DECLARATION FOR THE PhD THESIS

The undersigned

SURNAME	NOVELLI
NAME	ELENA
Registration number	1003797

Thesis title:

TECHNOLOGY DEVELOPMENT AND COMMERCIALIZATION STRATEGIES FOR INNOVATIVE FIRMS

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UNIVERSITA' COMMERCIALE "LUIGI BOCCONI"

PH.D. IN BUSINESS ADMINISTRATION AND MANAGEMENT

TECHNOLOGY DEVELOPMENT AND COMMERCIALIZATION STRATEGIES FOR INNOVATIVE FIRMS

Thesis Committee:

Prof. Alfonso Gambardella, Bocconi University

Prof. Giovanna Padula, Bocconi University

Prof. Gautam Ahuja, University of Michigan

Elena Novelli

Registration number:

1003797

Academic Year 2009/2010

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TECHNOLOGY DEVELOPMENT AND COMMERCIALIZATION STRATEGIES

FOR INNOVATIVE FIRMS

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INTRODUCTION

Strategic management theorists have argued that a firm's performance is determined by its ability to match its resources with the basis of competition in the industry (e.g. Andrews, 1980). However, in many industries technology evolves at a very fast rate, user preferences also change quickly and the very boundaries of markets evolve on a continuous basis. Even when firms achieve superior performance, the longevity of their competitive advantage is open to question. Such a competitive landscape requires firms to continuously update their sets of resources and capabilities to compete in the evolving markets that eventually emerge as profitable (Wernerfelt, 1984). In the case of technology-based firms particularly critical resource choices concern the choices made about technology.

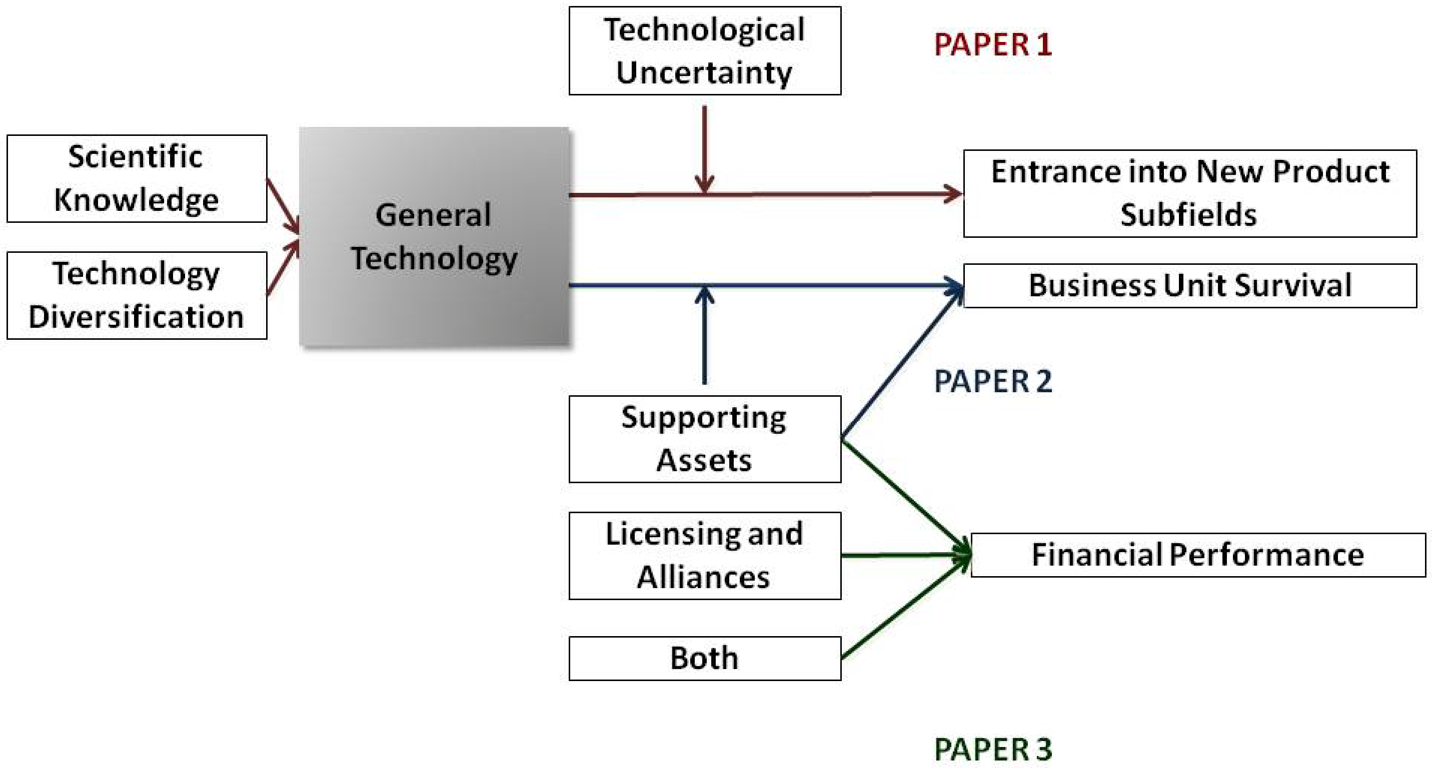
The purpose of my dissertation is to identify the mechanisms by which firms can organize their technology development and commercialization activities for achieving superior performance. Specifically it aims to respond to three broad research questions: 1) In the face of uncertainty, how do firms ex-ante develop resources that can be valuable ex-post? What are the firm-level antecedents of such general resources? 2) How do investments in these resources influence business survival? 3) How do different strategies for appropriating the value of these resources relate to each other? These questions are specified into three distinct papers.

