eventually went public. Study #3 approaches commercialization from the inventor side irrespective of how the new technology was commercialized. This adds to the generalizability of the overall research findings. This discussion illustrates how the three studies complement each other in terms of enhancing the reliability and validity of the overall research.

5.2 Study #1, a tale of three start-ups

The analyses in Study #1 use archival data related to the three start-ups examined. The primary sources of data used are documents issued by the start-ups and filed with the applicable securities regulators. Limited use is also made of information on the start-ups websites. The information filed by these start-ups with the applicable securities regulators includes prospectuses, annual reports, material change reports, significant contracts and news releases. This information is available from the date the firm became a public company.

A prospectus is a document issued by a firm when it offers securities, such as shares in the firm, to the public. Prospectuses are intended to ensure that potential investors receive “full, true and plain disclosure of all material facts” (Ontario Securities Act, 1990, s 56(1)). Prospectuses typically contain the following information (U.S. Securities and Exchange Commission, 2003):

- A description of the company's properties and business;

- A description of the security to be offered for sale;
- Information about the management of the company; and
- Financial statements audited by independent accountants.

Annual reports are reports issued by a firm to its shareholders. Annual reports typically include the following information:

- Management's discussion and analysis – this is an analysis by management of a firm's past performance and its future prospects (Canadian Performance Reporting Board, 2004); and
- Audited financial statements.

Material change reports are required to be filed by public companies whenever a material change in the business of the company occurs. A material change is "a change in the business, operations or capital of the reporting issuer that would reasonably be expected to have a significant effect on the market price or value of any of the securities of the [company]" (Canadian Securities Administrators, 2003, p. 67).

The reliability of the data in these documents is enhanced by a number of factors. These include the fact that substantial criminal and civil penalties can arise from filing false or misleading information with the securities commissions. In addition, these documents are subject to review, in full or in part, by the applicable securities commission, a firm's auditors, a firm's lawyers and, in the case of a prospectus, a firm's underwriters.

5.3 Study #2, an examination of public company start-ups

5.3.1 Sample

Study #2 uses two separate samples of public start-up firms that have commercialized new technologies arising from university research. The first sample is of Canadian companies built on National Sciences and Engineering Research Council of Canada ("NSERC") funded research. The second sample is of U.S. companies built on research conducted at the Massachusetts Institute of Technology ("MIT").

The Canadian start-up sample is derived from companies listed in NSERC's *Research Means Business* publication. This publication profiles start-up companies that have their origins in university research funded by NSERC (NSERC, 2002). NSERC is a primary source of funding for research in the natural sciences and engineering in Canada (NSERC, 2005). These natural sciences and engineering disciplines are an important source of commercialized new technologies (Read, 2003). *Research Means Business* is a periodic publication of NSERC and has been used in other research on the economic impacts of academic start-ups (Vincett, 2005). The Canadian start-up sample was constructed primarily using the 2002 edition of the publication. This edition profiles 134 start-up companies. From this list of companies, those that became public companies were identified. Only public companies are included in the sample as being a public company brings obligations to publicly report significant information about the company and it is this public information that is analyzed in this study. Public companies were identified through information contained in *Research Means Business*, visits to the companies' websites and through searches of public company databases maintained by Canadian and U.S. securities regulators. Of the 134 start-up companies listed in *Research Means Business*, 30 (22%) were found to be public companies. The 1998 edition of *Research Means Business* was also reviewed. Most of the companies included in the 1998 edition also appear in the 2002 edition. Nonetheless, one additional public start-up was identified bringing the total Canadian start-up sample to 31 firms.

The US start-up sample is based on MIT start-ups founded between 1980 and 1996 that went public as identified by Shane (2004). MIT is a preeminent source of start-up firms in the United States and its commercialization activities have been the most widely studied (see, for example, Agrawal and Henderson, 2002; Neckar and Shane, 2003; and Shane, 2004). Rough estimates by Shane (2001) suggest that MIT accounts for approximately7.5% of start-ups founded to exploit new technologies arising from university research in the United States. Shane (2004) identified 23 public start-ups and the fact that these start-ups became public companies was confirmed through searches of public company databases maintained by U.S. and Canadian securities regulators.

In summary, the Canadian start-up sample consists of 31 firms and the U.S. start-up sample consists of 23 firms for a total of 54 firms. These two samples may not be representative of all start-ups created to commercialize new technologies arising from university research. While NSERC funded research is an important source of new technologies, new technologies also result from university research not funded by NSERC.

MIT start-ups also may not be representative of start-ups from other universities due to geographic advantages and strong ties to the venture capital community (Shane, 2001). Nonetheless, the samples represent important sources of new technologies and afford the benefits arising from having two separate samples from different countries and derived from two different sources.

5.3.2 Measurement

This study involves comparisons between the method used to commercialize a new technology and the business activities of the start-up involved in commercializing the technology.

5.3.2.1 Method of commercialization

The method of commercialization was classified as build, rent, sell, hybrid or development stage. The criteria used for classifying the method as build, rent or sell were those developed in chapter 3. The method used was classified as hybrid if commercialization of the technology involved the combined efforts of the start-up and an established firm rather than being commercialized primarily by the start-up or an established firm. For example, the technology may have been commercialized through a joint venture or partnership with an established firm with the start-up contributing manufacturing capabilities and the established firm contributing marketing and distribution capabilities to the joint venture. Start-ups were classified as development stage if products based on the technology had not yet been put into commercial use. In some cases, multiple methods of commercialization were used by the start-up. In these cases, the method of commercialization used was categorized based on the primary method used.

5.3.2.2 Business activities of the start-up

The nature and extent of business activities of the start-up was captured using four measures. Two of these measures relate to the markets in which the start-up operates. The other two measures relate to the allocation of internal resources to technology development activities and to production activities.

5.3.2.2.1 Markets the start-up operates in

As discussed in section 2.8.2, firms may operate in markets for products and markets for technology (Arora et al., 2001; Gans and Stern, 2003; Giuri and Luzzi, 2005). Two measures are used to determine the extent to which the start-ups operate in each of these markets.

Product market activity is measured by the percentage of the start-up's total revenue that is derived from products or services.

$$\text{Product market activity} = \frac{\text{Product market revenue}}{\text{Total revenue}}$$

Total revenue and product market revenue are measured in accordance with generally accepted accounting principles and are taken from the start-up's most recent audited financial statements. Product market revenue includes revenue from sales of products; long-term contracts for the provision of products or services; services and support; and software products.

Technology market activity is measured by the percentage of the start-up's total revenue that is derived from intellectual property (U.S. Department of Justice, 1995).

$$\text{Technology market activity} = \frac{\text{Technology market revenue}}{\text{Total revenue}}$$

Technology market revenue includes revenue from milestone payments, licensing fees and royalties related to contracts allowing other firms to use the start-ups intellectual property.

Excluded from both product market activity and technology market activity is revenue derived from other sources. These other sources include contract research and development where the start-up undertakes R&D activities related to another firm's technology, investment income and other miscellaneous sources of revenue.

5.3.2.2.2 Allocation of internal resources to technology development activities and to production activities

The allocation of internal resources between different business activities is a critical element in implementing a firm's strategy (Porter, 1980). Performing activities generates costs (Hope and Hope, 1997) and, consequently, an examination of a firm's costs can indicate the emphasis the firm places on various business activities.

Technology development activity is measured by the percentage of the start-up's total operating costs that is spent on research and development activities.

$$\text{Technology development activity} = \frac{\text{Research and development costs}}{\text{Total operating costs}}$$

Total operating costs and research and development costs are measured in accordance with generally accepted accounting principles and are taken from the start-ups most recent audited financial statements. Research and development costs are measured net of any related government assistance (e.g., R&D tax credits).

Production activity is measured by the percentage of the start-up's total operating costs that is spent on production activities.

$$\text{Production activity} = \frac{\text{Cost of goods sold}}{\text{Total operating costs}}$$

Cost of goods sold reflects the costs incurred to purchase or produce the products sold by the firm. Cost of goods sold includes the cost of material and labor used in the production of goods or services.

5.3.3 Procedures

The analyses use archival data related to the start-ups contained in the annual filings of the start-ups with the applicable securities regulator. In the case of start-ups required to file information with the Canadian securities regulators, this information is available through the System for Electronic Document Analysis and Retrieval ('SEDAR') available at http://www.sedar.com. In the case of start-ups required to file information with the U.S. Securities and Exchange Commission, this information is available through the Electronic Data Gathering, Analysis, and Retrieval system ('EDGAR') available at http://www.sec.gov/edgar.shtml. The annual filings of start-ups typically include the following information:

- Annual information form – this document includes various information about the firm including a description of the business of the firm (Canadian Securities Administrators, 2003);
- Management's discussion and analysis – this is an analysis by management of a firm's past performance and its future prospects (Canadian Securities Administrators, 2003);
- Audited financial statements.

Annual filings with the U.S. Securities and Exchange Commission on Form 10K contain similar contents to those listed above.

5.3.3.1 Method of commercialization

The methods of commercialization were determined using the criteria developed in section 3.5. Appendix A includes the descriptions of the categories that were used for this purpose. Two individuals identified the method of commercialization for each start-up: the author and another researcher who conducts research in the area of scientific research commercialization. Appendix A also includes the instructions given to the second coder. The second coder was trained by providing the coder with the materials contained in Appendix A and by working through two examples with the coder to ensure that the instructions were understood. The identification of the methods of commercialization used by the start-ups were done independently by the two coders and then compared. Of the 54 start-ups in the sample, the two coders identified the same method of commercialization in 50 cases (93%). Cohen's Kappa measure of inter-rater reliability is .89. A Kappa greater than .70 is generally considered satisfactory. The four cases where the coders identified different methods of commercialization were discussed by the coders and a final resolution was reached that was acceptable to both coders.

5.3.3.2 Business activities of the start-up

The data needed to calculate the four measures of the business activities of the start-up were identified from the audited financial statements contained in the annual reports of the firms.

5.4 Study #3, survey of academic researchers

Study #3 consisted of two phases. The measure development and preliminary fieldwork phase focused on the development and testing of the measures to be used in the study. The survey phase focused on gathering data related to individual innovations from researchers.

5.4.1 Measure development and preliminary fieldwork

The development of measures followed the general approach set out in Churchill (1979). The steps of this approach and the specific activities undertaken are described in the following sections.

5.4.1.1 Specifying the domain of the constructs

Specifying the domain of the construct involves delineating what is included and excluded from the concept (Churchill, 1979). Each of the independent variables has previously been specified and used in research on technology transfer or transaction cost economics (see chapter 2, Literature review, and Table 5.1). The dependent variable, the governance structure used in the commercialization of the innovation, is developed and specified in chapter 3.

5.4.1.2 Generate item pool

Generating the item pool involves 1) identifying how the variables have been defined previously and how many dimensions they have and 2) identifying or generating items which tap each of the dimensions of the constructs (Churchill, 1979).

Items related to the independent variables were identified from a review of the literature. The wording of these items was reviewed and amended as necessary to ensure the wording of items was as precise as possible and suited to the university commercialization environment. The items identified were further refined using the results of the pilot survey (see section 5.4.1.3). Table 5.1 sets out the items identified for the independent variables and identifies their sources.

Table 5.1 Items for independent variables and their sources

Variables and items	*Source*
Patent or other legal protection	
The intellectual property protection obtained was effective in deterring imitation of the innovation	Gans et al. (2000)
Fundamentally similar innovations exist. (R)	Schilling and Steensma (2002)
Few credible substitutes competed with this innovation.	Schilling and Steensma (2002)
Tacitness	
Manuals and documents accurately explained the implementation and operation of this innovation. (R)	Gopalakrishnan and Bierly (2001)
Educating and training personnel for this innovation was a quick and easy job. (R)	Gopalakrishnan and Bierly (2001)
The critical elements of this innovation could be easily explained to my colleagues (e.g., in a paper or at a conference). (R) (Note 1)	
Complexity	
Interactions between this innovation and related components or systems were poorly understood.	Derived from Chesbrough and Kusunoki (2001)
Technical information about how this innovation functions together with other components or systems was well defined. (R)	Derived from Chesbrough and Kusunoki (2001)
This innovation was a component of a larger product, process or system. (Note 1)	
A change in the design of this innovation would require compensating design changes in related components or systems. (Note 1)	

Table 5.1 ***(continued)***

Variables and items	*Source*
Risk of substitutes	
It would be easy for others to imitate this innovation.	Schilling and Steensma (2002)
The ‘reverse engineering’ of this innovation by a competitor would be technically difficult. (R)	Schilling and Steensma (2002)
Technology volatility	
I was confident that this innovation would perform as it was originally designed.	Schilling and Steensma (2002)
It was clear that this innovation would work as it was intended technologically.	Schilling and Steensma (2002)
Market volatility	
I was certain this innovation would meet user demands.	Schilling and Steensma (2002)
Technology dynamism	
Future technological breakthroughs were likely to render this innovation of little value in a short time period.	Schilling and Steensma (2002)
Market dynamism	
I expected this innovation to have a relatively long life cycle. (R)	Schilling and Steensma (2002)
Complementary assets	
The following were important for the commercialization of the innovation: a) Manufacturing capabilities, b) distribution channels, c) Salesforce, d) After-sales support capabilities, e) Complementary technologies, f) Other (specify)	Gans et al. (2000)
The following needed to be tailored to the innovation: a) Manufacturing capabilities, b) distribution channels, c) Salesforce, d) After-sales support capabilities, e) Complementary technologies, f) Other (specify)	Gans et al. (2000)

Notes:
1. Item was included in final survey but was dropped from final measures for the reasons described in section 8.2.
(R) indicates that the item is reverse coded.

For the dependent variable, two dimensions related to the governance structures used to commercialize the technology were identified in chapter 3. These are 1) whether a new firm or an established firm commercialized the new technology and 2) ownership of the property rights to the innovation. Items for these dimensions were generated through discussions with a small number of experienced persons (Churchill, 1979). Specifically, individuals in the University of Waterloo's Technology Transfer and Licensing Office and faculty members who are experienced in commercialization were interviewed. For the ownership of property rights dimension of governance structures, numerous factors could be considered as indicators of ownership of the property rights (see section, for example, section 6.4.1.2). Based on the discussions with experts, it was decided that holding equity rights in the commercializing firm was a strong indicator that the university/inventor retained property rights to the invention. This decision is consistent with Oxley (1999) who identifies the possession of equity as an important break point in market-hierarchy governance structures. Table 5.2 sets out the items identified for the two dimensions.

5.4.1.3 Purify the measures (pilot study)

Based on the above, an initial survey instrument was developed containing multiple items for each variable (Churchill, 1979). This initial instrument was sent to approximately 25 faculty members in the Department of Management Sciences at the University of Waterloo. They were asked to complete the survey and also to provide opinions and comments relating to the face validity of the measures. The feedback received and analysis of the responses provided supported most of the items in the survey. Nonetheless, a small number of changes to the measures were made.

5.4.2 Survey phase

5.4.2.1 Sample

The population for the survey is faculty members who have had new technologies resulting from their academic research put into commercial use and who are located at one of two of the universities participating in the "C4" consortium. The C4 consortium is the result of an agreement between four south-western Ontario universities to cooperate in areas related to the support of technology transfer. The choice of intense examination of faculty from a small geographic area rather than a broader sample from numerous universities was made to minimize the impact of environmental factors such as differing economic environments and the availability of venture capital (see section 2.2). This choice is also convenient and limits the costs of performing the research. Research into commercialization of university research has often taken this approach. Agrawal and Henderson (2002) and Shane (2002) both focused on innovations at the Massachusetts Institute of Technology. Colyvas et al. (2002) examined innovations from two universities. This approach limits somewhat the generalizability of the findings. Future research can extend the population to other universities.

Table 5.2 Dimensions and items for dependent variable

Dimension	*Items*
Firm that commercializes the technology	The innovation was commercialized by:
	1) A newly created firm founded by you/other key researchers on the project,
	2) A newly created firm founded by someone other than you/other key researchers on the project,
	3) One or more established firms,
	4) Other (please describe)
	[If 1) above] The purpose of the newly created firm was to:
	1) Produce and sell new products or services based on the innovation,
	2) Market the innovation to other firms that would produce and sell new products or services based on the innovation. Marketing the innovation may occur through selling licenses, development kits, or consulting services related to the innovation,
	3) Other (please describe)
Ownership of property rights to the technology	My/my university's rights to receive income from the innovation took the form of:
	1) A fixed license fee or consulting fees,
	2) Royalties based on product sales,
	3) Equity in the commercializing firm (e.g., shares in the commercializing firm, stock options, dividends),
	4) I have no rights to receive income from the innovation,
	5) Other (please describe)

One of the universities has a strong reputation for entrepreneurial activity and for its engineering and computer science schools. The other university has strong medical and engineering schools. Research has shown that medical schools and engineering faculties are significant producers of commercialized research. Thursby et al. (2001) found that 33% of the inventions disclosed in their survey came from medical schools and 29% came from engineering schools. These were the two largest sources of inventions in their survey.

Faculty members who have been involved in commercialization were identified as follows. Members of the Technology Transfer and Licensing Office at the first university indicated that reported disclosures to the university's Office were not a reliable source for identifying faculty members who have been involved in commercialization as there is evidence that many commercialized innovations are not disclosed to the Office. Consequently, the following sources were used to develop a list of faculty members who may have been involved in commercialization:

- Waterloo Region "TechMap." This document, produced by PriceWaterhouseCoopers, CTT and Communitech, identifies high technology firms in the Waterloo Region and identifies technology and people links to local universities;
- OCE/CITO Innovation Tree. This document, produced by the Ontario Centres of Excellence, identifies spin-off companies and receivers of technology transfer resulting from technology transferred from research sponsored by Communication and Information Technology Ontario ("CITO");
- Spin-off Company Profiles. This internal publication of the Technology Transfer and Licensing Office of University #1 is a compilation of corporate profiles of numerous companies that have a connection to technologies or people from the university; and
- The University's Technology Transfer and Licensing Office website. This site lists technologies available for licensing.

Some faculty members involved in commercialization were also identified from references by other faculty members and articles in the local newspaper. Multiple sources were used to ensure as complete an identification of faculty members who may have been involved in commercialization as possible. A high proportion of the faculty members were identified by multiple sources. This finding provides some evidence as to the overall completeness of the list.

At the second university, a senior member of the university's Technology Transfer and Licensing Office indicated that he believed that their records did comprise a complete listing of faculty members who had been involved in commercialization activities. In this case, a listing of these faculty members provided by the Office was used as the sampling frame.

For both universities, the lists included faculty members who *may* have been involved in commercialization. However, the commercialization activities were at various stages. In many cases, the commercialization process had begun but the technology was not yet in commercial use. This study is concerned with the governance structures in place when the technology is commercialized and, consequently, it was necessary to identify those instances where the technology had been put into commercial use.

Attempts were made to contact by telephone each of the faculty members identified to determine whether the technology they had invented had been put into commercial use. Table 5.3 indicates the results of these contacts. In some cases, contact was not made after multiple attempts. This may be because the faculty member was away from the university for an extended period of time (e.g., on sabbatical) or because the faculty member chose not to return messages left for them. In total, there were only 13 cases where contact was not made. In a high proportion of the cases, contact was made and the faculty member indicated that the technology they had invented was not yet in commercial use. The difference in the proportion of such cases between the two universities is due to the differences in the way the faculty members were identified. As indicated above, the list for University #1 was compiled from multiple sources and, in order to be as complete as possible, included all faculty members who appeared in these sources regardless of the likelihood that their inventions had been put into commercial use. At University #2, the list was compiled by members of the University's Technology Transfer and Licensing Office who were more familiar with the cases and, therefore, could more accurately eliminate cases that had not been put into commercial use. Overall, the large proportion of cases where technologies were not yet in commercial use indicates the difficulties and time involved in commercializing a new technology. The number of cases where technologies were in commercial use is much greater at University #1 than University #2. This is not an usual finding. Clayman (2004) analyzed reported information on commercialization activity at Canadian universities and found great variability between universities in most measures of commercialization activity. In total, 64 faculty members who have invented new technologies that have been put into commercial use were identified.

Table 5.3 Number of faculty members who have been involved with commercialized technologies

Description	*University #1*	*University #2*
Number of faculty members identified as possibly having commercialized new technologies	207 (100%)	13 (100%)
Number where contact was not made	9 (4%)	4 (30%)
Number where technologies were not yet in commercial use	138 (67%)	5 (38%)
Number where technologies were in commercial use	60 (29%)	4 (31%)

5.4.2.2 Design and procedures

A survey approach was used to collect the data. The survey consisted of a self-administered questionnaire that was mailed to participants. A copy of the questionnaire is contained in Appendix B. Since the survey involved human participants, ethics approval was solicited from the University of Waterloo's Office of Research Ethics. Full ethics clearance was received in September 2003.