The first paper, "*As You Sow, So Shall You Reap: General Technologies And Entry Into New Product Subfields In The Face Of Technological Uncertainty*", builds on the premise that the Resource Based View has left a fundamental question unanswered. The RBV argues that firms' performance is explained by strategic investments into factor markets. However, research in this area has provided only limited guidance on how firms facing high uncertainty can identify and ex-ante make technology investment decisions that prove valuable ex-post. This paper identifies investment in general technologies (technology customizable to different domains) as one ex-ante mechanism for dealing with uncertainty. It theorizes that having invested in general technologies enhances the firm's ability to introduce products into new industry subfields. In the second part, the paper also explores the question of why some firms are able to develop more general technologies than others. It identifies two preconditions for successfully creating general technologies, i.e. investment in scientific knowledge and investment in a portfolio of diversified technologies. It argues that prior exposure to scientific principles provides the context for deductive development while prior exposure to multiple distinct technologies can provide an impetus for inductive development. Since both processes propel the creation of more general and abstract knowledge, they improve the firm's ability to develop more general technologies. In order to test the predictions of this theoretical framework the paper studies a sample of photonics firms, relating data on a variety of their organizational, technological and financial characteristics with their product introduction behavior over a 10 year period. The implications for the Resource-Based View, the relationship between prior experience and new business entry, and research in general purpose technologies are discussed.

The second paper, "*What Doesn't Kill You Makes You Stronger: General Technologies, Supporting Assets And Firm Survival*" addresses a natural follow-up question from the first paper, i.e. what are the tradeoffs implied by the choice of investing in more general resources. Specifically the paper focuses on upstream investments in technology and downstream investments in supporting assets and looks at the implications of these choices on business survival. It predicts that both investments in more general technologies and in supporting assets constitute risky investments that may increase business' exit rates. However it also predicts that the combination of general technology and downstream assets may increase a business' likelihood of survival. Since general technologies can be adapted to different contexts, investments in more general technologies reduce the problem of asset inflexibility by improving a firm's ability to find alternative uses for its facilities. The paper tests the predictions by using a panel dataset of photonics firms over a 10 year period.

The third paper, "*How do Innovative SMEs commercialize their technology? Investigating the Substitution Effect between Vertical Integration and Cooperation*" compares different commercialization options for appropriating rents from technological investments, distinguishing between the cases of vertical-integration based vs cooperation-based commercialization. The paper proposes a reconceptualization of commercialization strategies in terms of pure strategies (picking one strategy) versus mixed ones (using both strategies) and looks at the effects of these strategies on performance. Results show that, under certain conditions, combining multiple commercialization options can be sub-additive for firm performance. Thus, “more” is not necessarily “better”. In order to test the theoretical framework this paper uses a cross sectional database including data on all US firms with more than 5 patents in the NBER US patent dataset during 1996-2001 and fewer than 250 employees, and covers multiple industries. It includes financial, accounting, and industry affiliation data as well as data on firm technology commercialization activities in the period 1996-2001. Data were collected and triangulated through an extensive search of press releases (using Factiva and Lexis-Nexis datasets), corporate reports (Security and Exchange Commission –SEC- filings, Lexis-Nexis) and corporate websites.

The findings that I present in this dissertation are important from both a theoretical and a practical perspective. Theoretically, these issues can inform the debate on how certain characteristics of the technology developed, i.e. technology generality, as well as the commercialization strategies implemented by the firm, influence firms performance. Practically, these arguments can improve our ability to guide future technological investments by high technology firms. Figure 1 presents a schematic view of my dissertation.


Technological Uncertainty
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Scientific Knowledge
Technology Diversification
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Figure 1

AS YOU SOW, SO SHALL YOU REAP: GENERAL TECHNOLOGIES AND ENTRY INTO NEW PRODUCT SUBFIELDS IN THE FACE OF TECHNOLOGICAL UNCERTAINTY

ABSTRACT

The Resource-based View of the firm suggests that ex-ante resource choices drive ex-post firm performance. However, the theoretical completeness of the RBV is constrained by a key limitation: how can firms identify and make ex-ante investments that become valuable ex-post? In this paper I examine this theoretical puzzle in the context of technology based firms and focus on the circumstance of technological uncertainty, a condition that makes this question a particularly difficult one for firms. I identify investing in *general technologies* (technology customizable to different domains) as one ex-ante mechanism for dealing with uncertainty. I theorize that having invested in general technologies enhances the firm's ability to introduce products into new industry subfields. Being able to adapt the technology and target multiple application domains by introducing products in different subfields is particularly important in the face of technological uncertainty, relative to the situation of being focused on a single application domain. In the second part of the paper I also explore the question of why some firms are able to develop more general technologies than others. I identify two preconditions for successfully creating general technologies, i.e. exposure to scientific knowledge and to a diversified portfolio of technologies. I argue that prior exposure to scientific principles provides the context for deductive development while prior exposure to multiple distinct technologies can provide an impetus for inductive development. Since both processes propel the creation of more general and abstract knowledge, they improve the firm's ability to develop more general technologies. I discuss the implications of my results for the Resource-Based View, the relationship between prior experience and new business entry, and research in general purpose technologies.

AS YOU SOW, SO SHALL YOU REAP: GENERAL TECHNOLOGIES AND ENTRY INTO NEW PRODUCT SUBFIELDS IN THE FACE OF TECHNOLOGICAL UNCERTAINTY

INTRODUCTION

The Resource-based View of the firm suggests that ex-ante resource choices drive ex-post firm performance. However, the theoretical completeness of the RBV is constrained by a key limitation: how can firms identify and make ex-ante investments that prove valuable ex-post? In this paper I examine this theoretical puzzle in the context of a particularly critical resource choice: which of a set of different technologies for solving a set of techno-economic problems should the firm invest in? I focus on the circumstance of technological uncertainty, a condition that makes this question a particularly difficult one for firms. Uncertainty refers to the extent to which future outcomes cannot be anticipated or accurately predicted (Pfeffer and Salancik, 1978). In the case of technology based firms this refers, for instance, to the inability of firms to assess which investments in technology will yield products that can be successfully commercialized. As Tushman and Anderson (1986) emphasize, technological progress entails technological experimentation and competition between technologies (Utterback and Abernathy, 1975; Abernathy, 1978). The choice of a technology that will not prove valuable in the industry can critically affect firms' performance (Christensen, Suarez and Utterback, 1998).