Faculty members identified as possibly having been involved in commercialization (see section 5.4.2.1) were contacted by telephone. The purposes of the telephone call were to 1) determine whether technologies resulting from their academic research had been put into commercial use (i.e., they are part of the target population) and 2) to ask for their participation in the research. The survey was mailed to those who agreed to participate in the research. Multiple attempts were made to contact faculty members. The choice to make multiple attempts to contact faculty members rather than to leave voice messages asking for a response was made based on early experience in contacting faculty members. This early experience indicated that the response rate to voice messages was very low. Up to 10 attempts were made to contact an individual over multiple academic terms. As indicated in Table 5.3, these procedures resulted in contact being made with 203 (94.1%) of the 220 faculty members identified as potentially having been involved in commercialization activities.

A number of steps were taken to increase response rates to the survey. First, the survey was designed to make it easy to complete. This included laying out the survey clearly, making the questions easy to read and well spaced, and making responses easy to complete by simply circling the appropriate response (Fowler, 2002). Second, a number of follow-up procedures were used to encourage participants to respond (Babbie, 1999; Dillman, 2000). The first follow-up procedure conducted was a telephone follow-up. This follow-up reminded the participants of the survey, confirmed that they had received the survey and encouraged them to respond to it. The second follow-up procedure was a written memo. This memo again reminded the participants of the survey and their agreement to participate and encouraged them to respond. A copy of the survey was included with this memo. Follow-up procedures were timed to reach participants at less busy times of the year. Specifically, experience in contacting potential participants suggested that the beginning of academic terms was a better time to obtain cooperation from participants than later in the term when examinations and other deadlines were imminent. Consequently, follow-up procedures were performed early in the term. As a result of these procedures, an overall response rate of 70% was achieved.

These procedures were conducted over the period from January 2004 to September 2005. In total, over 1,000 contact attempts were made through telephone calls, e-mails and memoranda to achieve the participation and response rates indicated above. Chapter 8 reports the results of the analysis of the survey responses including the results of tests designed to assess the reliability and validity of the data obtained (Churchill, 1979).

5.5 Summary

Three studies were conducted in the course of this research. Study #1 analyzes three start-ups based on new technologies arising from research conducted at the University of Waterloo. Study #2 examines the business activities of a number of Canadian and U.S. public start-up firms. Study #3 is a survey of university faculty members who have had new technologies arising from their academic research put into commercial use. Each of these studies uses different methods providing multiple perspectives on the research question. The results of these studies are presented in chapters 6, 7 and 8, respectively.

Chapter 6

Results Study #1 – A Tale of Three Start-ups

This chapter contains the results of the analysis of three start-ups based on new technologies arising from research conducted at the University of Waterloo. The primary purpose of these examples is to illustrate the significant differences that exist in the governance structures used to commercialize new technologies.

6.1 Background to the three start-ups

Table 6.1 contains a summary of key information about the three start-ups. It also indicates the specific sources of the information obtained.

DALSA Corporation ("DALSA") is a start-up that commercialized image capture charge-coupled device ("CCD") technology. Dr. Savvas Chamberlain founded DALSA. Dr. Chamberlain was a Professor of Electrical and Computer Engineering at the University of Waterloo from 1974 to December 1994. DALSA was founded in 1980 and was originally involved in performing contract R&D work for other firms. In the late 1980's, DALSA adopted a "business strategy to focus on developing and expanding standard product lines of high performance CCD image sensor silicon chips and electronic cameras" (DALSA, 1996, p. 8).

Certicom Corp. ("Certicom") is a start-up that commercialized elliptical curve cryptography technology. Dr. Scott Vanstone was involved in the founding of Certicom. Dr. Vanstone is a Professor of Combinatorics and Optimization in the Faculty of Mathematics at the University of Waterloo. Certicom was founded in 1985 as a research and development company to develop a high speed cryptographic integrated circuit for Newbridge Networks. In 1993, Certicom "decided to emphasize the provision of OEM cryptographic technologies based on ECC to major vendors of computing and communications products" (Certicom, 1998, p. 10).

Senesco Technologies, Inc. ("Senesco") is a start-up involved in commercializing a lipase gene that controls the aging of plants. Senesco was founded in 1998 to commercialize this technology discovered by Dr. John Thompson. Dr. Thompson is a Professor of Biology in the Faculty of Science at the University of Waterloo.

Table 6.1 Summary of key information about the three start-ups

Information category	*DALSA*	*Certicom*	*Senesco*
Technology commercialized	Image capture charge-coupled device (“CCD”) technology (Note 1)	Elliptical curve cryptography (“ECC”) (Note 2)	Lipase gene which controls the aging (senescence) of plants (Note 3)
Primary inventor and founder of start-up	Dr. Savvas Chamberlain / University of Waterloo (Note 1)	Dr. Scott Vanstone / University of Waterloo (Note 2)	Dr. John Thompson / University of Waterloo (Note 3)
Date of start-up formation	1980. Originally involved in performing contract R&D work. In the late 1980’s, DALSA began to develop products incorporating CCD technologies. (Note 1)	1985. Originally founded as a R&D company. In 1993, Certicom began to focus on commercializing ECC technologies (Note 2)	1998 (Note 3)
Method of commercialization	DALSA designs, develops, manufactures and markets image sensor and electronic camera products based on the technology (Note 1)	Licensing of the technologies covered by Certicom’s patent portfolio to firms who build their own products based on the technologies (Note 4)	Licensing of Senesco’s technology to firms dealing in specific application areas who conduct further technological development and market and distribute products incorporating Senesco’s technology (Note 5)

Notes: Sources of information:

1. DALSA Corporation, Initial Public Offering and Secondary Offering prospectus dated May 10, 1996.
2. Certicom Corp., Additional Offering prospectus dated January 14, 1998.
3. Senesco Technologies, Inc., Proxy Statement in connection with reverse take over of Nava Leisure USA, Inc. dated January 8, 1999.
4. Certicom Corp., Renewal Annual Information Form dated September 3, 2004.
5. Senesco Technologies, Inc., 2004 Annual Report.

6.1.1 Transfer of technologies to the start-ups

The University of Waterloo has an 'inventor owns' intellectual property policy. Specifically, the University's Policy 73 states that "ownership of rights in IP created in the course of teaching and research activities belong to the creator(s)" (University of Waterloo, 2000). Consequently, transfer of intellectual property rights from the university to the start-ups is not required as it is at universities with a 'university owns' intellectual property policy. Nonetheless, the start-ups still have a need to obtain the rights to the technologies from their inventors. In the cases of DALSA and Certicom, a search of the United States Patent and Trademark Office patent databases conducted on July 20, 2005 identified seven patents with Dr. Chamberlain as an inventor that had been assigned to DALSA and 32 patents with Dr. Vanstone as an inventor that had been assigned to Certicom. In the case of Senesco, the start-up's 1999 proxy statement indicates that "by assignment dated June 25, 1998 …, Dr. Thompson and Meesrs. Hong and Hudak assigned all of their rights in and to the Patent Application … with respect to the invention and/or improvements thereto to Senesco" (Senesco, 1999, p.6). Thus each start-up has acquired rights to the technologies from their inventors.

6.1.2 Approaches taken to the commercialization of the technologies by the start-ups

In its 1996 Initial Public Offering prospectus, DALSA described its business as the "design, development, manufacture and marketing of image sensor and electronic camera products" (DALSA, 1996, p. 4). In commercializing its technology, DALSA designed a number of standard sensor and camera products, created a manufacturing facility in Waterloo, developed distribution channels to service customers in North America, Europe and the Asia-Pacific region, and formed a team to market its products (DALSA, 1996).

In 1998, Certicom's description of its business was that Certicom "develops and markets cryptographic algorithms and licenses cryptographic software and integrated circuits to manufacturers of equipment and software" (Certicom, 1998, p. 4). Certicom developed cryptographic and information security protocol toolkits to help other firms integrate Certicom's security features into their products (Certicom, 2004a). Certicom also developed systems integration consulting and development support capabilities as well as selling and marketing capabilities to support the commercialization of its technology (Certicom, 1998).

In 2004, Certicom adopted a new strategy for commercializing its technology. “Certicom’s Intellectual Property Licensing Program provides licenses to organizations that have implemented or are wishing to implement the technologies covered in Certicom’s extensive patent portfolio” (Certicom, 2004b, p. 7). Under this strategy, Certicom grants other firms licenses to its portfolio of patents. These firms then have the flexibility to build their own security products using Certicom’s technologies.

Senesco’s strategy is “to follow a … commercialization strategy that involves the licensing of our technology to business partners for the purpose of further technological development, marketing and distribution … who will pay us royalties when they market and distribute products incorporating our technology upon commercialization” (Senesco, 2004, p. 33). This approach means that Senesco does not need to develop manufacturing, marketing or selling capabilities and was adopted “so that we can direct our resources to what we do best: further understanding the role of Factor 5A [its patented technology]” (Senesco, 2004, p. 4).

6.2 Analysis

This section contains two analyses of information related to the three start-ups. The first compares the start-ups on the basis of criteria developed for the build, rent and sell governance structures. The second analysis looks at differences in the nature of the business operations of the three start-ups.

6.2.1 Comparison of the three start-ups in relation to specified criteria

This section compares the three start-ups using the criteria for distinguishing between the build, rent and sell governance structures developed in chapter 3. These criteria include who commercializes the technology and who retains the risks and benefits of ownership related to the technology. Detailed motivation for the choice of these criteria is given in section 3.5. Table 6.2 summarizes the analysis of the three start-ups in relation to the criteria.

Table 6.2 Comparison of start-ups in relation to specified criteria

Criteria	*DALSA*	*Certicom*	*Senesco*
Who commercializes the technology?	DALSA Start-up operates in product market	Other established firms: National Security Agency, General Dynamics, Pitney Bowes and Research In Motion Start-up operates in market for technologies	Other established firms: ArborGen, Cal/West, Rahan Meristem, Harris Moran, The Scotts Company and the Broin Companies Start-up operates in market for technologies
Rights of ownership of technology			
Right to use the technology	DALSA retains all rights to use the technology and to prevent others from using the technology	Certicom retains the right to use the technology and to license to other firms Licensees have limited rights to use the technology. Licensees do not have the right to prevent others from using the technology	Senesco has given up the right to use its technology in certain fields Licensees have acquired the right to use the technology in certain fields and to prevent others from using the technology in these fields
Right to appropriate returns from the technology	DALSA retains all of the rights to appropriate returns from the technology	Certicom's returns from licensees are limited to the contractually determined amounts though it can appropriate additional returns from licensing to other firms Licencees obtain the residual returns from selling products based on the technology	Senesco's returns in the fields covered by the licenses are limited to the contractually determined amounts Licencees obtain the residual returns from selling products based on the technology in the specified fields of use
Right to change the technology's form or substance	DALSA retains all rights to change the technology's form or substance	Certicom retains all rights to change the technology's form or substance	Senesco retains rights to improvements in the technology but not to inventions developed by the licensee during commercialization

6.2.1.1 Who commercializes the technology

“Commercialization is the production, manufacturing, packaging, marketing, and distribution of a product that embodies an innovation” (Rogers, 1995, p. 143). Using this definition of commercialization, it is clear that DALSA itself commercializes the CCD technology that it controls. The previous sections contain evidence demonstrating that DALSA has developed sensor and camera products and that it manufactures, markets and distributes these products to its customers.

Under Certicom’s current primary strategy of intellectual property licensing, it is other established firms that commercialize the ECC technologies on which the company is based. As described previously, these other established firms acquire the right to use Certicom’s patented technology in order to develop their own products. Established firms that use Certicom’s technology to develop their own products include the United States National Security Agency, General Dynamics, Pitney Bowes and Research In Motion (Certicom, 2005).

Likewise, in Senesco’s case, it is other established firms that commercialize the gene technology on which the company is based. Established firms license Senesco’s technology in order to develop specific crops incorporating Senesco’s technology. These established firms include “ArborGen for forestry products, Cal/West for alfalfa, Rahan Meristem for bananas, Harris Moran for lettuces and melons, The Scotts Company for turf and ornamentals and the Broin Companies for ethanol” (Senesco, 2004, p. 4).

These differences in whether the technology is commercialized by the start-up or by other established firms reflect fundamental differences in the commercialization strategies of the start-ups. Start-ups that commercialize products themselves operate in the ‘product market.’ Conversely, start-ups that execute “agreements with other firms—usually incumbents—who serve as conduits for commercializing technology to the product market” (Gans and Stern, 2003, p. 336) operate in markets for technology. Using these classifications, DALSA operates in the product market while Certicom and Senesco operate through markets for technology.

6.2.1.2 Rights of ownership of the technology

This section examines three specific rights related to the ownership of the technology. These rights are 1) the right to use the technology, 2) the right to appropriate returns from the technology and 3) the right to change the technology's form or substance. These criteria are based on the concept of property rights discussed in section 3.5.

6.2.1.3 Right to use the technology

DALSA retains all of the rights to use its technology and exercises these rights through the production of products based on the technology. Through its patents, DALSA has ability to prevent others from using its technology.

Certicom has licensed some of the rights to use its technology to other parties. For example, Certicom has granted the United States National Security Agency a non-exclusive worldwide license to use Certicom's ECC intellectual property (Certicom, 2003). The licensees obtain the right to use the technology under these arrangements though these rights are limited by the terms of the agreement. For example, the licensees do not have the right to prevent others from using the technology. In addition, Certicom retains the right to use the technology itself. It exercises this right through sale of internally developed products and through the licensing of the technology to other firms. For example, Certicom has licensed some of the same technology it licensed to the National Security Agency to Research In Motion Limited (Certicom, 2004).

Senesco has also licensed some of the rights to use its technology to other parties. For example, Senesco has granted The Scotts Company ("Scotts") the exclusive right to use its technology in the fields of garden plants, potted plants and turf grass (Senesco, 2004b). This license covers the period until the expiration of the last of Senesco's patents involved in the agreement. Scotts has acquired the rights to use the technology in the specified fields and to exclude others from using the technology in these fields. Senesco has given up the right to use the technology in these fields though it retains the right to use the technology in other fields.

6.2.1.4 Right to appropriate returns from the technology

DALSA retains all of the rights to appropriate returns from the technology. It exercises this right through the sale of products based on the technology and retains all of the profits resulting from the sale of the products.

Certicom appropriates returns from its technology through its intellectual property licensing agreements. Certicom's returns from licensees are limited to the contractually determined amounts though it can appropriate additional returns from licensing to other firms. The licensees obtain the residual returns from selling products based on the technology (i.e., the profit resulting from the sale of the products after paying the contractually agreed amounts to Certicom).

Senesco's returns in the fields covered by the licenses are limited to the contractually determined amounts. These contractually determined amounts include benchmark payments payable on the meeting of conditions set out in the contract and a royalty of a fixed percentage of net sales of products developed and sold by the licensee (Senesco, 2004b). Senesco can appropriate no returns other than those specified in the licensee agreement in the specified areas of use. The licensees have obtained the right to appropriate all returns from the technology in the specified fields of use after paying the contractually agreed amounts. Senesco can appropriate additional returns from the technology only by licensing rights to use the technology in other fields of use.

6.2.1.5 Right to change the technology's substance or form

DALSA retains all rights to change the technology's substance or form (e.g., to develop and patent improvements or enhancements to the technology). Certicom's non-exclusive licenses of its intellectual property suggest that Certicom has given the licensees the rights to use its technology but not the right to own improvements or enhancements of the technology.

Senesco's license to Scotts provides that Senesco will own modification or improvements to Senesco's technology made by Scotts (Senesco, 2004b). However, any inventions by Scotts developed during the commercialization process will belong to Scotts. Consequently, Senesco's rights to changes in the technology are limited to the basic technology and do not extent to new inventions in the field of use set out in the agreement.

6.2.1.6 Summary of rights of ownership of the technology

The three start-ups have very different levels of interest in the risks and benefits of ownership of technology. DALSA has retained substantially all of the rights of ownership discussed in this section. Certicom has transferred limited rights to the use of and returns from the technology to its licensees. Nonetheless, Certicom has retained the primary rights of ownership to its technology. Conversely, Senesco has transferred the primary rights of ownership to its technology to its licensees in the specific fields covered by the liceneses. Senesco's rights of ownership to its technology apply primarily to fields of use not covered by its license agreements.

The difference between Certicom's and Senesco's situations is analogous to the difference between an owner of a residential building who rents apartments and one who sells condominium units. The property owner who rents apartments gives tenants limited rights to use his/her property but retains the primary rights to the property. The property owner who sells condominium units transfers the primary rights to the unit to the buyer. Certicom's situation is analogous to the property own who rents out his property while Senesco's situation is analogous to the property owner who sells units in his/her building to others.

6.2.1.7 Methods used to commercialize the technology

Based on the analysis in this section and using the criteria developed in section 3.5, DALSA has used a build governance structure to commercialize its technology since it is a new firm, DALSA, that commercializes the technology and this new firm has ownership of the property rights to the technology. Certicom has used a rent governance structure to commercialize its technology since it is established firms that commercialize the technology but the majority of the property rights are retained by a firm, Certicom, created by the inventor to market the technology to established firms. Senesco has used a sell governance structure to commercialize its technology since it is established firms, rather than Senesco, that commercialize the technology and these established firms have acquired the majority of the property rights to the technology in the fields of use where the technology is commercialized.

6.2.2 Nature of business operations

This section analyses the nature of the business operations of each of the start-ups. Two elements of the nature of business operations are considered. The first is the method used by the start-up to appropriate returns from the technology. Inventing a successful new technology that provides significant value to customers is necessary for the successful commercialization of a new technology. But it is not enough. The gains from a new technology often go to competitors who imitate the technology, customers or suppliers of the complementary assets needed to commercialize the technology (Teece, 1986). Therefore, successful commercialization also involves finding a way to appropriate enough of the gains from the new technology to make the commercialization effort worthwhile (Winter, 2000). The second element is the nature of core activities undertaken by the start-up. The commercialization of a technology requires a number of capabilities in addition to the technology itself. These capabilities include manufacturing, marketing, distribution and service activities (Teece, 1986). This section identifies which of these core activities are conducted by the start-ups versus which are conducted by other firms. Table 6.3 summarizes the results of these analyses.

Table 6.3 Nature of business operations of the start-ups

Characteristic	*DALSA*	*Certicom*	*Senesco*
Method of appropriating returns from technology	Standard product sales (Note 1)	Royalties from nonexclusive licensing of technology (Note 2)	Nonrefundable upfront license fees, milestone payments and royalty payments from exclusive licensing of technology (Note 3)
Commercialization activities undertaken by the start-up	Research and development Manufacturing Marketing Sales and distribution (Note 1)	Research and development (Note 2)	Research and development (Note 3)

Notes: Sources of information:
1. DALSA Corporation, 2004 Annual Report.
2. Certicom Corp., 2004 Annual Report.
3. Senesco Technologies, Inc., 2004 Annual Report.

6.2.2.1 Method of appropriating returns from technology

DALSA earns returns on its technology primarily through sales of standard products based on the technology. In 2004, standard product sales produced revenues of $159m representing 94% of the company's total revenue (DALSA, 2004).

Under its Intellectual Property Licensing Program, Certicom earns returns on its technology through royalties from licensing its technology to other firms. These licensing agreements generally give the licensees non-exclusive rights to use Certicom's patented technologies (Certicom, 2004a). In 2004, royalties from technology licenses produced revenues of $25m representing 72% of the company's total revenue (Certicom, 2004a).

Senesco licenses its technology on a crop by crop basis and earns returns on its technology from:

- nonrefundable upfront license fees received in exchange for the transfer of the technology to the licensee;
- milestone payments contingent on the achievement of certain research goals; and
- royalty payments on the commercial introduction of products using Senesco's technology.

These licensing agreements are generally worldwide exclusive rights to use Senesco's patented technologies for a specific crop. In 2004, earned US$16,667 in nonrefundable upfront license fees representing 100% of the company's total revenue (Senesco, 2004).

In summary, DALSA derives its revenues from product market activity while Certicom and Senesco derive their revenues from technology market activity. These findings are consistent with Hypotheses 1a: The build option is positively associated with new firms created to commercialize technologies deriving revenue primarily from product market activity and 1b: The rent and sell options are positively associated with new firms created to commercialize technologies deriving revenue primarily from technology market activity.

6.2.2.2 Operating activities

DALSA designs, develops, manufactures, markets and sells products based on its technology. In 2004, the costs of manufacturing it standard products were $88m representing 63% of its total operating costs. Research and development expenditures totaled $23m representing 16% of its total operating costs. The cost of marketing and selling activities are not separately broken out in DALSA's financial statements but are part of a $26m expense category (DALSA, 2004). Thus DALSA is directly involved in all of the activities involved in commercializing its technologies.