I address this issue by identifying a mechanism that allow firms to deal with technological uncertainty, i.e. investment in *general* (or higher order) *knowledge (*Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998). General knowledge differs from specific knowledge in that it can be adapted to be used in multiple application domains, whereas specific knowledge is dedicated in that it can be used in only one application domain. The general knowledge approach tackles the problems of uncertainty by giving the firm flexibility to adapt its knowledge to fit the state of the world that eventually emerges. In the context of my study I focus specifically on technological knowledge and define *general technologies* as technologies that can be adapted relatively easily to different technological domains rather than being specialized to a single domain.

I explore the construct of general technology in two ways. In the first part of the paper I investigate whether and how investment in general technologies may improve firms' ability to tackle technological uncertainty. To accomplish this I develop a theoretical framework relating investment in general technologies to the firm's ability to enter new subfields in a dynamic, evolving industry. By entry into new subfields I refer to a firm's introduction of a product in a subfield that it has not been present in before. Evolving, technology-intensive industries represent environments of significant uncertainty (Martin and Mitchell, 1998; Mitchell, 1989). A firm cannot be sure ex-ante that a certain technology can be applied successfully to an intended application domain (e.g. Rosenberg, 1996). Being able to eventually adapt the technology and target multiple application domains by introducing products in different subfields may insure the firm against the risk of failure present when it is focused on a single application domain (Anand, 2008). I argue and show that under conditions of high uncertainty, investment in a general technology is superior to investment in a specific technology in favouring entrance into new subfields.

Since general technologies convey the above benefit it is natural to wonder what enables some firms to develop more general technologies than others. In the second part of the paper I address this question by identifying two preconditions that enable firms to successfully develop general technologies. To identify these preconditions I treat the problem of developing general technologies as a special case of the more basic problem of creating general or abstracted knowledge. More general or abstract solutions to problems are usually obtained in two broad ways - through processes of deduction wherein basic principles are used to infer the relationships between a set of constructs, or through processes of induction wherein exposure to multiple distinct cases is the basis of developing a more general encompassing model. I argue that in the context of general technologies, prior exposure to scientific principles provides the context for deductive development while prior exposure to multiple distinct technologies can provide an impetus for inductive development. Based on this argument I suggest that firms that have invested in scientific knowledge and in developing a diversified technology portfolio are advantaged in developing general technologies. My empirical investigation of the photonics industry confirms these intuitions.

The issues that I address are important from the perspective of developing the resource-based view, improving our understanding of how firms can better prepare themselves to enter new related subfields and to further our understanding of general purpose technologies (Bresnahan and Gambardella, 1998). Research in the RBV area has suggested that sustained superior performance depends on firms' ability to select ex-ante resources that remain valuable in the long term. Yet, this perspective provides only limited guidance on how firms can select ex-post valuable resources, ex-ante. I use the construct of *general technologies* to demonstrate mechanism by which firms can ex-ante pick resources that are valuable in different future states of the world. I show that this mechanism represent a valid source of superior performance for firms facing uncertain environments. In doing so I help to show that competitive advantage does not necessarily come from specialized dedicated investments (Wernerfelt, 1984; Madhok and Tallman, 1998), but can come from general, more widely applicable ones.