In the case of Certicom's Intellectual Property Licensing Program, Certicom has undertaken the research and development activities necessary develop its patent portfolio. Once the patents are licensed, Certicom has "no continuing obligations" (Certicom, 2004a, p. 27) related to the licenses. The licensee is responsible for developing products based on the technology and manufacturing, marketing and selling those products.

Senesco is similar to Certicom in that it undertakes research and development activities but not the other activities involved in the commercialization of its technology. Senseco develops partnerships with other firms who take on further technological development, marketing and distribution of products based on Senesco's technology (Senesco, 2004, p. 4).

In summary, DALSA is involved in both technology development activities and production activities while Certicom and Senesco are involved in technology development activities but not production activities. This finding is consistent with Hypotheses 2a: The build option is positively associated with new firms created to commercialize technologies expending significant resources on both technology development activities and production activities and 2b: The rent and sell options are positively associated with new firms created to commercialize technologies expending significant resources on technology development activities but not on production activities.

6.3 Discussion

6.3.1 Limitations

The analyses above are based examination of only three firms. These three firms were selected because of the differences in their approach to the commercialization of new technologies rather than to be a representative sample of start-up firms involved in the commercialization of new technologies arising from university research. For these reasons, while the findings are consistent with Hypotheses 1a, 1b, 2a, and 2b, they cannot be considered strong evidence in support of the hypotheses. The findings may also not be generalizable to other firms. These issues are addressed in part by the broader sample in Study #2. In addition, these analyses are based on archival data sources and it is not possible to gather information about the technology attributes that are involved in Hypotheses 3 through 8 from these sources. Consequently, no evidence concerning these hypotheses is provided by this study. This issue is addressed in part by Study #3 which involves gathering information about technology attributes through a survey of inventors.

6.3.2 Implications

The above analyses highlight a number of important considerations related to start-ups that commercialize new technologies arising from university research. The first is that start-ups can have very distinctive approaches to commercialization. DALSA's approach of building a business that manufactures and sells products based on the new technology is the conventional one most often thought of when commercialization through start-ups is discussed. However, Certicom and Senesco have taken different approaches to commercialization. Neither manufactures and sells products based on their technology. Rather they operate in markets for technology where they sell rights to use their technology to other firms who manufacture and sell products based on the technology. These differences suggest that there may be important differences between start-ups that are not accounted for when all start-ups are grouped together and considered a single method of commercialization.

Secondly, even though all three firms reflect situations where a start-up was involved in the commercialization of a technology, in two of the three cases (Certicom and Senesco) the situations also involved the subsequent licensing of the technology to established firms. This finding suggests that the traditional method of analyzing the commercialization of technologies arising from university research as either start-up *or* licensing do not reflect the variety of approaches to commercialization actually found in practice. Related to this is the finding that the method used to transfer an innovation out of a university may not reflect the method used to commercialize the technology. In the cases of both Certicom and Senesco, start-up firms were used to transfer the technology out of the university environment and into the commercial one. However, the actual commercialization of the technology was done by established firms who licensed the technologies from Certicom and Senesco respectively. This finding suggests that classifying the method used to commercialize a technology based on the method used to transfer the innovation out of the university may not reflect the actual method of commercialization.

Thirdly, there are significant differences in the nature of the operations of the three firms. DALSA is organized to provide a full range of operating activities from research and development, through product development, manufacturing, marketing and distribution of products based on the technology. Certicom and Senesco have much more limited operating activities focused primarily on research and development activities related to developing the technology involved. An important finding is that differences in the nature of operations of these start-ups are reflected in the nature of the revenues the start-up receives and in the types of operating expenses it incurs. This finding is used in Study #2 to analyze a larger sample of start-ups.

6.4 Summary

In summary, this tale of three start-ups supports the concerns raised in section 3.1 about the licensing vs. start-up dichotomy for analyzing the commercialization of new technologies arising from university research. It also provides some support for the build, rent and sell classification of governance structures proposed in chapter 3. Further, the findings of this study are consistent with Hypotheses 1a, 1b, 2a and 2b.

Chapter 7

Results Study #2 – An Examination into the Nature of Business Activities of Public Start-up Firms

This chapter presents the results of the examination of the nature of the business activities of public start-up firms involved in the commercialization of new technologies arising from university research. The purposes of this examination are 1) to demonstrate that the criteria identified in chapter 3 can be applied effectively in practice to classify the method used to commercialize a new technology arising from university research, 2) to demonstrate that the build, rent and sell methods are all common approaches to commercialization, and 3) to demonstrate that there are substantive differences in the business activities of firms depending on the method of commercialization used.

7.1 Results

This study uses two separate samples of public start-up firms that have commercialized new technologies arising from university research. The first sample is of Canadian companies built on National Sciences and Engineering Research Council of Canada ("NSERC") funded research. The second sample is of U.S. companies built on research conducted at the Massachusetts Institute of Technology ("MIT"). Tables 7.1 and 7.2 list the firms and the years they were founded.

Table 7.3 contains demographic information on the firms. Average revenues and total operating costs are broadly comparable between the Canadian and U.S. samples although the U.S. firms are somewhat larger. In both samples, there is significant variability in revenues and operating costs between the individual firms. The industries in which these firms operate were classified as either life sciences or physical sciences. Life sciences firms are primarily involved in biotechnology and pharmaceuticals. Physical sciences firms are primarily involved in electronics and software. Approximately one half of the firms are involved in life sciences and one half in physical sciences in both the Canadian and U.S. samples.

Table 7.1 Canadian start-up firms and years of founding

Firm name	*Year of founding*
AD OPT Technologies Inc.	1987
Advitech Inc.	1996
BioChem Pharma Inc.	1986
Biomira Inc.	1985
Biorem Technologies Inc.	1990
Cell-Loc Location Technologies Inc.	1995
Certicom Corp.	1985
DALSA Corporation	1980
Forbes Medi-Tech Inc.	1993
GeneMax Corp.	1999
Innova LifeSciences Corporation	1992
Innovotech Inc.	1996
Kipp &Zonen Inc.	1981
Lumenon Innovative Lightwave Technology, Inc.	1998
MacDonald, Dettwiler and Associates Ltd.	1969
Micrologix Biotech Inc.	1993
Millenium Biologix Corporation	1992
Nexia Biotechnologies Inc.	1993
NTI Newmerical Inc.	1998
Open Text Corporation	1991
Polyphalt Inc.	1992
Prescient NeuroPharma Inc.	1992
QLT Inc.	1981
SatCon Technology Corporation	1980
SemBioSys Genetics Inc.	1994
TIR Systems Ltd.	1982
TurboSonic Technologies, Inc.	1976
Virtek Vision International Inc.	1986
Westport Innovations Inc.	1995
Wi-LAN Inc.	1992
ZENON Environmental Inc.	1980

Notes: Some firms have changed names over time. The most current names are listed in this table. Years of founding for the Canadian start-up sample come from *Research Means Business* (NSERC, 2002).

Table 7.2 U.S. start-up firms and years of founding

Firm name	*Year of founding*
Algos Pharmaceutical Corporation	1992
Alpha-Beta Technology, Inc.	1988
American Superconductor Corporation	1987
ARIAD Pharmaceuticals, Inc.	1991
Aspen Technology, Inc.	1981
Aware, Inc.	1986
Axys Pharmaceuticals, Inc.	1989
Cambridge Heart, Inc.	1990
Cirrus Logic, Inc.	1984
Cubist Pharmaceuticals, Inc.	1992
Electronics for Imaging Inc.	1989
GelTex Pharmaceuticals, Inc.	1991
ImmuLogic Pharmaceutical Corporation	1987
Indevus Pharmaceuticals, Inc.	1988
Integra LifeSciences Holdings Corporation	1989
Kopin Corporation	1984
Matritech, Inc.	1987
Open Market, Inc.	1993
Organogenesis Inc.	1985
Soligen Technologies, Inc.	1991
Somatix Therapy Corporation	1991
SpectraScience, Inc.	1983
Stressgen Biotechnologies Corporation	1990

Notes: Some firms have changed names over time. The most current names are listed in this table. Years of founding for US start-up sample come from company Annual Reports filed on Form 10K, company websites or Standard & Poor's Stock Report for the company.

Table 7.3 Total revenues, total operating costs and industry classification of the start-up firms

Characteristic		*Mean*	*s.d.*	*n*	*%*
Total revenues:	Canadian sample	77,628,629	158,953,727		
	U.S. sample (in Cdn$)	87,279,582	144,661,405		
Total operating costs:	Canadian sample	66,701,127	132,920,839		
	U.S. sample (in Cdn$)	117,558,186	145,286,377		
Industrial classification					
Life sciences:	Canadian sample			13	42
	U.S. sample			12	52
Physical sciences:	Canadian sample			18	58
	U.S. sample			11	48

7.1.1 Method of commercialization

Table 7.4 summarizes the results of the analysis of the methods of commercialization for the start-up firms. The start-ups were classified using the methods described in section 5.3.3.1. The build method of commercialization was the most frequently observed method of commercialization among the start-ups (50%). The rent and sell methods of commercialization were observed less frequently. Nonetheless, they are important methods representing in total 13% of the start-ups examined and 18% of those that have emerged from development stage. As indicated in section 3.1, little attention has been paid in the literature on university technology transfer to these start-ups that compete through the market for technologies rather than through the product market. Hybrids represent 7.4% of the start-ups examined. Hybrids reflect situations where commercialization of the technology involves the combined efforts of both the startup and an established firm(s). For example, the technology may have been commercialized through a joint venture or partnership with an established firm with the startup contributing manufacturing capabilities and the established firm contributing marketing and distribution capabilities to the joint venture. As described in section 2.6.1, hybrids represent governance structures that fall between markets and hierarchies. The development stage start-ups (29.6%) represent firms whose technologies had not yet been put into commercial use.

Table 7.4 Methods used to commercialize technologies

Method used	*Canadian start-ups*		*U.S. start-ups*		*Total*	
	n	*%*	*n*	*%*	*n*	*%*
Build	16	51.6	11	47.8	27	50.0
Rent	3	9.7	1	4.3	4	7.4
Sell	1	3.2	2	8.7	3	5.6
Hybrid	2	6.5	2	8.7	4	7.4
Development stage	9	29.0	7	30.4	16	29.6
Total	31	100.0	23	100.0	54	100.0

7.1.2 Business activities of the start-up

Table 7.5 summarizes the means, standard deviations and correlations between the four measures of business activities used in this study. These measures are defined in section 5.3.2.

One of the objectives of this study is to demonstrate that there are substantive differences in the business activities of firms depending on the method of commercialization used. Cluster analysis is a technique for grouping items in a population based on the characteristics they possess (Hair et al., 1998). Cluster analysis has the benefit that it does not depend on the normality, linearity and homoscedasticity of the data that many other techniques rely on. This is important because the data on business activities have nonnormal distributions. Criticisms of cluster analysis are that it is descriptive, uses no theoretical basis for clustering the data and does not provide a statistical basis for drawing inferences (Hair et al, 1998).

Acknowledging these limits of cluster analysis, it is, nonetheless, well suited for identifying differences in the business activities of the start-ups.

Table 7.5 Descriptive statistics and correlation matrix for business activity measures (*N* = 54)

	Business activity measures	*Mean*	*s.d.*	*1*	*2*	*3*
1	Product market activity	.59	.46			
2	Technology market activity	.17	.32	-.53		
3	Technology development activity	.32	.25	-.74	.43	
4	Production activity	.26	.24	.84	-.45	-.74

Cluster analysis was run separately on the Canadian and U.S. data as a test of the validity of the cluster solutions (Hair et al., 1998). As a first step, both samples were analyzed using the Ward's linkage hierarchical method in SPSS. Based on a review of the agglomeration coefficients and dendrograms, a three-cluster solution proved to be the simplest and most appropriate structure in both cases. To fine-tune the cluster analysis, both samples were analyzed using the quick cluster nonhierarchical method in SPSS. The two analyses produced clusters with very similar cluster centers. These results support the validity of the cluster solutions. Since the results are very similar, the samples were combined and the analyses repeated on the combined sample. The results that follow are from the combined samples. Two items in the Canadian sample had missing data and were excluded from the analyses resulting in a sample size of 52.

Table 7.6 reports the number of items in each cluster and the cluster centers for each variable. Also reported is an *F* value reflecting the ratio of between-cluster variation to within-cluster variation. Due to the nature of cluster analysis, these *F* values are considered descriptive rather than as measures of statistical significance (Hair et al., 1998). Nonetheless, these *F* values suggest a very good overall fit to the cluster model. Figures 7.1 and 7.2 are plots of the start-ups on the two market measures and the two resources measures respectively. Figure 7.1 demonstrates very clear differences between the clusters in relation to the product market activity and technology market activity measures. The differences between clusters in Figure 7.2 are less pronounced but still show difference between the clusters in relation to the technology development activity and production activity measures.

Table 7.6 Cluster analysis for combined sample (*N* = 52)

Variable	*Cluster 1*	*Cluster 2*	*Cluster 3*	*F value*
Number of start-ups in cluster	30	10	12	
Product market activity	.97	.14	.01	588.11*
Technology market activity	.01	.75	.02	348.78*
Technology development activity	.18	.52	.52	22.03*
Production activity	.43	.05	.02	56.13*

Note: * $p < .001$

Figure 7.1 Cluster membership by market measures

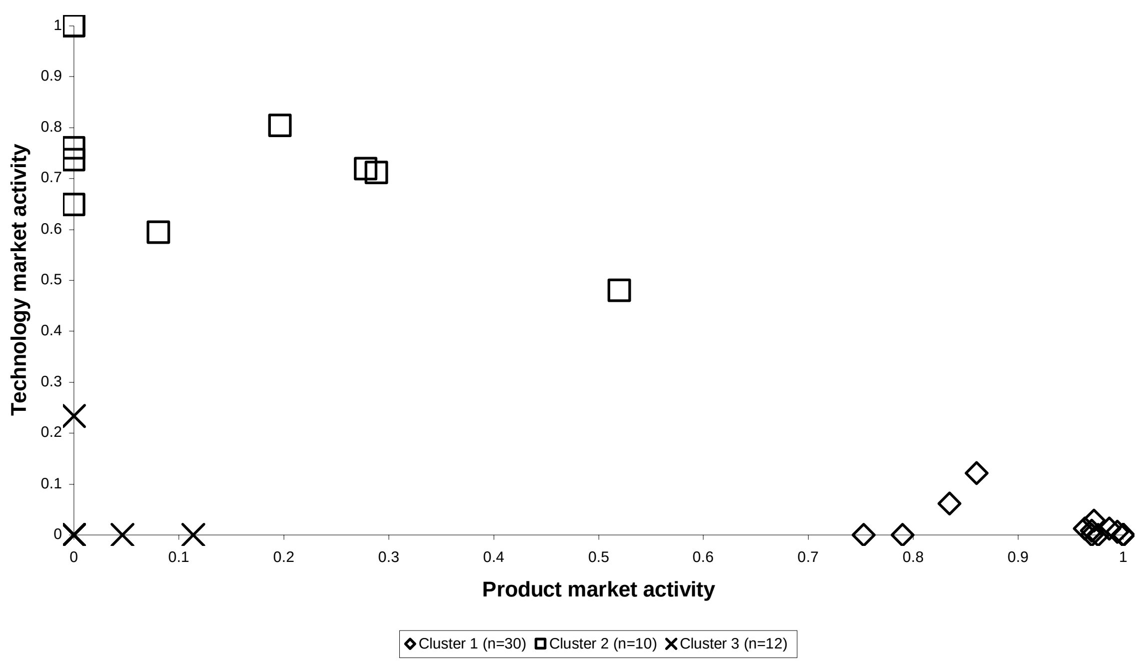
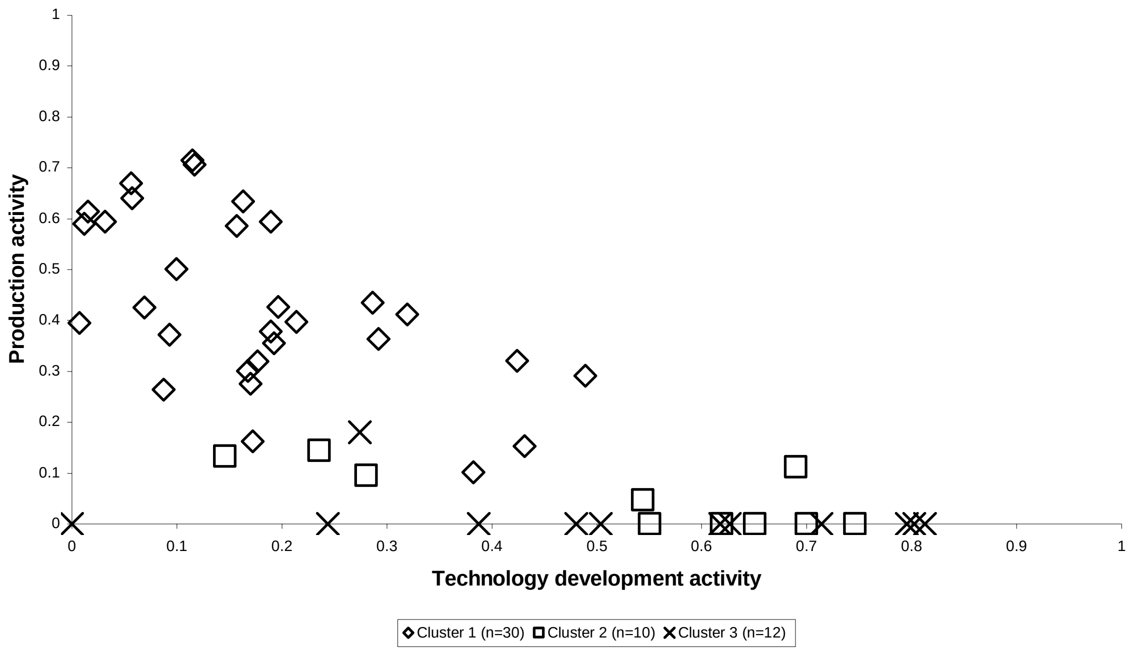


Figure 7.2 Cluster membership by resource measures



7.1.2.1 Characterization of the three clusters

Start-ups in Cluster 1 are firms that operate almost exclusively in product markets with little activity in markets for technology. They also expend a significant amount of their resources on production activities and a more limited amount of their resources on technology development activities.

Start-ups in Cluster 2 are firms that operate primarily in markets for technology with limited activity in product markets. They expend the majority of their resources on technology development activities and a very limited amount of resources on production activities.

Start-ups in Cluster 3 are firms that are not yet active in either product markets or markets for technology. Like start-ups in Cluster 2, they expend the majority of their resources on technology development activities and virtually none on production activities. These characterizations serve to illustrate the substantive differences in the business activities of firms in the three clusters.

7.2 Comparison of methods of commercialization with cluster analysis

Table 7.7 contains a comparison of the results of the analysis of the methods of commercialization with the results of the cluster analysis.

Table 7.7 Comparison of methods of commercialization with cluster analysis

Method of commercialization	*Cluster 1*	*Cluster 2*	*Cluster 3*	*Missing data*	*Total*
Build	26	0	0	1	27
Rent	0	3	0	1	4
Sell	0	3	0	0	3
Hybrid	3	1	0	0	4
Development stage	1	3	12	0	16
Total	30	10	12	2	54

The hypotheses related to governance choices and firm characteristics are:

> H1a: The build option is positively associated with new firms created to commercialize technologies deriving revenue primarily from product market activity.
>
> H1b: The rent and sell options are positively associated with new firms created to commercialize technologies deriving revenue primarily from technology market activity.
>
> H2a: The build option is positively associated with new firms created to commercialize technologies expending resources on

> both technology development activities and production activities.
>
> H2b: The rent and sell options are positively associated with new firms created to commercialize technologies expending resources on technology development activities but not on production activities.

As indicated in section 7.1.2.1, Cluster 1 characterizes firms that derive revenue primarily from product market activity and expend resources on both technology development activities and production activities. Cluster 2 characterizes firms that derive revenue primarily from technology market activity and expend resources on technology development activities but not on production activities. Consequently, these hypotheses can be reframed as considering whether there is an association between firms using the build method of commercialization and the characteristics of firms in Cluster 1 and between firms using the rent or sell methods of commercialization and the characteristics of firms in Cluster 2. The Fisher exact test for the 2x2 table (build vs. rent or sell, Cluster 1 vs. Cluster 2) is highly statistically significant ($p < .001$). Thus, hypotheses H1a, H1b, H2a and H2b are supported.