My study also contributes to our understanding of how firms can successfully enter new businesses. Research on how firms adapt successfully to a dynamic environment has indicated that prior commitments are important to understanding how firms perform in the face of change (March, 1991; Kraatz and Zajac, 2001). For instance, Cohen and Levinthal (1994) persuasively argue that “fortune favors the prepared firm”. However, they do not detail exactly how firms can become “prepared”. In this study I build on this stream of work by identifying one specific path to becoming better “prepared” and also identifying the preconditions to using such a strategy. My study also shows that, in contrast to research that argues for a very limited role for purposive behavior of firms dealing with changing environments, it is possible for firms to build a superior ability to react to changing environments. For instance, several scholars have emphasized the importance of mechanisms of pre-adaptation as the key to firms successfully negotiating a changing environment (eg. Levinthal, 1998; Cattani, 2005; Cattani, 2006). The main logic underlying pre-adaptation arguments is that firms "happen to have" technologies adaptable to new domains, but these potential pre-adapted technologies reveal themselves only ex-post. In this study, I argue that firms do successfully adapt by anticipating changes and making investments *ex-ante*. By showing that in conditions of uncertainty market entry decisions are influenced by the ex-ante level of generality of the technology, I suggest that firms are aware – at least to some extent – of the breadth of application of the technology at the time of its development. There is nevertheless a role for pre-adaptation and path-dependence even in my framework: the ability to successfully develop general technologies is underwritten by prior investments in a diversified technology portfolio and in scientific knowledge.

Finally my work contributes to the literature on general purpose technologies by looking at the implications and antecedents of general technologies. Focusing on the implications of developing these technologies, I show that general technologies open up strategic opportunities for firms by increasing their ability to introduce products into multiple application domains and, consequently, of dealing with technological uncertainty. To understand the antecedents of general technologies, I integrate literature on general purpose technologies (GPTs) (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998; Arora, Fosfuri and Gambardella, 2001, Gambardella and Giarratana, 2009) with research on the impact of scientific knowledge on innovation (e.g. Nelson, 1959; Rosenberg, 1990; Gambardella, 1995) and on technology diversification (e.g. Argyres, 1996; Nelson,1959) showing that firms with a stronger basis on scientific knowledge and with a diversified portfolio of knowledge are in a better position to develop general technologies.

In order to test my theoretical framework I use a novel longitudinal dataset of over 900 photonics firms over a 10 year period. This data-set includes information on firms' technologies, product portfolios and several other economic characteristics. This paper is structured as follows. In the first section I review extant literature on this issue, provide definitions for the relevant constructs and develop predictions. In the second section I describe the sample, methodology, variables and measure that I use to test my predictions. Finally, in the third section, I highlight my primary contributions.

THEORETICAL BACKGROUND AND PREDICTIONS

Tackling Uncertainty: Foresight, Commitment and the Creation of Options

Relatively limited research has investigated how firms can invest ex-ante to become prepared for an uncertain future. Extant literature has focused on three potential answers to this question. A first perspective has emphasized the idea that a possible way to deal with uncertainty is to try and *anticipate* future states of the environment. Literature on strategic foresight, for instance, posits that – at least to a certain extent - it is actually possible for firms to identify in advance emerging opportunities and get prepared to exploit them (e.g. Ahuja, Coff and Lee. 2005). Yet, the final shape in which a technology emerges successful or is commercialized is often not resolved in fine-grained detail, ex-ante. Technological change is usually characterized by high levels of uncertainty. Competing technologies emerge and are obsolesced, information is revealed about user preferences that increases the importance of some hedonic attributes and reduces that of others, new product categories emerge as firms combine different bundles of attributes to anticipate demand. As Allen Kay, Apple fellow, puts it "The future was predictable, but hardly anyone predicted it". Strategic foresight theories currently do not offer insight on what specific strategies firms may use to hedge against technological uncertainty, an omission that is partly rectified by this study.