7.3 Conclusions

7.3.1 Limitations of the study

This study is subject to a number of limitations. First, as described earlier, the sample population may not be representative of all start-ups created to commercialize new technologies arising from university research. While NSERC funded research is an important source of new technologies, new technologies also result from university research not funded by NSERC. MIT start-ups also may not be representative of start-ups from other universities. Consequently, the results of this study may not be generalizable to all commercialized technologies arising from university research. Nonetheless, the samples represent important sources of new technologies and afford the benefits arising from having two separate samples from different countries and derived from different sources. A second limitation is that the variables used in the cluster analysis are not sensitive to differences between the rent and sell methods of commercialization. The cluster analysis is based on accounting data and this data does not address the issues of ownership of property rights to the technology that distinguish between the rent and sell methods. Future research can attempt to identify an additional variable(s) that capture these differences and can be used to distinguish between the two methods. A third limitation of the study is that the analysis does not capture all ways that the sell method can be implemented. The analysis in this chapter uses financial statement information. Financial statements capture situations where rights to a technology are transferred to an established firm by way of a transaction between the start-up and the established firm. They do not, however, capture situations where the established firm acquires the technology by acquiring the start-up. In the course of performing this study, three situations were identified where established firms acquired a technology indirectly by acquiring the start-up while it was still in the development stage.

7.3.2 Implications

This study has a number of implications for examining the commercialization of new technologies arising from university research. First, it demonstrates that the criteria developed in chapter 3 to distinguish between the build, rent and sell categories can be applied to actual commercialization situations. This is important as it demonstrates that the build, rent and sell categorization scheme is not only theoretically based but also is a practical tool for looking at the actual commercialization of specific technologies.

Second, it demonstrates that the build, rent and sell methods of commercialization are all frequently occurring methods of commercialization. This is important since theoretically derived categories might describe situations that are theoretically possible but do not occur in actual practice. This analysis has shown that the build, rent and sell methods of commercialization do, in fact, occur in actual practice.

A third implication is that the build, rent and sell categorization scheme identifies substantive differences in the operating activities associated with commercialization of a new technology. Significant differences were identified in the markets in which the firms operate and in how they allocate their resources. This is important since it demonstrates that the differences between the build, rent and sell methods of commercialization are not subtle distinctions but rather reflect substantive differences in how the firms operate.

7.3.3 Summary

The study in this chapter demonstrates that build, rent and sell are common and viable approaches to commercialization and that there are substantive differences between the approaches. In doing so, it provides evidence as to the validity of the build, rent and sell categorization approach. The next chapter builds on the findings in this and the preceding chapter using the build, rent and sell categorization approach to examine whether characteristics of technologies affect the methods used to commercialize the technologies.

Chapter 8
Results Study #3 – Survey of academic inventors

This chapter contains the results of the survey of academic inventors. The primary purpose of this study was to examine the connection between the characteristics of a new technology and the method used to commercialize the technology.

8.1 Demographic information

The sample consisted of 42 participants. Table 8.1 includes information about the faculty affiliation, academic rank, number of years actively involved in academic research and number of innovations put into commercial use of the participants.

The distribution of faculty affiliations is reasonably consistent with the findings of Thursby et al. (2001) whose survey of 62 U.S. universities found that the most common affiliations of inventors were medical schools (33% of inventions), engineering (29%) and science (22%). Faculty from medical schools are underrepresented in this study since University #1, which is the primary source of data, does not have a medical school. This finding might suggest that life sciences technologies are not represented in the sample. However, as indicated in Table 8.2, a number of life sciences technologies are represented in the sample. These life sciences technologies were developed by faculty members in science (e.g., biology, optometry) and engineering (e.g., chemical engineering).

The academic rank and number of years actively involved in academic research of the respondents indicates a broad range of experience among those who have commercialized new technologies. While most of those who have commercialized new technologies are senior faculty members with significant experience, more junior faculty members with much less research experience are also represented.

Participants were asked how many new technologies resulting from their academic research have been put into commercial use. Faculty members reported an average of 2.5 commercialized technologies. Of those who responded to this question (n = 37), 14 respondents (38%) reported one commercialized technology, eight respondents (22%) reported two commercialized technologies and 15 respondents (41%) reported more than two commercialized technologies. The maximum number of commercialized technologies reported was ten by two respondents. The large number of respondents reporting multiple commercialized technologies suggests the existence of a class of serial commercializers among faculty members.

Table 8.1 Faculty affiliation, academic rank, experience and number of commercialized technologies of survey participants

Characteristic		*n*	*%*	*Mean*	*s.d.*
Faculty affiliation:	Engineering	21	50		
	Science	13	31		
	Mathematics	6	14		
	Other	2	5		
Academic rank:	Professor emeritus	3	7		
	Professor	24	57		
	Associate professor	9	21		
	Assistant professor	3	7		
	Other	3	7		
Number of years actively involved in academic research				24.0	10.2
Number of technologies put into commercial use				2.5	2.2

Participants were asked to identify the most significant new technology they had invented that had been put into commercial use and the remainder of the survey addressed this technology. The use of the most significant innovation of an inventor as the unit of analysis is consistent with the approach taken by both the Organisation for Economic Co-operation and Development (1996) and Statistics Canada. Table 8.2 shows information about the field of use, type and stage of development of the technologies.

Respondents were asked to provide a brief description of the new technology. These were classified by field of use. The sample covers a broad variety of fields with the most common being computer related (26%), environmental (17%) and life sciences (14%). The majority of the technologies are product innovations (64%) while the balance are primarily process innovations (31%). The information gathered on the stage of development of the technologies supports the findings of Thursby et al. (2001) that most technologies coming out of universities are at an early stage. Only 17% of the technologies were unchanged through the commercialization process. Approximately equal proportions (38%) required minor or major change and a small proportion 7% were substantially changed during the commercialization process.

Table 8.2 Field of use, type and stage of development of technologies

Characteristic		*n*	*%*
Field of use:	Computer related	11	26
	Environmental	7	17
	Life sciences	6	14
	Electronics	4	10
	Manufacturing	4	10
	Transportation	2	5
	Other	8	19
Type of technology:	Product	27	64
	Process	13	31
	Knowledge not embodied in a specific product, process or service	4	10
Stage of development:			
Technology unchanged through transfer from research environment to commercial one		7	17
Technology underwent minor change during transfer from research environment to commercial one		16	38
Technology changed significantly during transfer from research environment to commercial one		16	38
Technology put into commercial use bore little resemblance to the one that emerged from the research environment		3	7

Note: Percentages for type of technology add to more than 100% due to multiple responses.

In summary, the survey covers a broad range of faculty affiliations, researcher experience, types of technologies and stages of development. Further, the distribution of survey respondents across these categories is consistent with other research on the commercialization of new technologies arising from university research.

8.2 Independent variables

Consistent with the process set out by Churchill (1979), the reliability of the independent variable measures was assessed using the survey data. This was done by calculating Cronbach's alpha for each of the independent variables using the items listed in Table 5.1.

Two issues arose in this analysis. The first issue involves the tacitness and complexity variables. Cronbach's alpha for the tacitness and complexity variables, .40 and .37 respectively, were below the levels generally required to conclude that the measures are reliable (Hair et al., 1998). One of the items for the tacitness variable, 'The critical elements of this innovation could be easily explained to my colleagues (e.g., in a paper or at a conference),' is highly skewed (52% of participants gave responses of 5 to this item on a 5-point scale where 1 represented "Strongly disagree" and 5 represented "Strongly agree"). It also had very low correlations with the other two items for tacitness. Based on these analyses and the fact that this is an additional item developed by the author of this thesis and is not from the same source as the other two items, this item was removed from the tacitness measure. Two of the items for the complexity measure, 'This innovation was a component of a larger product, process or system' and 'A change in the design of this innovation would require compensating design changes in related components or system,' had low correlations with each other and with the other two items for complexity. Because of this and the fact that these were additional items not derived from the source used for the other two items, these items were removed from the complexity measure. The remaining items in the tacitness and complexity measures had strong correlations to each other. Based on a review of the items, it was concluded that the items reflected a single underlying construct. The complexity items were derived from Chesbrough and Kusunoki (2001) who suggest that new technologies typically begin in an 'integral' phase where the interactions between components of the system are not well understood. They suggest that only later in the development process do "standards develop that articulate and codify the interactions between elements of a system" (p. 205). The items in the measure for tacitness can reasonably be interpreted as reflecting this codification. Consequently, it is reasonable to interpret the correlations as indications that a single construct is being measured.

The second issue that arose involves the volatility and dynamism constructs. The survey included items related to technology volatility, technology dynamism, market volatility and market dynamism. The results show strong correlations between the technology volatility and market volatility items. Accordingly, these items were combined into a single volatility construct. Similarly, the results show strong correlations between the technology dynamism and market dynamism items. These items were combined into a single dynamism construct.

Table 8.3 shows the adjusted constructs and items together with the values for Cronbach's alpha. Values exceeding .70 for Cronbach's alpha are generally considered good indicators of measure reliability though lower values exceeding .60 are considered acceptable in exploratory research (Hair et al., 1998). All of the values for Cronbach's alpha exceed this lower threshold.

The measures and items used in this study come from previous research (see Table 5.1). The evidence gathered in these previous studies provides significant support for the validity of the measures. However, since the measures come from more than one previous study, there is a risk that the scales and items derived by two different authors may be measuring the same underlying construct. To test for this, an exploratory factor analysis was conducted using the 14 items listed in Table 8.3. The analysis was performed using principal component analysis with varimax rotation. Using a cut-off of eigenvalues greater than 1.0, the analysis produced a five factor solution. The five factors align with the independent variables. For each of the 14 items, the largest factor loading in the rotated solution aligned with the variable to which it was predicted to be associated. The five factors account for 73% of the variance of the 14 items. These findings provide further support for the validity of the measures.

8.2.1 Specialized complementary assets

The importance and specificity of complementary assets are addressed through two questions in the survey. The first, question 24, asked about the importance of various complementary assets for the commercialization of the technology. The second, question 25, asked whether these complementary assets need to be tailored to the technology. Each question was measured using a 5-point scale from "strongly disagree" to "strongly agree." Hypothesis H6 is concerned with complementary assets that are specialized to the technology (i.e., those that are tailored to the technology). However, if complementary assets are specialized but are not important for commercialization, they will not create contracting problems and, therefore, are

Table 8.3 Technology attribute variables and items

Variables and items	*Cronbach's alpha*
Patent or other legal protection (IP)	.61
The intellectual property protection obtained was effective in deterring imitation of the innovation	
Fundamentally similar innovations exist. (R)	
Few credible substitutes competed with this innovation.	
Tacitness/Complexity (TACCOM)	.72
Manuals and documents accurately explained the implementation and operation of this innovation. (R)	
Educating and training personnel for this innovation was a quick and easy job. (R)	
Interactions between this innovation and related components or systems were poorly understood.	
Technical information about how this innovation functions together with other components or systems was well defined. (R)	
Risk of substitutes (SUBSTITUTE)	.66
It would be easy for others to imitate this innovation.	
The 'reverse engineering' of this innovation by a competitor would be technically difficult. (R)	
Volatility (VOLATILITY)	.87
I was confident that this innovation would perform as it was originally designed.	
It was clear that this innovation would work as it was intended technologically.	
I was certain this innovation would meet user demands.	
Dynamism (DYNAMISM)	.65
Future technological breakthroughs were likely to render this innovation of little value in a short time period.	
I expected this innovation to have a relatively long life cycle. (R)	

unlikely to affect the choice of governance structure. Consequently, only specialized complementary assets that are important for the commercialization of the technology are addressed in this section. To capture important specialized complementary assets, the measure SPECCA was created. This measure has the value 1 if there was a complementary asset that was identified as both important (i.e., assessed as 5 on the 5-point scale used for question 24) and specialized (i.e., assessed as 5 on the 5-point scale used for question 25). SPECCA has a value of 0 if no complementary asset was identified as both important and specialized. In the sample, 21 (50%) items have a value of 1 for SPECCA and 21 (50%) items have a value of 0 for SPECCA. This approach to the measurement of complementary assets is similar to that used by Gans et al. (2002) who use a measure for complementary assets that is the maximum over 5-point scales measuring the importance and effectiveness of ownership of various complementary assets.

8.2.2 Control variables

Two control variables were considered in the analysis. The first is the affiliation of the faculty inventor. Previous research suggests that university differences may have an influence on commercialization (see section 2.3). The sample comes from universities in the same geographic area minimizing the impact of geographic differences. The two universities do have differing intellectual property ownership policies. University #1 has an ‘inventor owns’ policy while University #2 has a ‘university owns policy.’ Differences in intellectual property policy might influence the methods used to commercialize an innovation since individual inventors may take a wide variety of approaches to commercialization while universities may develop routines over times that tend to restrict the approaches to commercialization that they consider (Cyert and March, 1963; Simon, 1961). However, the number of sample items from University #2 ($n = 3$) is very limited and, consequently, the university affiliation of the faculty inventor is not an effective control variable. This limitation will be addressed as part of future research (see section 9.3). Within a university, differences that might affect methods of commercialization could occur at the faculty and department levels. For example, Todorovic (2004) suggests that the entrepreneurial orientation of university departments influences commercialization activity. Considering the trade off between the benefits of being more specific and the limitations of the overall sample size, the decision was made to consider the faculty level affiliation of faculty inventors as a control variable.

The second factor considered as a control variable is the stage of development of the innovation. As described in section 2.4, some researchers have suggested that the stage of development may affect the method used to commercialize an innovation.

8.2.2.1 Faculty affiliation

Table 8.4 shows the faculty affiliations of the faculty inventors in the sample categorized by whether the technologies were commercialized using the build, rent or sell option and by whether a Start-up or Licensing was involved. Fisher's exact test for the 4 x 3 table (Faculty affiliation vs. governance structure) was not significant (p = .07) though it approached significance. Examination of the table suggests that this is due to a low proportion of technologies developed by Science faculty members that were commercialized using the build option. Fisher's exact test on the 2 x 2 table (science/other faculty vs. build/other options) was significant (p = .01). This suggests that it is appropriate to control for Science affiliations when testing hypotheses related to governance structure.

Table 8.4 Faculty affiliations and methods used to commercialize innovation

Faculty affiliations	*Build*	*Rent*	*Sell*	*Total*	*Start-up*	*Licensing*	*Total*
Engineering	14	4	3	21	17	4	21
Science	3	4	6	13	5	8	13
Mathematics	5	0	1	6	6	0	6
Other	1	1	0	2	2	0	2
Total	23	9	10	42	30	12	42

Fisher's exact test on the 4 x 2 table (Faculty affiliation vs. Start-up) was also significant (p = .01). This is due to the proportion of technologies from the science faculty that involved start-ups (38%) being substantially lower than the proportion of technologies from other faculties that involved start-ups (86%). These findings suggest that it is appropriate to include a control for faculty affiliations in Science in tests involving licensing vs. start-up approaches to commercialization.

While there is no direct evidence concerning why affiliation with science faculties affects the method of commercialization, it may be that researchers in science faculties pursue more basic research than researchers in other faculties and are less likely to appreciate the potential markets for products and services based on the technology. As a result, they may be more likely to commercialize a technology by transferring it to an established firm than by creating a new firm to commercialize the technology.

8.2.2.2 Stage of development

Table 8.5 shows the stage of development of the technologies in the sample categorized by whether the technologies were commercialized using the build, rent or sell option and by whether a Start-up or Licensing was involved. Fisher's exact test for the 4 x 3 table (Stage of development vs. governance structure) was not significant (p = .57). Fisher's exact test for the 4 x 2 table (Stage of development vs. start-up) also was not significant (p = .45). Based on these findings and examination of the table, there no evidence suggesting that the stage of development has any relationship to the choice of governance structure or whether the technology was commercialized using a start-up. Thus, stage of development will not be controlled for in the tests of the hypotheses related to governance structures.

8.2.3 Dependent variable – Governance structure

The dependent variable for this study is the governance structure used to commercialize the innovation. More specifically, the dependent variable measures whether a build, rent or sell option to commercialization was adopted. The classification of governance structure is based on whether the technology was commercialized by a new firm or existing firm and on ownership of the property rights to the technology (see section 3.5). Participants were asked whether the innovation was commercialized by a newly created firm or by one or more established firms (question 29). When participants indicated that a newly created firm was involved, they were further asked whether the newly created firm produced products or services based on the innovation or whether the newly created firm marketed the innovation to other firms that produced products or services based on the innovation (question 30). When it was indicated that a new firm was created and that the newly created firm produced products or services based on the technology, the technology was assessed as having been commercialized by a new firm. In these cases, the technology was coded as having been commercialized using the build option consistent with the criteria in section 3.5. When it was indicated that a new firm was created and that the newly created firm marketed the

Table 8.5 Stage of development and methods used to commercialize innovation

Stage of development	*Build*	*Rent*	*Sell*	*Total*	*Start-up*	*Licensing*	*Total*
Technology unchanged through transfer from research environment to commercial one	3	1	3	7	4	3	7
Technology underwent minor change during transfer from research environment to commercial one	9	5	2	16	13	3	16
Technology changed significantly during transfer from research environment to commercial one	8	3	5	16	10	6	16
Technology put into commercial use bore little resemblance to the one that emerged from the research environment	3	0	0	3	3	0	3
Total	23	9	10	42	30	12	42

technology to other established firms who produced products or services based on the technology or when it was indicated that the technology was commercialized directly by established firms, the technology was assessed as having been commercialized by established firms. Ownership of the residual property rights to the technology was assessed based on whether the faculty inventor or their university held an equity ownership interest in the technology. Oxley (1999) identifies the sharing of equity as “a discrete, observable, ‘step function’ in governance attributes, effectively separating it from contractual forms. As such this is a useful ‘break point’ in the underlying market-hierarchy continuum” (p. 288). When the faculty inventor or their university held an equity interest in the technology, the technology was assessed as having been commercialized using the rent method consistent with the criteria in section 3.5. When the faculty inventor and their university did not hold an equity interest, the technology was assessed as having been commercialized using the sell method consistent with the criteria in section 3.5. Based on this method of classification, 23 sample items (55%) were classified as using the build option, nine sample items (21%) were classified as using the rent option and ten sample items (24%) were classified as using the sell option.

In this research, it is suggested that the build, rent and sell classification scheme better reflects the substance of the methods used to commercialize new technologies than the licensing vs. start-up dichotomy. In order to allow comparisons between the two classification approaches, a second dependent variable (STARTUP) was created. This variable was coded as 1 if the respondent indicated that a newly created firm was founded in response to question 29 and 0 otherwise. Based on this method of classification, 30 sample items (71%) were classified as involving the creation of a start-up.

8.2.4 Summary of independent, control and dependent variables

Table 8.6 contains the means, standard deviations and correlations for the independent, control and dependent variables described above.

8.3 Tests of hypotheses

Because the dependent variables are categorical, logistic regression was used as the primary method of testing the hypotheses. While there are three categories for the governance structure dependent variable, each of the hypotheses groups two of the categories together. For example, Hypothesis 3 is that "the greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option." When using logistic regression to test this hypothesis, the build and sell categories are combined for comparison against the rent category.

8.3.1 Patent and other intellectual property protection for the technology

Hypothesis 3 is that "the greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option." Table 8.7 show the results of logistic regressions of the patent and other intellectual property protection variable IP on the rent option vs. the build and sell options. Model 1 "explains" approximately 22% (Nagelkerke R^2) of the total variation in governance structures. Also, the model is a significantly better fit to the data (change in –2 log likelihood from base model = 6.40, $df = 1$, $p = .01$) than a model which excludes IP (i.e., one that considers only the mean). The estimated coefficient for IP is .43. This indicates that the odds of being in the rent category increase by approximately 1.5 times ($e^{.43}$) for each increase of 1 in the IP scale. This coefficient for the IP variable is statistically significant and in the predicted direction. Thus Hypothesis 3 is supported. These data were also analyzed controlling for faculty affiliation in science (see section 8.2.2). The results are shown in Table 8.7 as Model 2. Controlling for faculty affiliation in science has no significant impact on the model fit or coefficient estimates.

Table 8.6 Means, standard deviations and correlations for the independent, control and dependent variables

Variable	*M*	*s.d.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1 IP	10.30	2.98										
2 TACCOM	10.70	4.03	-.16									
3 SUBSTITUTE	5.50	2.37	-.14	-.12								
4 VOLATILITY	11.79	2.74	.32*	-.39*	-.06							
5 DYNAMISM	3.76	1.96	-.33*	-.08	.09	-.23						
6 SPECCA	.50	.51	.23	-.13	.21	.17	.03					
7 SCIENCE	.31	.47	.13	-.10	.36*	.13	-.24	-.05				
8 BUILD	.55	.50	-.14	-.03	-.24	-.04	.33*	.24	-.43**			
9 RENT	.21	.42	.35*	.18	.06	-.20	-.27	-.17	.15	n.m.		
10 SELL	.24	.43	-.17	-.14	.22	.23	-.13	-.11	.35*	n.m.	n.m.	
11 STARTUP	.71	.46	.16	.25	-.32*	-.05	.14	.11	-.49**	.70**	-.06	-.76**

Note: "n.m." indicates that these values are not meaningful as the variables represent alternative values for the primary dependent variable.
* $p < .05$
** $p < .01$

Table 8.7 also shows the results of a logistic regression on the alternative dependent variable STARTUP. This regression has substantially poorer fit than the primary model (change in –2 log likelihood from base model = 1.09, $df = 1$, $p = .30$) and the estimated coefficient for the IP variable (.12) is not statistically significant in this model.

Table 8.7 Results of logistic regression related to patent and other protection

Independent variable	*Rent – Model 1*	*Rent – Model 2*	*Start-up*
IP	.43* (.20)	.40* (.20)	.12 (.12)
Science		-.47 (.86)	
Constant	-6.07* (2.44)	-5.51* (2.58)	-.29 (1.19)
Fit statistics:			
-2 log likelihood	37.24	36.95	49.17
Change in –2 log likelihood from base model (χ^2)	6.40*	6.69*	1.09
Nagelkerke R^2	.22	.23	.04

Notes: Standard errors in parentheses.
* $p < .05$

8.3.2 Tacitness and complexity

Hypothesis 4 is that "the greater the combined levels of tacitness and complexity of the knowledge inherent in a technology, the greater the likelihood that the technology will be commercialized using the build or sell options." Table 8.8 shows the results of the logistic regression of the tacitness and complexity variable TACCOM on the build and sell options vs. the rent option. The model "explains" approximately 5% (Nagelkerke R^2) of the total variation in governance structures. The model does not produce a significantly better fit to the data (change in –2 log likelihood from base model = 1.37, $df = 1$, $p = .24$) than a model which excludes TACCOM (i.e., one that includes only the constant term). Thus this model does not provide a good fit to the data. The estimated coefficient for TACCOM is -.11. This coefficient for the TACCOM variable is not statistically significant and is not in the direction hypothesized. Thus Hypothesis 4 is not supported.

Table 8.8 Results of logistic regression related to tacitness and complexity

Independent variable	*Build or sell*	*Start-up*
TACCOM	-.11 (.10)	.15 (.10)
Constant	2.54 (1.19)	-.62 (1.00)
Fit statistics:		
-2 log likelihood	42.28	47.55
Change in –2 log likelihood from base model (χ^2)	1.37	2.71
Nagelkerke R^2	.05	.09

Notes: Standard errors in parentheses.
* $p < .05$

Table 8.8 also shows the results of a logistic regression on the alternative dependent variable STARTUP. This regression also has a poor fit to the data (change in –2 log likelihood from base model = 2.71, *df* = 1, *p* =.10) and the estimated coefficient for the TACCOM variable (.15) is not statistically significant in this model.

8.3.3 Risk of substitutes

Hypothesis 5 is that "the greater the risk of substitutes, the greater the likelihood that the technology will be commercialized using the rent option." Table 8.9 includes the results of a logistic regression of the risk of substitutes variable SUBSTITUTE on the rent option vs. the build and sell options. The model "explains" approximately 1% (Nagelkerke R^2) of the total variation in governance structures. The model does not produce a significantly better fit to the data (change in –2 log likelihood from base model = .16, *df* = 1, *p* =.69) than a model which excludes SUBSTITUTE (i.e., one that includes only the constant term). Thus the model does not provide a good fit to the data. The estimated coefficient for SUBSTITUTE is .06. This coefficient for the SUBSTITUTE variable is in the predicted direction but is not statistically significant. Thus Hypothesis 5 is not supported.

Table 8.9 also includes the results of a logistic regression on the alternative dependent variable STARTUP. The model "explains" approximately 14% (Nagelkerke R^2) of the total variation in start-up vs. licensing activity. Also, the model is a significantly better fit to the data (change in –2 log likelihood from base model = 6.40, *df* = 1, *p* =.04) than a model which excludes SUBSTITUTE (i.e., one that includes only the constant term). The estimated coefficient for SUBSTITUTE is -.31. This indicates that the odds of being in the rent category decrease by approximately .7 times ($e^{-.31}$) for each increase of 1 in the SUBSTITUTE scale. This coefficient for the SUBSTITUTE variable is statistically significant (p = .05). These data were also analyzed controlling for faculty affiliation in science (see section 8.2.2). The results are shown in Table 8.9 as Model 2. Controlling for faculty affiliation in science results in a better fitting model than the model that does not control for faculty affiliation in science. In addition, the SUBSTITUTE variable is no longer statistically significant. Thus, the alternative hypothesis that the greater the risk of substitutes, the greater the likelihood that the technology will be commercialized using start-up option is not supported by the data.

Table 8.9 Results of logistic regression related to risk of substitutes

Independent variable	*Rent*	*Start-up – Model 1*	*Start-up – Model 2*
SUBST	.06 (.16)	-.31* (.16)	-.20 (.18)
SCIENCE			2.03* (.81)
Constant	-1.66 (.98)	2.70* (1.02)	.84 (1.32)
Fit statistics:			
-2 log likelihood	43.49	46.07	39.38
Change in –2 log likelihood from base model (χ^2)	.16	4.19*	10.87*
Nagelkerke R^2	.01	.14	.33

Notes: Standard errors in parentheses.
* $p < .05$

8.3.4 Complementary assets

Hypothesis 6 is that “the greater the importance of specialized complementary assets, the greater the likelihood that the technology will be commercialized using the sell option.” Table 8.10 includes the results of a logistic regression of the complementary asset variable SPECCA on the sell option vs. the build and rent options. The model “explains” approximately 2% (Nagelkerke R^2) of the total variation in governance structures. The model does not produce a significantly better fit to the data (change in –2 log likelihood from base model = .53, *df* = 1, *p* =.47) than a model which excludes SPECCA (i.e., one that includes only the constant term). Thus the model does not provide a good fit to the data. The estimated coefficient for SPECCA is -.53. This coefficient for the SPECCA variable is not statistically significant and is not in the predicted direction. Thus Hypothesis 6 is not supported.

Table 8.10 Results of logistic regression related to complementary assets

Independent variable	*Sell*	*Start-up*
SPECCA	-.53 (.74)	.47 (.69)
Constant	1.45* (.56)	-1.16* (.51)
Fit statistics:		
-2 log likelihood	45.58	49.79
Change in –2 log likelihood from base model (χ^2)	.53	.47
Nagelkerke R^2	.02	.02

Notes: Standard errors in parentheses.
* *p* < .05

Table 8.10 also includes the results of a logistic regression on the alternative dependent variable STARTUP. This regression also has poor fit to the data (change in –2 log likelihood from base model = .47, *df* = 1, *p* =.49) and the estimated coefficient for the SPECCA variable (.47) is not statistically significant in this model.

8.3.5 Uncertainty

8.3.5.1 Volatility

Hypothesis 7 is that "the greater the volatility relating to the technology, the greater the likelihood that the technology will be commercialized using the build or sell options." Table 8.11 includes the results of a logistic regression of the volatility variable, VOLATILITY, on the build and sell options vs. the rent option. The model "explains" approximately 6% (Nagelkerke R^2) of the total variation in governance structures. The model does not produce a significantly better fit to the data (change in –2 log likelihood from base model = 1.51, *df* = 1, *p* = .22) than a model which excludes VOLATILITY (i.e., one that includes only the constant term). Thus this model does not provide a good fit to the data. The estimated coefficient for VOLATILITY is .17. This coefficient for the VOLATILITY variable is in the predicted direction but is not statistically significant. Thus Hypothesis 7 is not supported.

Table 8.11 Results of logistic regression related to volatility

Independent variable	*Build or sell*	*Start-up*
VOLATILITY	.17 (.13)	-.04 (.13)
Constant	-.59 (1.54)	1.41 (1.58)
Fit statistics:		
-2 log likelihood	42.13	50.15
Change in –2 log likelihood from base model (χ^2)	1.51	.11
Nagelkerke R^2	.06	.00

Notes: Standard errors in parentheses.
* $p < .05$

Table 8.11 also includes the results of a logistic regression on the alternative dependent variable STARTUP. This regression also has poor fit to the data (change in –2 log likelihood from base model = .11, *df* = 1, *p* =.74) and the estimated coefficient for the VOLATILITY variable (-.04) is not statistically significant in this model.

8.3.5.2 Dynamism

Hypothesis 8 is that "the greater the dynamism relating to the technology, the greater the likelihood that the technology will be commercialized using the rent option." Table 8.12 includes the results of a logistic regression of the dynamism variable, DYNAMISM, on the rent option vs. the build and sell options. The model "explains" approximately 14% (Nagelkerke R^2) of the total variation in governance structures. Also, the model is a significantly better fit to the data (change in –2 log likelihood from base model = 3.92, $df = 1$, p =.05) than a model which excludes DYNAMISM (i.e., one that includes only the constant term). The estimated coefficient for DYNAMISM is -.55. This indicates that the odds of being in the rent category decrease by approximately .58 times ($e^{-.55}$) for each increase of 1 in the IP scale. This coefficient for the DYNAMISM variable is not statistically significant (p = .11) and is not in the predicted direction. Thus Hypothesis 8 is not supported.

Table 8.12 Results of logistic regression related to dynamism

Independent variable	*Rent*	*Start-up*
DYNAMISM	-.55 (.34)	.18 (.20)
Constant	.49 (1.07)	.26 (.79)
Fit statistics:		
-2 log likelihood	39.73	49.37
Change in –2 log likelihood from base model (χ^2)	3.92*	.89
Nagelkerke R^2	.14	.03

Notes: Standard errors in parentheses.
* $p < .05$

Table 8.12 also includes the results of a logistic regression on the alternative dependent variable STARTUP. This regression has substantially poorer fit than the primary model (change in –2 log likelihood from base model = .89, $df = 1$, p =.35) and the estimated coefficient for the DYNAMISM variable (.18) is not statistically significant in this model.

8.3.6 Multiple attributes

The preceding analyses considered the transaction attributes individually. In this section, the impact of multiple attributes is considered. Table 8.13 shows the results of multinomial logistic regressions run on the data. Model 1 is a base model including only the control variable for faculty affiliation in science. Model 2 adds IP as this was the attribute found to be significant in the previous analyses. Model 3 continues the stepwise addition of variables adding VOLATILITY. This variable was added as it resulted in the next largest reduction in the -2 Log Likelihood value. Model 4 includes all of the transaction attribute variables. The reference category for the dependent variable is the build governance structure.

The chi-square test for the change in the –2 log likelihood value from the base model tests the null hypothesis that all of the logistic regression coefficients except the constant are zero. For all models, this test is statistically significant providing support for acceptance of the models as significant logistic regressions. Table 8.14 shows the classification table for model 4. The model correctly classifies 67% of the cases. However, the model does misclassify a large percentage of the cases that used the sell option as having used the build option. This may be a result of the build and sell options both reflecting hierarchy governance structures with the model not being able to distinguish differences between the two hierarchy governance structures. Overall, consideration of the various fit measures suggests the models provide a good fit to the data given the limited sample size.

The coefficient for the IP variable related to the rent governance structure is statistically significant and in the direction hypothesized by H3. The coefficient for the VOLATILITY variable is also statistically significant and in the direction hypothesized by H7. The coefficients for the SPECCA and DYNAMISM variables approach statistical significance. In the case of the SPECCA variable, no difference was hypothesized between the build and rent governance structures by H6. In the case of the DYNAMISM variable, the coefficient is not in the direction hypothesized by H8. Thus, the results provide some support for H3 and H7 but do not support H4, H5, H6 and H8.

Table 8.13 Multiple logistical regression analysis of governance structures

Variable	*Model 1*		*Model 2*		*Model 3*		*Model 4*	
	Coeff	*SE*	*Coeff*	*SE*	*Coeff*	*SE*	*Coeff*	*SE*
Rent								
SCIENCE	1.68	.91	1.31	.98	1.21	1.07	-.17	1.83
IP			.37	.21	.77*	.35	1.10*	.51
TACCOM							-.03	.22
SUBSTITUTE							.30	.37
SPECCA							-2.48	1.43
VOLATILITY					-.45*	.23	-.90*	.45
DYNAMISM							-1.5	.81
Intercept	.29	.76	-4.12	2.70	-3.73	3.22	-1.03	7.02
Sell								
SCIENCE	2.30*	.89	2.36*	.91	2.26*	.94	1.83	1.00
IP			-.09	.14	-.17	.16	-.06	.20
TACCOM							-.02	.12
SUBSTITUTE							.34	.25
SPECCA							-1.35	1.19
VOLATILITY					.25	.21	.17	.23
DYNAMISM							-.17	.26
Intercept	.69	.71	1.60	1.63			-2.84	5.29
Fit statistics:								
-2 log likelihood (-2LL)	11.88		48.29		56.71		48.43	
Change in –2LL from base model (χ^2)	8.34*		14.49**		23.26**		35.71**	
Nagelkerke R^2	.21		.34		.49		.66	

Notes. Reference category is build governance structure.
*$p < .05$
**$p < .01$

Table 8.14 Classification table for model 4

	Predicted			
Observed	*Build*	*Rent*	*Sell*	*Percent correct*
Build	18	2	3	78%
Rent	2	6	1	67%
Sell	5	1	4	40%
Overall percentage	60%	21%	19%	67%

None of the coefficients for the transaction attribute variables related to the sell governance structure are statistically significant. Thus, these results do not provide direct support for any of the hypotheses. They do, however, provide some support for the rationale behind the build, rent and sell governance structures. Both the build and sell governance structures are hierarchies while the rent option is a market governance structure (see section 3.4). The absence of differences between the build and rent governance structures is consistent with their both being hierarchy governance structures. The coefficient for the SCIENCE control variable is statistically significant. While no definitive conclusion can be drawn from the data as to why the SCIENCE control variable is significant, it may be that faculty affiliation in science is an indication that the technologies are at a more basic stage than those from faculty members affiliated with more applied faculties such as engineering and mathematics (primarily, computer science). If this is the case, it may indicate technologies that are further from market. New firms may lack the resources to commercialize these further from market technologies and, consequently, they may be commercialized by established firms rather than new firms resulting in the observed difference between the build and sell governance structures. This explanation is consistent with the findings of Colyvas et al. (2002) who found that, of the four technologies they examined that were usable without further development, three were commercialized by new firms rather than established firms.

8.4 Discussion

The results of this study provide statistically significant support for Hypothesis 3 related to patent and other legal protection in both the logistic regression and multiple logistic regression tests. The results of this study provide statistically significant support for

Hypothesis 7 related to volatility in the multiple logistic regression test. The results of the logistic regression test of this hypothesis are in the direction hypothesized but are not statistically significant. Evidence related to the risk of substitutes was in the predicted direction but failed to achieve statistical significance. The results of this study do not provide support for the other hypotheses related to transaction attributes. These findings are discussed further in the following sections.

8.4.1 Intellectual property protection

The results provide support for the hypothesis that intellectual property protection is an important consideration in selecting methods of commercialization. Specifically, the evidence supports the hypothesis that the greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option. This is a particularly important finding since, as described in section 2.4.4, previous research found conflicting evidence concerning the impact of the strength of intellectual property protection on the choice of method for commercializing the innovation. For example Shane (2002) found that, when patents are effective, the new technology is likely to be commercialized by licensing while del Campo, et al. (1999) suggest that, when the proprietary position of a technology is narrow or unpatentable, licensing is an appropriate method of commercializing the technology. The build, rent and sell governance structures proposed in this thesis and the results of Study #3 provide a possible explanation for, and reconciliation of, these conflicting findings.

Shane (2002) examined 717 licensed patents from the Massachusetts Institute of Technology and found that when patents are not effective, technologies are likely to be licensed back to the inventors. Shane's discussion suggests that the situations involving licensing back to the inventors represent situations where the inventor commercializes the technology by creating a start-up firm to develop new products or services based on the technology. Thus, this study can be reframed as suggesting that, when patents are ineffective, technologies are likely to be commercialized using the build option.

Del Campo, Sparks, Hill and Keller (1999) discuss the attempt to commercialize superconducting quantum interference devices. They conclude that "licensing may be the best strategy when the proprietary position of the intellectual property is narrow or unpatentable and when the capabilities of the developer are limited" (p. 294). Further, they conclude that start-ups need inventions that represent a core technology with a large market potential and, if possible, multiple product applications to compensate for the high risks involved in creating a start-up firm. The discussion of start-ups in their study suggests that the types of start-up firms they are describing are those that represent the build option. In their discussion of the licensing option, they refer to the licensee as a single firm and indicate that commonly the licensee will have the rights to improvements in the technology. This description is consistent with the sell option in the proposed taxonomy. Thus, this study can be reframed as suggesting that, when intellectual property protection is weak, a sell approach to commercialization is appropriate.

The hypothesis that the greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option which was supported by Study #3 is consistent with the reframed analyses of both Shane and del Campo, et al. and provides a method for reconciling these previously inconsistent findings.

8.4.2 Absence of support for other hypotheses related to transaction attributes

Except for intellectual property protection and to a more limited extent volatility, there was a lack of support for the other hypotheses related to transaction attributes. Three possible explanations for this lack of support exist. First, the measures used in the study might not be valid and reliable measures of the underlying constructs. Second, the hypothesized relationships do exist but the effect sizes are too small to be detected by the sample size of the test. Third, the hypothesized relationships do not exist. Each of these possibilities is discussed in turn.

The first possible explanation for the lack of support for the transaction attribute hypotheses is that the measures used in the study are not valid and reliable measures of the underlying constructs. Based on the findings described above and detailed review of the survey responses, two particular issues may exist. The first relates to the measure for specialized complementary assets. The idea of specialized complementary assets is a difficult one (see section 2.6.3 for further discussion of this concept). While others have attempted to measure the importance of specialized complementary assets using surveys (Gans, et al., 2002), it may be that the concept is too complex to reliably measure using survey methods (Babbie, 1999). Gans, et al. (2002) who used a similar measure also did not find a statistically significant result with their measure. The second construct that may pose measurement difficulties is the build, rent and sell governance structures; particularly, the distinction between the rent and sell options. As described in section 3.5, two criteria are used to distinguish the governance structures. The first criterion is whether a new firm or an established firm commercializes the technology. The second criterion relates to the ownership of the property rights to the technology. The first criterion is straightforward and distinguishes the build option from the rent and sell options. The second criterion, which distinguishes between the rent and sell options, is more complex. Following on Oxley (1999), Study #3 uses equity rights as a proxy for ownership of property rights (see section 8.2.3). It may be that equity rights are not a good proxy for ownership of property rights to the technology. Again, however, a more detailed examination of property rights is likely beyond what could reasonably be accomplished using survey methodology (Babbie, 1999).

The second possible explanation for the lack of support for the transaction attribute hypotheses is that, while the hypothesized relationships exist, the power of the tests was not large to detect them. Small sample sizes are only able to detect relatively large effect sizes (Bohrnstedt and Knoke, 1994). For example, the analysis in section 8.3.1 estimated the coefficient for IP at .43. This indicates that the odds of being in the rent category increase by approximately 1.5 times ($e^{.43}$) for each increase of 1 in the IP scale. Given that the overall odds of being in the rent category are .27:1, this is a large effect size. The small sample size is a limitation of this study (see section 8.4.4).

The third possible explanation for the lack of support for the transaction attribute hypotheses is that the hypothesized relationships do not exist. Since the hypotheses are based on transaction cost economics, this would imply that transaction cost economics is not a useful approach for explaining the methods used to commercialize new technologies arising from university research. However, as demonstrated in the next section, the results provide some limited evidence that governance structures and transaction cost economics are useful for explaining commercialization approaches.

While the above represent possible explanations for the lack of support for the transaction attribute hypotheses, there is no evidence to suggest which one or combination of these factors explains the results observed.

8.4.3 Comparison of the build, rent and sell classification scheme to the licensing vs. start-up dichotomy

In this research, it is suggested that the build, rent and sell classification scheme better reflects the substance of the methods used to commercialize new technologies than the licensing vs. start-up dichotomy. In order to allow comparisons between the two classification approaches, a second dependent variable was created to reflect the licensing vs. start-up approach commonly used to analyze the methods used to commercialize new technologies. No statistically significant relationships to the transaction attribute variables were found using this alternative dependent variable. A comparison of the fit of the models can also provide a sense of which dependent variable better fits the data. A comparison of the results of the analyses in sections 8.3.1 to 8.3.5 indicates that the build, rent or sell dependent variable models had the better fit to the data in four of the six cases and the licensing vs. start-up dependent variable models had the better fit to the data in two of the six cases. Based on the fit of the models and the fact that the build, rent and sell models identified one statistically significant relationship related to the transaction attribute variables, there is some evidence that the build, rent and sell classification scheme did better at 'explaining' commercialization structures based on technology characteristics than did the licensing vs. start-up dichotomy traditionally used to look at methods of commercialization.

8.4.4 Limitations

Section 8.4.2 identified two limitations in this study. One is the small sample size which limits the ability of the analyses to detect small effect sizes. The second limitation identified is the limitation of survey methodologies for measuring complex variables. This limitation impacts on the ability to measure specialized complementary assets and the property rights to a technology.

A third limitation of this study results from the sample being drawn from two universities located in the same geographic area. As indicated in section 5.4.2.1, the choice of intense examination of faculty from a small geographic area rather than a broader sample from numerous universities was made to minimize the impact of environmental factors such as differing economic environments and the availability of venture capital. This choice is also convenient and limits the costs of performing the research. However, this approach limits somewhat the generalizability of the findings.

8.4.5 Implications

The findings of this study have a number of implications. First, they suggest that technology attributes may have an impact on the methods used to commercialize a new technology arising from university research. Specifically, they suggest that, when intellectual property protection for a technology is weak, the build and sell approaches are likely to be more effective. The rent approach requires stronger intellectual property protection to enable the inventor to appropriate gains from the technology since secrecy and other methods of appropriate gains are unlikely to be effective when the rent option is used.

Second, as described in section 8.4.1, these findings help to resolve conflicts in previous research on the role of intellectual property protection. Specifically, the findings suggest that there are differences in the importance of intellectual property protection when a technology is licensed to numerous established firms as in the rent approach compared to when a technology is licensed to a single establish firm as in the sell approach.

Third, these findings suggest that the build, rent and sell classification scheme proposed in this thesis provides insights into the commercialization process that the licensing vs. start-up approach does not. This is suggested both by the analyses of the effect of intellectual property protection using both approaches and by the overall comparison of the two approaches.

8.5 Summary

The study in this chapter demonstrates that there are connections between the characteristics of a particular new technology and the method used to commercialize the technology. It also provides further support for the usefulness of the build, rent and sell categorization approach.

Chapter 9
Conclusions

In this chapter, the key results of the three studies conducted are summarized. In addition, the theoretical and managerial implications of the research are described. The chapter concludes with a discussion of the limitations of the research and opportunities for future research.

9.1 Summary of key results

The build, rent and sell classification approach is proposed in this thesis as an alternative to the licensing vs. start-up approach traditionally used to analyze the methods used to commercialize new technologies arising from university research. The build, rent and sell classification scheme has the advantages of being theoretically based and reflects the substance rather than the legal form of the governance structures adopted to commercialize a new technology. Specific criteria for distinguishing between the build, rent and sell options were developed and hypotheses linking the options to transaction attributes were developed using transaction cost economics theory.

Study #1 involves the analysis of three start-ups based on new technologies arising from research conducted at the University of Waterloo. These examples illustrate the significant differences that exist in the governance structures used to commercialize new technologies. The results support the concerns raised in chapter 3 about the licensing vs. start-up dichotomy. The results also provide some support for the build, rent and sell classification of governance structures. Further, the findings of this study are consistent with the hypotheses related to firm characteristics associated with the strategic governance choices of build, rent or sell.

Study #2 involves the examination of the nature of business activities of a sample of public start-up firms that have been involved in commercializing new technologies arising from university research. The results of this study 1) demonstrate that the criteria distinguishing the build, rent and sell methods can be applied effectively in practice to classify the method used to commercialize a new technology, 2) demonstrate that the build, rent and sell methods are all common approaches to commercialization, and 3) demonstrate that there are substantive differences in the business activities of firms depending on the method of commercialization used. The results of this study also support the hypotheses related to firm characteristics associated with the strategic governance choices of build, rent or sell.

Study #3 involves a survey of academic inventors. The study examines the connection between the characteristics of a new technologies and the method used to commercialize the technology. This study results in a number of major findings. First, the findings from this study suggest that technology attributes may have an impact on the methods used to commercialize a new technology arising from university research. Specifically, the results suggest that, when intellectual property protection for a technology is weak, the build and sell approaches are likely to be more effective than the rent approach. The rent approach requires stronger intellectual property protection to enable the inventor to appropriate gains from the technology since secrecy and other methods of appropriate gains are unlikely to be effective when the rent option is used. Second, the findings help to resolve conflicts in previous research on the role of intellectual property protection. Specifically, the findings suggest that there are differences in the importance of intellectual property protection when a technology is licensed to numerous established firms as in the rent approach compared to when a technology is licensed to a single establish firm as in the sell approach. Third, the findings suggest that the build, rent and sell classification scheme proposed in this thesis provides insights into the commercialization process that the licensing vs. start-up approach does not.

Table 9.1 summarizes the results of the tests of the hypotheses contained in this thesis. Three of the eight hypotheses (H1a/b, H2a/b and H3) are strongly supported and one of the hypotheses (H7) received limited support. In addition, evidence for another of the hypotheses (H5) is in the predicted direction but failed to achieve statistical significance. The other three hypotheses (H4, H6 and H8) are not supported. A number of possible reasons for the lack of support these hypotheses are discussed in section 8.4.2. These results demonstrate the value of the build, rent or sell approach in helping to understand how new technologies arising from university research are commercialized. They also demonstrate that more work is needed to better understand the factors that affect the governance choices made in commercializing these technologies (see section 9.3).

Table 9.1 Summary of results of tests of hypotheses

	Hypotheses	*Evidence*
Firm characteristics associated with the strategic governance choices of build, rent or sell:		
H1a	The build option is positively associated with new firms created to commercialize technologies deriving revenue primarily from product market activity.	Results of Study #1 are consistent with this hypothesis.
H1b	The rent and sell options are positively associated with new firms created to commercialize technologies deriving revenue primarily from technology market activity.	Results of Study #2 strongly support this hypothesis.
H2a	The build option is positively associated with new firms created to commercialize technologies expending resources on both technology development activities and production activities.	Results of Study #1 are consistent with this hypothesis.
H2b	The rent and sell options are positively associated with new firms created to commercialize technologies expending resources on technology development activities but not on production activities.	Results of Study #2 strongly support this hypothesis.
Transaction attributes and the strategic governance choices made in their commercialization:		
H3	The greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option.	Results of Study #3 provide statistically significant support for this hypothesis.
H4	The greater the tacitness and complexity of the knowledge inherent in a technology, the greater the likelihood that the technology will be commercialized using the build or sell options.	Results of Study #3 do not support this hypothesis (coefficient for TACCOM variable not statistically significant and not in hypothesized direction).
H5	The greater the risk of substitutes, the greater the likelihood that the technology will be commercialized using the rent option.	Results of Study #3 are in the predicted direction but failed to achieve statistical significance.
H6	The greater the importance of specialized complementary assets, the greater the likelihood that the technology will be commercialized using the sell option.	Results of Study #3 do not support this hypothesis (coefficient for SPECCA variable not statistically significant and not in hypothesized direction).
H7	The greater the volatility associated with the technology, the greater the likelihood that the technology will be commercialized using the build or sell options.	Results of Study #3 provide some support for this hypothesis. Coefficient for VOLATILITY variable is in hypothesized direction and is statistically significant in one of the two tests performed.
H8	The greater the dynamism associated with the technology, the greater the likelihood that the technology will be commercialized using the rent option.	Results of Study #3 do not support this hypothesis (coefficient for DYNAMISM variable not statistically significant and not in hypothesized direction).

9.2 Implications

9.2.1 Theoretical implications

The build, rent or sell model is proposed in this thesis as an alternative to the traditional approach of classifying the methods used to commercialize new technologies arising from university research as licensing or start-ups. This model contributes to understanding how technologies arising from university research are commercialized in a number of ways.

The build, rent or sell model provides a theoretical basis for the classification of methods that is lacking in the licensing vs. start-up approach. Licensing vs. start-up is commonly used in the analysis of commercialization activities but no theoretical argument is provided as to what the important differences are between these methods and why these differences matter. The build, rent or sell model uses the well established concepts of markets and hierarchies to distinguish between different approaches to commercialization. Market governance structures provide strong incentives to the individual firms to minimize costs and to adapt quickly to changing circumstances in order to maximize their income. These structures are very good at adapting to situations where coordination between the parties is not necessary and each can act autonomously (i.e., autonomous adaptation). Hierarchies have much weaker incentives but have greater administrative controls over activities providing greater abilities to adapt to situations requiring coordination between activities (i.e., cooperation adaptation) (Williamson, 1991). The choice of governance structure has consequences for the firm. A firm that adopts a hierarchy structure when a market approach is more appropriate will invest resources in activities but received no strategic benefit for doing so. A firm that adopts a market structure when a hierarchy structure is more appropriate may find itself in a weak bargaining position with another firm that controls the other complementary assets needed to commercialize the technology with the result that its profitability is diminished. In some cases, it may even find that its survival is threatened (Teece, 2000). By linking the methods used to commercialize a new technology to the concepts of markets and hierarchies, the build, rent or sell model provides a new theoretically based approach to the analysis of commercialization methods.

The build, rent or sell approach better reflects the ideas of markets and hierarchies than does the licensing vs. start-up approach. There are difficulties in linking the licensing vs. start-up dichotomy to the literature on markets and hierarchies. These difficulties relate primarily to the fact that the licensing and start-up categories do not align well with the market and hierarchy governance structures respectively. Shane (2002) recognizes this difficulty in arguing that licensing to firms founded by inventors represents, in substance, a hierarchy governance structure rather than a market one (i.e., that licensing cannot always be equated with a market governance structure). Likewise, Certicom (described in Study #1) is a start-up firm but one that operates through a market governance structure with the established firms that put its technologies into use. In this case, commercialization by a start-up firm cannot be equated with a hierarchy governance structure. These examples show that a simple 'licensing = market, start-up = hierarchy' model does not adequately reflect the complexities that exist in the business models used to commercialize new technologies arising from university research. Conversely, the build, rent or sell approach is explicitly designed to align with the market and hierarchy governance structures.

The focus on governance structures enables researchers to draw on an extensive body of literature to study the commercialization of new technologies arising from university research. This includes the literature on firm boundaries (e.g., Coase, 1937; various theories of the firm described in chapter 2) and the literature on markets for technology (e.g., Arora et al., 2001; Gans and Stern, 2003; Giuri and Luzzi, 2005). In this thesis, the literature on transaction cost economics theory is used to develop hypotheses concerning the relationship between certain characteristics of technologies and the methods used to commercialize them. It is significant to note that the hypotheses developed using the build, rent or sell model differ in important ways from those developed using the licensing vs. start-up dichotomy. For example, the Association of University Technology Manager's Licensing Survey for 2003 indicates that 87% of licenses were to existing companies (52.5% of licenses were to small companies and 34.5% of licenses were to large companies). A significant number of these licenses (35% of licenses to large companies and 43% of licenses to small companies) are exclusive (AUTM, 2004). Many of these licenses will be classified as *sell* transactions as they reflect a hierarchy governance structure. These licenses are grouped with other licensing arrangements and considered market governance structures under the licensing vs. start-up approach. This ability to draw more broadly on existing literature in related fields can help to advance significantly the study of the commercialization of new technologies arising from university research and to link it to research in these related fields.

The build, rent or sell approach also is easily reconcilable to the broader literature on commercializing innovations. For example, Teece (2000) identifies the following four options available to independent inventors and stand-alone laboratories:

> (1) licensing the technology to incumbent firms who already have the necessary complementary assets in place; (2) using intellectual property as collateral to raise debt funds to establish an organization to exploit the technology; (3) exchanging the patent for equity in a new venture-funded firm; (4) exchanging the intellectual property for cash or equity in an established firm. (p. 55)

The first of these options is comparable to the rent option; the second and third options are comparable to the build option and the forth option is comparable to the sell option. Teece argues that appropriability conditions and control of complementary assets are the key factors in determining which of these options is preferable in a particular circumstance. Again, this link to the broader literature on commercializing innovations can help to advance the study of the commercialization of university research.

Another important benefit of the build, rent or sell model is that it captures the governance structure in place at the time when the new technology is commercialized. The licensing vs. start-up approach focuses on the point in time when a technology leaves the university. However, there is evidence that significant time can pass between the point when a technology leaves the university and when it is commercialized and that different approaches may be tried before commercialization actually occurs (see section 2.4.3). The licensing vs. start-up approach fails to take into account the significant changes that can occur between the time a technology leaves the university setting and when it is put into commercial use.

The build, rent and sell categories capture non-traditional forms of commercialization that are becoming more important due to the emergence of markets for technology. Existing research on start-ups commercializing new technologies arising from university research presumes that these firms operate in the product market (see, for example, Shane 2004). However, firms like Certicom and Senesco do not produce products or services but rather operate in markets for technology granting rights to their technology to established firms who use it in their businesses. The build, rent and sell categories recognize that start-ups can operate either in product markets or markets for technology.

The build, rent and sell model also can help to resolve and explain inconsistent findings in previous research. For example, previous research found conflicting evidence concerning the impact of the strength of intellectual property protection on the choice of method for commercializing the innovation. Shane (2002) found that, when patents are effective, the new technology is likely to be commercialized by licensing while del Campo, et al. (1999)

suggest that, when the proprietary position of a technology is narrow or unpatentable, that licensing is an appropriate method of commercializing the technology. The build, rent and sell governance structures proposed in this thesis and the results of Study #3 provide an explanation for and reconciliation of these conflicting findings. The explanation for these apparently inconsistent findings suggested by this thesis is that effective patents may be important for the rent option but not as important for the sell option. Under this reframed way of looking at commercialization, Shane's study (2002) suggests that, when intellectual property protection is weak, a build approach to commercialization is appropriate while del Campo, et al.'s study (1999) suggests that, when intellectual property protection is weak, a sell approach to commercialization is appropriate. The hypothesis that the greater the patent or other legal protection for the technology, the greater the likelihood that the technology will be commercialized using the rent option which was supported by Study #3 is consistent with the reframed analyses of Shane and del Campo, et al. and provides a method for reconciling these previously inconsistent findings.

9.2.2 Managerial implications

The build, rent and sell model and the findings from this research can be used to help managers decide on a commercialization strategy for a new technology arising from university research. The results of this research suggest that the characteristics of a technology imply that certain approaches to commercialization are better suited to a particular technology than other alternatives. Specifically, the results suggest that strong IP protection is more important if a rent strategy is to be adopted than it is if a build or sell strategy is adopted. In addition, while not directly supported by Study #3, other research (Teece, 1986; Winter, 2000) suggests that consideration of the need for specialized complementary assets is also important in selecting a commercialization strategy. In particular, when specialized complementary assets are involved, established firms may be able to appropriate most of the returns to a technology (Teece, 1986) and, consequently, rent or sell strategies than involve cooperation with established firms rather than competition with them may be appropriate.

The build, rent or sell approach has implications for the development strategies of start-up firms. Technology based start-up firms engage in a number of activities including technology development, product development and business development. New technologies arising from university research are rarely ready for immediate conversion into commercial products or services (Rogers, 2003; Thursby, Jensen and Thursby, 2001). Thus, further development of the technology is an important activity toward commercialization of the technology. Commercial products or services need to be developed using the technology. Consequently, product development is also an important commercialization activity. In addition, if a start-up intends to operate in product markets, it needs to develop various managerial, marketing, distribution, manufacturing and other capabilities (hereinafter referred to as business development activities). Study #2 demonstrated that the relative emphasis on various business activities varies for firms adopting build, rent or sell strategies. Firms adopting a build strategy plan to operate in product markets selling products or services based on their technology. Consequently, their development strategies must include technology development, product development and business development. University researchers forming start-ups to commercialize technologies they invent may have technology development skills but typically lack product development and business development skills (Shane, 2002). Consequently, these firms generally need to develop or acquire the relevant product development and business development capabilities. This requires significant resources on the part of the start-up and may expose the start-up to significant risks since these capabilities may be difficult to acquire or may be possessed by potential competitors.

Firms adopting a rent strategy plan to develop their technology and market it to established firms to use in their businesses. Consequently, their development strategies will be focused on technology development. In the rent model, product development and business development activities will generally be done by the established firms that acquire the rights to use the start-ups technology. Thus the rent strategy is a more focused approach than the build one and may pose less risk and require fewer resources than a build strategy. Firms adopting a sell strategy plan to dispose of the technology to an established firm. These firms will typically undertake technology development activities in order to further develop their technology to make it more attractive to potential buyers. They may also engage in some product development activities to demonstrate to the potential buyers the commercial potential of the technology. However, they normally will not engage in significant business development activities since their strategy is to sell the technology rather than to develop an ongoing market presence. The sell strategy like the rent strategy is a more focused approach than the build one and may pose less risk and require fewer resources than a build strategy. Thus, start-ups adopting rent or sell strategies generally do not need to expend significant resources on business development activities. Start-ups adopting these strategies that do expend significant resources on business development activities may be wasting time and money that are often in short supply for start-ups. Thus, the build, rent and sell model can help start-up firms to prioritize the activities that they undertake in order to commercialize their technology and to avoid wasting valuable resources on activities that are not important to their success.

The build, rent or sell model and the findings in this thesis, also have implications for university support for commercialization. As described above, the model and findings provide resources for individuals in university technology transfer and licensing offices to aid them in determining or advising on commercialization strategies and on development strategies. The research in this thesis also suggests the existence of innovation strategies that may aid in the commercialization of new technologies. As indicated earlier, many new technologies arising from university research are at an early stage of development. In addition, those involved in commercialization activities often comment on the lack of receptor capacity for new technologies by established firms (AUCC, 2003; NSERC, 2005). A strategy for overcoming these issues is suggested by the examples of firms such as Senesco described in Study #1. These examples suggest that, for some early stage technologies, a viable strategy may be to use start-ups as a method of financing technology development prior to licensing to established firms. Universities typically do not have the resources to finance technology development but financing from venture capitalists and even public markets may be available to start-ups. In these circumstances, use of a start-up may provide a method of accessing capital for technology development. As the technologies are further developed and the technological viability of the innovations are established, established firms may be more willing to take on these technologies (i.e., receptor capacity is increased). This is an example of how the concepts underlying the build, rent and sell approach can be used to develop innovative strategies to aid in the commercialization of new technologies.

9.3 Limitations and future research

The studies in this thesis are subject to a number of limitations. Study #1 is based on the examination of only three firms. These three firms were selected because of the differences in their approach to the commercialization of new technologies rather than to be a representative sample of start-up firms. For these reasons, while the findings are consistent with hypotheses 1a, 1b, 2a, and 2b, they cannot be considered strong evidence in support of the hypotheses. The findings may also not be generalizable to other firms. These issues are addressed in part by the broader sample in Study #2. In addition, these analyses are based on archival data sources and it was not possible to gather information about the technology attributes that are involved in hypotheses 3-8. Consequently, no evidence concerning these hypotheses is provided by this study. This issue is addressed in part by Study #3 which involves gather information about technology attributes through a survey of inventors.

For Study #2, the sample population may not be representative of all start-ups created to commercialize new technologies arising from university research. While NSERC funded research is an important source of new technologies, new technologies also result from university research not funded by NSERC. MIT start-ups also may not be representative of start-ups from other universities. The samples represent important sources of new technologies and afford the benefits arising from having two separate samples from different countries and derived from two different sources. Nonetheless, the results of this study may not be generalizable to all commercialized technologies arising from university research. A second limitation is that the variables used in the cluster analysis are not sensitive to differences between the rent and sell methods of commercialization. The cluster analysis is based on accounting data and these data do not address the issues of ownership of property rights to the technology. Ownership of property rights to the technology is the criterion that distinguishes between the rent and sell methods. Future research can attempt to identify additional variables that capture these differences and can be used to distinguish between the two methods. A third limitation of the study is that the analysis does not capture all ways that the sell method can be implemented. The analysis uses financial statement information. Financial statements capture situations where rights to a technology are transferred to an established firm by way of a transaction between the start-up and the established firm. They do not, however, capture situations where the established firm acquires the technology by acquiring the start-up. Three situations were identified where established firms acquired a technology by acquiring the start-up while it was still in the development stage. Future research can address this issue in a number of ways. First, the classification of firms as using the sell strategy can be broadened to include situations where start-ups are acquired by established firms while still in the development stage. Another way of addressing this limitation is to look specifically at situations where an established firm acquires a technology by acquiring a start-up firm. This approach to commercialization has not received much attention in past research even though it appears to be a common approach to commercializing technologies particularly in the biotechnology field (Kurtzman, 2005).

Study #3 is subject to a number of limitations. One is the small sample size which limits the ability of the analyses to detect small effect sizes. While the sample size for Study #3 is limited, the information in Table 2.3 demonstrates that there are very few large sample studies in this field (Shane, 2004) and, therefore, this study provides a valuable contribution to the field despite this limitation. Future research can address this limitation by extending the sample to researchers at other institutions. Currently, plans are in process to extend the survey to the other universities in the C4 consortium of south-western Ontario universities. The second limitation identified is the limitation of survey methodologies for measuring complex variables. This limitation impacts on the ability to measure specialized complementary assets and the property rights to a technology. Future research can address these issues by considering alternative measures and sources of data. For example, previous studies have looked at the effectiveness of patents on an industry wide basis (Levin, Klevorick, Nelson and Winter, 1987) and used these measures of effectiveness when considering individual new technologies (Shane, 2002). A similar approach might be practicable for complementary assets since it is reasonable to expect that the existence of specialized complementary assets varies by industry. A third limitation of this study results from the sample being drawn from two universities located in the same geographic area. The choice of intense examination of faculty from a small geographic area rather than a broader sample from numerous universities was made to minimize the impact of environmental factors such as differing economic environments and the availability of venture capital. However, this approach limits the generalizability of the findings. Future research can address this issue by extending the sample to researcher at a broader sample of universities.

A number of other areas of future research are suggested by findings in this thesis. In the course of this research, a number of firms were identified that used multiple methods to commercialize their technologies. For example, while not part of the studies described in this thesis, Research in Motion ("RIM") uses both a build and a rent approach to commercializing its technology. RIM both sells Blackberry wireless handheld products and licenses its technology to other mobile device manufacturers through its Blackberry licensing program (Research in Motion, 2005). Future research could examine these firms to determine why they adopt multiple methods.

Similarly, Certicom is an example of a firm that has changed its approach to commercialization. As described in chapter 6, prior to 2004 Certicom's primary approach to commercializing its technologies was to develop and sell software and integrated circuits (i.e., it had adopted a build strategy for commercialization). In 2004, Certicom adopted a new strategy for commercializing its technology. This new approach involved licensing its patent portfolio to other firms who build their own security products using Certicom's technology (i.e., it changed to a rent strategy for commercialization). Future research could examine firms that have changed their commercialization approach to determine why firms change approaches. For example, Mahoney (2005) suggests that reduced uncertainty may lead to changes in governance structures. It may be that, in some cases, early stage technology-based firms need to enter product markets in order to prove that a market for products based on the technology exist before they can access markets for technology. Once this market uncertainty is reduced they may be able to switch to a more effective governance structure.

9.4 Conclusion

This thesis introduces a new method of looking at the strategic governance choices that are made in commercializing new technologies arising from university research and provides evidence from three studies that support the relevance and usefulness of this method. Universities are an important source of new knowledge. Getting the most out of this new knowledge requires that it be put into use. One important method of putting this knowledge into use is through commercialization activities. Improving commercialization performance is important to universities, government, the economy and to Canadians generally who benefit from the new products and services that result from commercialization activities. It is hoped that this research contributes to and helps encourage continued research into the commercialization of new technologies arising from university research.

Appendix A

Study #2 – Instructions to Coder

This appendix includes the instructions that were provided to the coder for use in classifying the method of commercialization used by the start-up companies in the study.

Classification of Startups

Instructions

1. Read the criteria in the document "Criteria for analysis of firms.doc" (reproduced below). If you have any questions about the criteria just ask.

2. Work through the example files to confirm that the process is understood.

3. Determine the commercializiation method for each of the startups in the sample using the criteria above.

4. Record your answers in the template "Classification Table.doc".

Suggested order of proceeding through documents to find relevant information

1. AIF or 10K – There is a description of the business at the beginning of these documents. Note that not all startups are required to produce these documents.

2. MD&A – The beginning of the Management's Discussion and Analysis section of a firm's annual report usually contains a description of the business.

3. Financial statements. There is sometimes a description of the business in the first note to the financial statements.

4. If a description of the business cannot be found in any of the above locations, look for a description in the early sections of the annual report.

Criteria for analysis of firms

	Build	*Rent*	*Sell*
Criteria:			
1) Firm that commercializes the technology	New firm (Start up sells products)	Established firm(s) (Start up sells IP)	Established firm (Start up sells IP)
Indicators:			
▪ Product development	Startup	Other firms	Other firms
▪ Manufacturing and distribution	Startup	Other firms	Other firms
Examples of what might appear in company descriptions	Product descriptions Manufacturing facilities Sales/distribution networks	Mention of other firms that manufacture and distribute products based on startups technology	Mention of other firms that manufacture and distribute products based on startups technology "Out-licensing"
2) Ownership of property rights to the technology	New firm	Majority retained by inventor/university or a firm created by them to market the technology to established firms	Established firm
Indicators:			
Right to use technology	Startup	Startup retains right to use technology and to let others use	Established firm – startup can no longer use in field of use covered by license
Right to appropriate returns from technology	Startup	Startup returns primarily from fixed payments and/or royalties	Startup returns primarily from milestone payments and royalties
Right to change assets form or substance	Startup	Startup	Established firm
Examples of what might appear in company descriptions	Product sales Discussion of operating margins	Licensing revenue Royalties Non-exclusive licenses Multiple licensees in same field of use Focus on developing technology in same field of use	Revenue from licensing Milestone payments Royalties Exclusive licenses Focus on developing technology in other fields of use or developing new technologies

Other classifications:
Hybrid – Commercialization of the technology involves the combined efforts of both the startup and an established firm(s). For example, the technology may have been commercialized through a joint venture or partnership with an established firm with the startup contributing manufacturing capabilities and the established firm contributing marketing and distribution capabilities to the joint venture.
Development stage –Products based on the technology have not yet been put into commercial use.
Multiple – In some cases, multiple methods of commercialization are used by the startup. In these cases, the method of commercialization used should be categorized based on the primary method used.

Appendix B

Study #3 Survey document

Survey on Innovations Arising from University Research

Information for the respondent

Survey purpose

Your participation in this survey will help us to better understand how innovations move from a research environment into broader use.

Confidentiality

Your answers will be kept strictly confidential. Only members of the research team will have access to individual data. All information collected will be presented in aggregate manner in any publications, presentations or workshops. This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo.

Instructions

Please answer the following questions and return this survey to us using the enclosed envelope. Alternatively, you can fax your response to the Institute for Innovation Research at (519) 746-7252.

Definitions of certain terms used in the survey can be found in the attached glossary.

Assistance

If you have questions or require assistance in completing the survey, please contact:

Fred Pries
Institute for Innovation Research, Department of Management Sciences
University of Waterloo, 200 University Ave. W., Waterloo, ON N2L 3G1
Telephone: 519-888-4567 x5240
E-mail: fw2pries@engmail.uwaterloo.ca

General information

1. Please indicate your primary academic affiliation:

   a) University ______________________

   b) Faculty ______________________

   c) Department ______________________

   d) Position ______________________

2. How many years have you been actively involved in academic research? __________

Commercialization experience

3. Have innovations resulting from your academic research been put into commercial use? (Circle the applicable answer.)

Yes ↓

a) How many innovations resulting from your academic research have been put into commercial use? _________

No ↓

Please return the survey in the accompanying return envelope. Thank you for your assistance.

Identification of innovation

The remainder of this survey is directed towards a single innovation. Please identify, what in your view is, your most significant innovation that has been put into commercial use.

4. Please provide a brief description of the innovation (10-20 words): ____________________________

____

____

5. Which of the following *best* describes the innovation? (Select one answer only):

____Product

____Process

____Service

____Knowledge not embodied in a specific product, process or service

6. Which of the following statements *best* describes the development of the innovation during the transfer into commercial use? (Select one answer only):

____The innovation was *unchanged* through the transfer from the research environment to the commercial one

____The innovation underwent *minor* change during the transfer from the research environment to the commercial one

____The innovation was changed *significantly* during the transfer from the research environment to the commercial one

____The innovation that was eventually put into commercial use bore *little resemblance* to the one that emerged from the research environment

Characteristics of the innovation

Listed below are statements concerning various characteristics of innovations. Please circle one number for each statement to show the extent to which the statement characterizes the innovation *as it was eventually put into commercial use*.

1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

	Strongly Disagree				Strongly Agree	Not Relevant
7. This innovation was a component of a larger product, process or system.	1	2	3	4	5	0
8. The critical elements of this innovation could be easily explained to my colleagues (e.g., in a paper or at a conference).	1	2	3	4	5	0
9. It would be easy for others to imitate this innovation.	1	2	3	4	5	0
10. Interactions between this innovation and related components or systems were poorly understood.	1	2	3	4	5	0
11. I was certain this innovation would meet user demands.	1	2	3	4	5	0
12. Fundamentally similar innovations exist.	1	2	3	4	5	0
13. Future technological breakthroughs were likely to render this innovation of little value in a short time period.	1	2	3	4	5	0
14. I was confident that this innovation would perform as it was originally designed.	1	2	3	4	5	0
15. Manuals and documents accurately explained the implementation and operation of this innovation.	1	2	3	4	5	0
16. The 'reverse engineering' of this innovation by a competitor would be technically difficult.	1	2	3	4	5	0
17. Technical information about how this innovation functions together with other components or systems was well defined.	1	2	3	4	5	0

	Strongly Disagree				Strongly Agree	Not Relevant
	←				→	
18. Few credible substitutes competed with this innovation.	1	2	3	4	5	0
19. I expected this innovation to have a relatively long life cycle.	1	2	3	4	5	0
20. It was clear that this innovation would work as it was intended technologically.	1	2	3	4	5	0
21. A change in the design of this innovation would require compensating design changes in related components or systems.	1	2	3	4	5	0
22. Educating and training personnel for this innovation was a quick and easy job.	1	2	3	4	5	0

23. Which, if any, of the following types of intellectual property protection were obtained for this innovation? (Select all that apply)

_____ Patent

_____ Copyright

_____ Registered industrial design

_____ Registered trademark

_____ Registered integrated circuit topography

_____ Trade secret and/or non-disclosure agreement

_____ Other (please specify) ____

↓

Answer only if one or more items selected in question 23

	Strongly Disagree				Strongly Agree	Not Relevant
	←				→	
a) The intellectual property protection obtained was effective in deterring imitation of the innovation.	1	2	3	4	5	0

Complementary assets

Bringing an innovation to market usually requires that the innovation be utilized in conjunction with other assets or capabilities. Examples of these complementary assets include competitive manufacturing capabilities, access to needed distribution channels, the existence of a qualified sales force, after-sales support capabilities and complementary technologies.

Listed below are statements concerning the complementary assets needed to commercialize the innovation. Please circle one number for each statement to show the extent to which the statement characterizes the applicable complementary assets.

1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

	Strongly Disagree ←				→ Strongly Agree	Not Relevant
24. The following were important for the commercialization of the innovation:						
a) Manufacturing capabilities	1	2	3	4	5	0
b) Distribution channels	1	2	3	4	5	0
c) Sales force	1	2	3	4	5	0
d) After-sales support capabilities	1	2	3	4	5	0
e) Complementary technologies	1	2	3	4	5	0
f) Other (specify) ___________________________	1	2	3	4	5	0
25. The following needed to be tailored to the innovation:						
a) Manufacturing capabilities	1	2	3	4	5	0
b) Distribution channels	1	2	3	4	5	0
c) Sales force	1	2	3	4	5	0
d) After-sales support capabilities	1	2	3	4	5	0
e) Complementary technologies	1	2	3	4	5	0
f) Other (specify) ___________________________	1	2	3	4	5	0

	Strongly Disagree				Strongly Agree	Not Relevant
26. Multiple sources were available for the following						
a) Manufacturing capabilities	1	2	3	4	5	0
b) Distribution channels	1	2	3	4	5	0
c) Sales force	1	2	3	4	5	0
d) After-sales support capabilities	1	2	3	4	5	0
e) Complementary technologies	1	2	3	4	5	0
f) Other (specify) ___________________________	1	2	3	4	5	0
27. The following were in the hands of potential competitors:						
a) Manufacturing capabilities	1	2	3	4	5	0
b) Distribution channels	1	2	3	4	5	0
c) Sales force	1	2	3	4	5	0
d) After-sales support capabilities	1	2	3	4	5	0
e) Complementary technologies	1	2	3	4	5	0
f) Other (specify) ___________________________	1	2	3	4	5	0

Organizational form used to commercialize the innovation

The following questions relate to the approaches used to commercialize the innovation. For example, innovations may be commercialized through licensing arrangements, start-ups, consulting arrangements, etc.

In the questions that follow, the *commercializing organization* is the organization that put the innovation into use (e.g., by producing and selling new products or services based on the innovation or by using the innovation in production or other processes).

28. Attempts to commercialize an innovation may involve a fluid phase where different approaches to commercialize the innovation are tried (e.g., licensing may be tried, a start-up venture may be created, etc.)

    Did your innovation go through a fluid stage where more than one approach to commercializing the innovation was tried? (Circle the applicable answer)

    Yes ↓   No (Proceed to question 29)

    a) Which of the following approaches were tried:

    ______Licensing

    ______Creation of start-up venture

    ______Consulting arrangements

    ______Sale of rights to the innovation to another firm

    ______Other (please describe) ____

    b) Approximately how long, in years, did this fluid phase last? ______

    c) Did the attempt to commercialize eventually settle into a stable approach? Y N

For the remaining questions, please focus on the *most recent* approach used to commercialize the innovation.

29. The innovation was commercialized by: (Select one answer only)

    _____ A newly created firm founded by you/other key researchers on the project (Proceed to question 30)

    _____ A newly created firm founded by someone other than you/other key researchers on the project (Proceed to question 31)

    _____ One or more established firms (Proceed to question 31)

    _____ Other (please describe and proceed to question 32) ________________________________

30. The purpose of the newly created firm was to:

_____ Produce and sell new products or services based on the innovation

_____ Market the innovation to other firms that would produce and sell new products or services based on the innovation. Marketing the innovation may occur through selling licenses, development kits, or consulting services related to the innovation

_____ Other (please describe) ____

Proceed to question 32

31. The innovation was transferred to the established firm or independent start-up through: (Select all that apply)

_____ Non-exclusive license(s)

_____ Exclusive license

_____ Sale of intellectual property rights (e.g., database, patent, copyright, etc.)

_____ Other (please describe) ____

32. Researchers may be involved in the transfer of knowledge/know-how related to the innovation to the commercializing firm and/or may be involved in the ongoing operations of the commercializing firm. Which of the following best describes your involvement in *transferring knowledge* related to the innovation to the commercializing firm? (Select the answer that best describes your role)

_____ I had *no* involvement in transferring the innovation to the commercializing firm

_____ I had *limited* involvement in transferring the innovation to the commercializing firm (e.g., on a consultancy basis)

_____ I had *heavy* involvement for a *limited* period of time in transferring the innovation to the commercializing firm (e.g., through a fixed term employment or contract research arrangement)

_____ I had a significant *ongoing* operational role with the commercializing organization and transferring knowledge related to the innovation is part of that ongoing involvement

33. Which of the following describes your *operational role* with the commercializing firm? (Select all that apply)

_____ Principal

_____ Another executive position (e.g., chief technology officer)

_____ Member of the board of directors

_____ Member of the scientific advisory board

_____ No operational role

_____ Other (please describe) ____

34. My rights to receive income from the innovation took the form of: (Select all that apply)

_____ A fixed license fee or consulting fees

_____ Royalties based on product sales

_____ Equity in the commercializing firm (e.g., shares in the commercializing firm, stock options, dividends)

_____ I have no rights to receive income from the innovation

_____ Other (please describe) ____

_____ Don't know

35. My university's rights to receive income from the innovation took the form of: (Select all that apply)

_____ A fixed license fee

_____ Royalties based on product sales

_____ Equity in the commercializing firm (e.g., shares in the commercializing firm, stock options, dividends)

_____ My university has no rights to receive income from the innovation

_____ Other (please describe) ____

_____ Don't know

36. The right to further develop the innovation belongs to:

_____ Me or a firm controlled by me

_____ My university

_____ The commercializing firm

_____ Don't know

37. Did the innovation arise from industry sponsored research?

Yes ↓   No (Proceed to question 38)

a) If so, was the innovation commercialized by the sponsor of the research? Y N Don't know

b) Did the sponsor hold a right of refusal or right of offer on the innovation as a result of their sponsorship of the research? Y N Don't know

38. Was the innovation ultimately put into use (i.e., made available for sale to the ultimate consumer if a product/service or put into use if a process)?

Yes ↓   No (Proceed to question 39)   Don't know

a) In approximately what year was the innovation put into use? ___________

b) Is the innovation or a later revised or improved version of the innovation still in use? Y N Don't know

39. Has the innovation produced revenue (e.g., through license fees or sales of products or services)? Y N Don't know

40. If the innovation was licensed, have any of your other innovations been licensed to that particular licensee? Y N N/A Don't know

41. If the innovation was commercialized through a start-up company in which you were a founder, did you have any previous experience founding start-up companies? Y N N/A

Listed below are statements concerning the organizational form used to commercialize the innovation. Please circle one number for each statement to show the extent to which the statement characterized the method used to commercialize the innovation.

1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

	Strongly Disagree ←				→ Strongly Agree	Not Relevant
42. The commercializing organization had information on the state-of-the-art of the technology.	1	2	3	4	5	0
43. The commercializing organization had the technical competence to commercialize the innovation.	1	2	3	4	5	0
44. The commercializing organization had the managerial competence to commercialize the innovation.	1	2	3	4	5	0
45. The method used to commercialize the innovation was effective.	1	2	3	4	5	0
46. I would choose the same method of commercialization if I were doing it over again.	1	2	3	4	5	0

Please return the survey in the accompanying return envelope to:

Fred Pries
Institute for Innovation Research, Department of Management Sciences
University of Waterloo, 200 University Ave. W., Waterloo, ON N2L 3G1

Thank you for your assistance.

Glossary

Question 9 – Imitate (innovation) – Refers to other technologies that produce similar results to the innovation without infringing on any intellectual property rights related to the innovation.

Question 13 – Technological breakthroughs – Refers to new technologies that represent significant improvements over existing technologies.

Question 16 – Reverse engineering – Refers to the process of taking apart an object to see how it works in order to duplicate or enhance the object.

Question 23 – Intellectual property – Refers to products of the human intellect that is unique, novel, and unobvious. Intellectual property includes inventions, computer software or databases, industrial designs, trademarks, integrated circuit topographies, new plant varieties and know-how.

Question 24 – Distribution channels – Refers to the route that a product takes as it moves to the eventual consumer. Examples of distribution channels include the use of wholesalers or distributors, use of retail outlets and direct sales over the Internet.

Question 24 – After-sales support capabilities – Refers to customer support services such as installation assistance, help lines, on-site repair capabilities, etc.

Question 24 – Complementary technologies – Refers to other technologies that are necessary to the commercial application of the innovation. For example, computer hardware innovations may require specific software in order to operate.

Question 31 – Exclusive licenses – Are agreements allowing only one organization the right to use the intellectual property.

Question 31 – Non-exclusive licenses – Are agreements that do not limit the right to use the intellectual property to one specific organization. It is not necessary that more than one organization actually hold licenses only that more than one organization *may* hold licenses.

Question 36 – Commercializing firm – Refers to the organization that put the innovation into use (e.g., by introducing new products or services based on the innovation to the market or by using the innovation in production or other processes).

Question 39 – Revenue – Refers to the income produced by the innovation. Revenue may come from the sale of goods or services, license or royalty payments, consulting fees, or sale of intellectual property rights related to the innovation.

Question 43 – Technical competence – Refers to the practical knowledge or know-how needed to implement the innovation

Bibliography

Agrawal, A. (2001). University-to-industry knowledge transfer: literature review and unanswered questions. *International Journal of Management Reviews, 3*(4), 285-302.

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

Arora, A., Fosfuri, A. & Gambardella, A. (2001). *Markets for Technology: The Economics of Innovation and Corporate Strategy*. Cambridge, MA: The MIT Press.

Arrow, K.J. (1962). Economic welfare and the allocation of resources to invention. In R.R. Nelson (Ed.), *The Rate and Direction of Inventive Activities*. Princeton: Princeton University Press.

AUCC. (2002). *Framework of Agreed Principles on Federally Funded University Research*. Ottawa, Canada: Association of Universities and Colleges of Canada. Retrieved December 4, 2003 from the World Wide Web: http://222.aucc.ca/_pdf/english/reports/2002/frame_cadre_e.pdf

AUCC. (2003). *Action File: Commercialization*. Ottawa, Canada: Association of Universities and Colleges of Canada.

AUCC. (2005). *Momentum: The 2005 Report on University Research and Knowledge Transfer*. Ottawa, Canada: Association of Universities and Colleges of Canada.

AUTM. (2003). *AUTM Licensing Survey: FY 2002 Survey Summary*. Northbrook, IL: Association of University Technology Managers.

AUTM. (2004). *AUTM Licensing Survey: FY 2003 Survey Summary*. Northbrook, IL: Association of University Technology Managers.

Babbie, E.R. (1999). *The Basics of Social Research*. Belmont, CA: Wadsworth Publishing Company.

Barnard, C.I. (1938). *The Functions of the Executive*. Cambridge, MA: Harvard University Press.

Baumard, P. & Ibert, J. (2001). What approach with which data? In R. Thietart (Ed.), *Doing Management Research: A Comprehensive Guide.* London: SAGE Publications.

Bohrnstedt, G.W. & Knoke, D. (1994). *Statistics for Social Data Analysis* (3rd ed.). Itasca, IL: F.E. Peacock Publishers, Inc.

Bouchard, T.J. Jr. (1976). Unobtrusive measures: an inventory of uses. *Sociological Methods and Research, 4*, 267-300.

Canadian Performance Reporting Board. (2004). *Management's Discussion and Analysis: Guidance on Preparation and Disclosure.* Toronto, Canada: Author.

Canadian Securities Administrators. 2003. *Continuous Disclosure Obligations*. Montreal, Canada: Author. Retrieved August 25, 2005 from the World Wide Web: http://www.osc.gov.on.ca/Regulation/Rulemaking/Current/Part5/rule_20031219_51-102_con-dis.pdf

Carlsson, B. & Fridh, A. (2002). Technology transfer in United States universities: a survey and statistical analysis. *Journal of Evolutionary Economics, March 2002*, 199-232.

Certicom Corp. (1998). *Additional Offering*, *January 14, 1998*. Mississauga, Canada: Author.

Certicom Corp. (2003). *Material Change Report*, *October 24, 2003*. Mississauga, Canada: Author.

Certicom Corp. (2004a). *2004 Annual Report*. Mississauga, Canada: Author.

Certicom Corp. (2004b). *Renewal Annual Information Form For the fiscal year ended April 30, 2004*. Mississauga, Canada: Author.

Certicom Corp. (2004c). *Material Change Report, May 3, 2004*. Mississauga, Canada: Author.

Certicom Corp. (2005). *Certicom Reports Year-End Results for Fiscal 2005*. Mississauga, Canada: Author. Retrieved November 3, 2005 from the World Wide Web: http://www.certicom.com/index.php?action=company,press_archive&view=494

Chesbrough, H.W. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

Chesbrough, H.W. & Kusunoki, K. (2001). The modularity trap: innovation, technology phase shifts and the resulting limits of virtual organizations. In I. Nonaka and D. Teece (Eds.), *Managing Industrial Knowledge: Creation, Transfer and Utilization*. London: SAGE Publications Ltd.

Christensen, C.M. (1993). The rigid disk drive industry: a history of commercial and technological turbulence. *Business History Review, 67*(4), 531-589.

Churchill, G.A. Jr. (1979). A paradigm for developing better measures of marketing constructs. *Journal of Marketing Research, 16*, 64-73.

Clayman, B.P. (2004). *Technology Transfer at Canadian Universities: Fiscal Year 2002 Update, A Report for the Canada Foundation for Innovation*. Vancouver, Canada: Author. Retrieved November 1, 2005 from the World Wide Web: http://www.sfu.ca/vpresearch/vprreports.htm

Coase, R.H. (1937). The nature of the firm. *Economica*, New Series, *4*(16), 386-405.

Cohen, W. M. & Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly, 35*, 128-152.

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

Connor, K. & Prahalad, C.K. (1996). A resource-based theory of the firm: knowledge versus opportunism. *Organization Science, 7*, 477-501.

Cyert, R.M. & March, J.G. (1963). *A Behavioral Theory of the Firm*. Englewood Cliffs, NJ: Prentice Hall.

del Campo, A. A., Sparks, A., Hill, R. C. & Keller, R. T. (1999). The transfer and commercialization of university-developed medical imaging technology: opportunities and problems. *IEEE Transactions on Engineering Management, 46*(3), 289-298.

DALSA Corporation. (1996). *Initial Public Offering and Secondary Offering*, *May 10, 1996*. Waterloo, Canada: Author.

DALSA Corporation. (2004). *DALSA Corporation Annual Report 2004*. Waterloo, Canada: Author.

Denzin, N.K. (1978). *The Research Act* (2nd ed.). New York: McGraw-Hill.

Demsetz, H. (1967). Towards a theory of property rights. *The American Economic Review*, 57(2), 347-359.

Demsetz, H. (1988). *Ownership, Control, and the Firm*. Oxford, UK: Basil Blackwell.

Demsetz, H. (1997). The firm in economic theory: a quiet revolution. *The American Economic Review*, 87(2), 426-429.

Dillman, D.A. (2000). *Mail and Internet surveys: The tailored design method*. New York: John Wiley.

Eisenhardt, K.M. (1989). Agency theory: an assessment and review. *Academy of Management Review, 14*, 57-74.

Eisenhardt, K.M. & Martin, J.A. (2000). Dynamic capabilities: what are they? *Strategic Management Journal, 21*, 1105-1121.

Eisenstein, R.I. & Resnick, D.S., (2001). Going for the big one. *Nature Biotechnology, 19*(9), 881-881.

Fontes, M. (2005). The process of transformation of scientific and technological knowledge into economic value conducted by biotechnology spin-offs. *Technovation, 25*, 339-347.

Foss, N.J. (1996). Knowledge-based approaches to the theory of the firm: some critical comments. *Organization Science, 7*(5), 470-476.

Fowler, F.J. Jr. (2002). *Survey Research Methods* (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Gans, J.S., Hsu, D.H. & Stern, S. (2000). When does start-up innovation spur the gale of creative destruction? *NBER Working Paper Series (#7851)*. Cambridge, MA: National Bureau of Economic Research.

Gans, J.S., Hsu, D.H. & Stern, S. (2002). When does start-up innovation spur the gale of creative destruction? *RAND Journal of Economics, 33*(4), 571-586.

Gans, J.S. & Stern, S. (2003). The product market and the market for 'ideas': commercialization strategies for technology entrepreneurs. *Research Policy, 32*, 333-350.

Genentech Inc. (2005). *Corporate Chronology*. San Francisco, CA: Author. Retireved January 3, 2005 from the World Wide Web: http://www.gene.com/gene/about/corporate/history/timeline/

Ghoshal, S. & Moran, P. (1996). Bad for practice: a critique of the transaction cost theory. *Academy of Management Review, 21*, 13-47.

Giuri, P. & Luzzi, A. (2005). *Commercialisation Strategies of Technology-based European SMEs: Markets for Technology vs. Markets for Products* (LEM Working Paper #2005/08). Pisa, Italy: Laboratory of Economics and Management, Sant'Anna School of Advanced Studies.

Goffman, E. (1969). *Strategic Interaction*. Philadelphia: University of Pennsylvania Press.

Goldfarb, B. & Henrekson, M. (2003). Bottom-up versus top-down policies towards the commercialization of university intellectual property. *Research Policy, 32*(4), 639-658.

Gopalakrishnan, S. & Bierly, P. (2001). Analyzing innovation adoption using a knowledge-based approach. *Journal of Engineering and Technology Management, 18*, 107-130.

Grant, R.M. (2001). Knowledge and organization. In I. Nonaka & D.J. Teece (Eds.), *Managing Industrial Knowledge*. London: Sage Publications Ltd.

Gregory, W.D. & Sheahen, T.P. (1991). Technology transfer by spin-off companies versus licensing. In A.M. Brett, D.V. Gibson, & R.W. Smilor (Eds.), *University Spin-off Companies.* New York, NY: Rowan & Littlefield Publishers, Inc.

Gu, W. & Whewell, L. (1999). *University research and the commercialization of intellectual property in Canada.* Ottawa, Canada: Industry Canada.

Hair, J.F., Jr., Anderson, R.E., Tatham, R.L. & Black, W.C. (1998). *Multivariate Data Analysis* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Hart, O. (1995). *Firms, contracts, and financial structure*. Oxford, UK: Clarendon Press.

Hayek, F.A. (1945). The uses of knowledge in society. *American Economic Review, 35*, 519-530.

Holmstron, B. & Roberts, J. (1998). The boundaries of the firm revisited. *Journal of Economic Perspectives,* 12(3), 73-94).

Hope, J. & Hope, T. (1997). *Competing in the Third Wave*. Boston: Harvard Business School Press.

Hoye, K. & Roe, P. (2003). Intellectual property policies and university-industry licensing. In M. von Zedtwitz, G. Haour, T.M. Khalil & L.A. Lefebvre (Eds.), *Management of Technology: Growth through Business Innovation and Entrepreneurship* (pp. 351-366). Amsterdam: Pergamon.

Industry Canada. (2002). *Achieving excellence: Investing in people, knowledge and opportunity*. Ottawa, Canada: Author.

Jensen, M. & Meckling, W. (1976). Theory of the firm: managerial behavior, agency costs, and capital structure. *Journal of Financial Economics*, 3, 305-360.

Jick. T.D. (1979). Mixing qualitative and quantitative methods: triangulation in action. *Administrative Science Quarterly, 24*, 602-611.

Jostow, P.L. (1985). Vertical integration and long-term contracts: the case of coal-burning electric generating plants. *Journal of Law, Economics, and Organization*, 1(1), 33-80.

Klein, S., Frazier, G.L. & Roth, V.J. (1990). A transaction cost analysis model of channel integration in international markets. *Journal of Marketing Research, 22*, 196-208.

Kogut, B. & Zander, U. (1992). Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science, 3*, 383-397.

Kurtzman, J. (2005). *Startups that Work: The 10 Critical Factors that will Make or Break a New Company.* New York, NY: Portfolio.

Levin, R., Klevorick, A., Nelson, R. Winter, S. (1987). Appropriating the returns from industrial R&D. *Brookings Papers on Economic Activity* No. 3783-831.

Libecap, G.D. (1989). *Contracting for Property Rights*. Cambridge, UK: Cambridge University Press.

Link, A.N., Scott, J.T. & Siegel, D.S. (2003). The economics of intellectual property at universities: an overview of the special issue. *International Journal of Industrial Organization, 21*, 1217-1225.

Lux, D and Rorke, M. (n.d.). *From Invention to Innovation.* Washington, DC: U.S. Department of Energy. Retrieved October 13, 2005 from the World Wide Web: http://www.eere.energy.gov/inventions/docs/fromi2i.pdf

Macher, J.T. & Richman, B.D. (2005) Transaction cost economics: an assessment of empirical research in the social sciences. Under submission, *Journal of Economic Literature*. Retrieved October 14, 2005 from the World Wide Web: http://www.msb.edu/faculty/jtm4/Papers/JLEO.pdf

Mahoney, J.T. (2005). *Economic Foundations of Strategy*. Thousand Oaks, CA: SAGE Publications.

McEvily, S. K. & Chakravarthy, B. (2002). The persistence of knowledge-based advantage: an empirical test for product performance and technological knowledge. *Strategic Management Journal, 23*, 285-305.

McNaughton, R.B. & Bell, J. (2000). Channel switching between domestic and foreign markets. *Journal of International Marketing, 9*(1), 24-39.

Meyer, A.D., Tsui, A.S. & Hinings, C.R. (1993). Configurational approaches to organizational analysis. *Academy of Management Journal, 36*(6), 1175-1195.

Miner, A.S., Eesley, D.T., DeVaughn, M. & Rura-Polley, T. (2001). The magic beanstalk vision: commercializing university inventions and research. In C.B. Schoonhoven & E. Romanelli, (Eds.), *The Entrepreneurship Dynamic*. Stanford, CA: Stanford University Press, 2001.

Nerkar, A. & Shane, S. (2003). When do start-ups that exploit patented academic knowledge survive? *International Journal of Industrial Organization, 21*, 1391-1410.

Nicolaou, N. & Birley, S. (2003a). Social networks in organizational emergence: the university spinout phenomenon. *Management Science*, 49(12), 1702-1725.

Nicolaou, N. & Birley, S. (2003b). Academic networks in a trichotomous categorisation of university spinouts. *Journal of Business Venturing, 18*, 333-359.

NSERC (2002). *Research Means Business: A Directory of Companies Built on NSERC-Supported University Research*. Ottawa, Canada: National Sciences and Engineering Research Council of Canada.

NSERC (2005). *RPP 2005-2006 Natural Sciences and Engineering Research Council of Canada.* Ottawa, Canada: National Sciences and Engineering Research Council of Canada.

Ontario Securities Act, R.S.O. 1990, Chapter S.5 (1990).

Organisation for Economic Co-operation and Development (1996). *Oslo Manual. The Measurement of Scientific and Technological Activities, Proposed Guidelines for Collecting and Interpreting Technological Innovation Data.*

Oxley, J.E. (1999). Institutional environment and the mechanisms of governance: the impact of intellectual property protection on the structure of inter-firm alliances. *Journal of Economic Behavior & Organization, 38*, 283-309.

Penrose, E.T. (1959). *The Theory of the Growth of the Firm*. New York: John Wiley & Sons.

Perrow, C. (1986). *Complex Organizations: A Critical Essay* (3rd ed.). New York: McGraw-Hill, Inc.

Poppo, L. & Zenger, T. (1998). Testing alternative theories of the firm: transaction cost, knowledge-based, and measurement explanations for make-or-buy decisions in information services. *Strategic Management Journal, 19*, 853-877.

Porter, M.E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. New York, NY: The Free Press.

Pratt, J.W. & Zeckahuser, R.J. (1985). Principals and agents: an overview. In J.W. Pratt & R.J. Zeckahuser (Eds.), *Principals and Agents: The structure of Business*. Cambridge, MA: Harvard Business School Press.

Pries, F. and Guild, P. (2005). Build, rent or sell: Options for commercializing new technologies arising from university research. In T.R. Anderson, T.U. Daim & D.F. Kocaoglu (Eds.), *Technology Management: A Unifying Discipline for Melting the Boundaries* (pp. 470-479). Portland, OR: PICMET.

Rambus Inc. (2002). *2002 Form 10-K*. Los Altos, CA: Author. Retrieved 12/15/03 World Wide Web, http://www.rambus.com/inv/

Read, C. (2003). *Survey of Intellectual Property Commercialization in the Higher Education Sector, 2001*. Ottawa, Canada: Statistics Canada.

Research in Motion (2005). *Research in Motion Annual Report 2005*. Waterloo, Canada: Research in Motion.

Rogers, E. (2003). *Diffusions of Innovations* (5th ed.). New York: Free Press.

Scherer, F.M. & Harhoff, D. (2000). Technology policy for a world of skew-distributed outcomes. *Research Policy, 29*, 559-566.

Schilling, M.A. & Steensma, H.K. (2002). Disentangling the theories of firm boundaries: a path model and empirical test. *Organization Science, 13*(4), 387-401.

Senesco Technologies, Inc. (1999). *Proxy Statement (January 8, 1999)*. Princeton, NJ: Author.

Senesco Technologies, Inc. (2004). *2004 Annual Report*. Princeton, NJ: Author.

Senesco Technologies, Inc. (2004b). *Development and License Agreement*, March 8, 2004. Princeton, NJ: Author.

Shane, S. (2001). Technological opportunities and new firm creation. *Management Science, 47*(2), 205-220.

Shane, S. (2002). Selling university technology: patterns from MIT. *Management Science, 48*(1), 122-137.

Shane, S. (2003). *A General Theory of Entrepreneurship: The Individual-Opportunity Nexus*. Cheltenham, UK: Edward Elgar.

Shane, S. (2004). *Academic Entrepreneurship: University Spinoffs and Wealth Creation*. Cheltenham, UK: Edward Elgar.

Shane, S. (2004b). Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States. *Journal of Business Venturing, 19*, 127-151.

Shane, S. & Khurana, R. (2003). Bringing individuals back in: the effects of career experience on new firm founding. *Industrial and Corporate Change, 12*(3), 519-543.

Siegal, D.S. & Phan, P.H. (2005). Analyzing the effectiveness of university technology transfer: implication for entrepreneurship education. In J. Libecamp (Ed.), *University Entrepreneruship and Technology Transfer*. Jai Press, Inc.

Silverman, B.S. (1999). Technological resources and the direction of corporate diversification: toward an integration of the resource-based view and transaction cost economics. *Management Science, 45*(8), 1109-1124.

Simon, H.A. (1961). *Administrative behavior* (2nd ed.). New York: MacMillan.

Simonin, B.L. (1999). Ambiguity and the process of knowledge transfer in strategic alliances. *Strategic Management Journal, 20*, 595-623.

Slater, G. & Spencer, D.A. (2000). The Uncertain Foundations of Transaction Costs Economics. *Journal of Economic Issues*, 34(1), 61-87.

Steensma, H.K. & Corley, K.G. (2001). Organizational context as a moderator of theories on firm boundaries for technology sourcing. *Academy of Management Journal, 44*(2), 271-291.

Sutcliffe, K.M. & Zaheer, A. (1998). Uncertainty in the transaction environment: an empirical test. *Strategic Management Journal, 19*, 1-23.

Teece, D.J. (1986). Profiting from technological innovation. *Research Policy, 15*(6), 285-305.

Teece, D.J. (1996). Firm organization, industrial structure, and technological innovation. *Journal of Economic Behavior & Organization, 31*, 193-224.

Teece, D.J. (2000). *Managing Intellectual Capital*. Oxford, UK: Oxford University Press.

Teece, D.J., Pisano, G. & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18*(7), 509-533.

Thursby, J.G. & Kemp, S. (2002). Growth and productive efficiency of university intellectual property licensing. *Research Policy, 31*, 109-124.

Thursby, J.G., Jensen, R. & Thursby, M.C. (2001). Objectives, characteristics and outcomes of university licensing: a survey of major U.S. universities. *Journal of Technology Transfer, 26*, 59-72.

Todorovic, Z.W. (2004). *The entrepreneurial orientation of university departments and its relationship to the incidence of commercial activity.* Doctoral dissertation, University of Waterloo, Ontario, Canada.

Tsang, E.W.K. (2000). Transaction cost and resource-based explanations of joint ventures: a comparison and synthesis. *Organization Studies, 21*, 215-242.

Unico. (2004). *UK University Commercialisation Survey: Financial Year 2003.* Cambridge, UK: Unico.

U.S. Department of Justice. (1995). *Antitrust Guidelines for the Licensing of Intellectual Property*. Washington, DC: U.S. Department of Justice and the Federal Trade Commission.

U.S. Securities and Exchange Commission. (2003). *Registration Under the Securities Act of 1933.* Washington, DC: Author. Retrieved July 27, 2005 from the World Wide Web: http://www.sec.gov/answers/regis33.htm

University of Waterloo. (2000). *Policy 73 – Intellectual Property Rights.* Waterloo, Canada: Author. Retrieved November 3, 2005 from the World Wide Web: http://www.adm.uwaterloo.ca/infosec/Policies/policy73.htm

University of Waterloo. (2005). *Groundwater remediation technologies.* Waterloo, Canada: Author. Retrieved January 3, 2005 from the World Wide Web: http://www.research.uwaterloo.ca/ttlo/technologies/GroundWater/index.htm.

Vincett, P.S. (2005). Economic impacts of academic spin-off companies – implications for public policy. *Proceedings of the 14th International Conference on Management of Technology*.

Walker, G. and Weber, D. (1984). A transaction cost approach to make-or-buy decisions. *Administrative Science Quarterly, 29*, 373-391.

Wallmark, J.T. (1997). Inventions and patents at universities: the case of Chalmers University of Technology. *Technovation, 17*(3), 127-139.

Williamson, O.E. (1971). The vertical integration of production: market failure considerations. *American Economic Review, 61*, 112-123.

Williamson, O.E. (1975). *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: Free Press.

Williamson, O.E. (1981). The economics of organization: the transaction cost approach. *American Journal of Sociology, 87*(3), 548-577.

Williamson, O.E. (1985). *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*. New York: Free Press.

Williamson, O.E. (1991). Comparative economic organization: The analysis of discrete structural alternatives. *Administrative Science Quarterly, 36*, 269-296.

Williamson, O.E. (1996a). *The Mechanisms of Governance*. New York: Oxford University Press.

Williamson, O.E. (1996b). Economic organization: the case for candor. *Academy of Management Review, 21*, 48-57.

Williamson, O.E. (1999). Strategy research: governance and competence perspectives. *Strategic Management Journal, 20*, 1087-1108.

Williamson, O.E. (2002). The theory of the firm as governance structure: from choice to contract. *Journal of Economic Perspectives, 16*(3), 171-195.

Williamson, O.E. (2003). Foreward. In J.T. Mahoney, *Economic Foundations of Strategy*. Thousand Oaks, CA: SAGE Publications.

Winter, S.G. (2000). Appropriating the gains from innovation. In G.S. Day, P.J.H. Shoemaker & R.E. Gunther (Eds.), *Wharton on Managing Emerging Technologies*. New York, NY: John Wiley & Sons, Inc.

Wright, M., Vohora, A. & Lockett, A. (2004). The formation of high-tech university spinouts: the role of joint ventures and venture capital investors. *Journal of Technology Transfer, 29*, 287-310.

Zajac, E.J. & Olsen, C.P. (1993). From transaction cost to transactional value analysis: implications for the study of interorganizational strategies. *Journal of Management Studies, 30*, 131-145.

Zucker, L.G., Darby, M.R. & Armstrong, J. (2002). Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology. *Management Science, 48*(1), 138-153.