A second, partially complementary perspective suggests that firms can cope with uncertainty by trying to actively *shape* the future basis of competition in the industry. Research on commitment (e.g. Ghemawat 1991; Ghemawat and DelSol, 1998) suggests that – irrespective of the ability of forecasting future outcomes- the act of heavily investing into specialized factors of production ex ante might lead to superior performance, since this is going to change the state of nature that finally emerges. Such commitments are very strategic because investments in firm-specific resources are costly to reverse and can serve as entry barriers for the industry. For instance, firms that take central market positions or that are able to establish a technological standard gain greater influence in shaping future competitive dynamics. I build on the logic that firm actions can shape competitive dynamics, but expand the domain of such pro-active strategies by suggesting that sometimes even investments in general assets (as opposed to dedicated or specialized ones) can help to achieve this outcome.

These first two approaches are based on the idea of dealing with uncertainty by specializing investments. By the first approach firms specialize investments by focusing specifically on the knowledge assets they predict will be more valuable in the future. By the second, firms specialize investments in a path dependent way, following the constraints set by prior strategic decisions, under the assumption that such specific or dedicated investments will change future competitive dynamics in the firm's favor. Although these investment strategies might prove appropriate in several cases, the main issue is that they leave the firm without any backup options in case a certain specialized investment does not turn out valuable. This concern is especially relevant if the firm is making long term commitments. Indeed, a specialized investment in knowledge might be initially valuable for a firm, but as technologies evolve a new trajectory may well render such an investment less valuable.

Conversely in this paper I focus on an alternative mechanism for dealing with uncertainty that implies making more general, more widely applicable investments rather than specialized ones. This approach is based on the intuition that a possible path to dealing with uncertainty is by *getting prepared* for multiple possible scenarios that might emerge, rather than trying to anticipate or influence the scenario that eventually will emerge as dominant. A recent stream of research has looked at these kinds of investments through the lens of real option theory (e.g.McGrath, 1997; Oriani and Sobrero, 2008). The basic notion behind this perspective is that, in the face of uncertainty, firms may achieve superior performance by making investments that secure for them the ability of selecting an outcome only if it turns out favorable. For instance, firms may commit to early R&D investments to create an option that will enable them to switch to alternative technologies as the uncertainty is resolved (McGrath, 1997). The literature in this field has stressed the fundamental role of ex ante investments as a way to address the uncertainty problem. Yet, despite the value of the basic intuition, this research has provided only a limited understanding of the specific mechanisms by which firms can structure earlier R&D investments to respond to uncertainty. This paper fills this gap by identifying one specific mechanism for accomplishing this purpose, i.e. the development of general technologies.

Tackling Uncertainty through ex ante Investment in General Knowledge

In the face of uncertainty investments need to be handled in a fashion that secures firms some flexibility toward different future states of the environment. In order to meet this requirement firms can invest in *general knowledge,* i.e. knowledge valuable in different states of the world. In the context of my study, the primary source of uncertainty is technology. Accordingly, I operationalize this concept through the construct of *general technology.* In this section I define this construct and I investigate the effectiveness of this mechanism in the case of uncertainty.

General Technologies vs Specific Technologies

I define *general technologies* as technologies that are capable of application in multiple technological domains (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998). Generality refers to the ease with which the technology can be *upgraded* (Garud and Kumaraswamy, 1995) or *sidegraded* over time to different uses. If a technology is not general, the application of the technology to a domain different from the one it was originally intended for may involve a complete redesign. To be general, a technology must possess degrees of freedom that enable improvement in existing functions and the addition of new functions, making it suitable for many different end-uses. In that sense general technologies are usage-flexible resources (Ghemawat, 1991), meaning that their value does not decrease when a firm applies them to different uses.

My concept of general technologies builds upon the construct of general purpose technologies (GPTs) from the endogenous growth and technical change literatures (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998; Arora, Fosfuri and Gambardella, 2001, Gambardella and Giarratana, 2009). General purpose technologies are defined as technologies that draw upon an underlying common body of specialized knowledge but are used across a wide range of sectors or applications. The concept of GPT's has generally been discussed in conjunction with the idea of *pervasiveness* in the economy (Bresnahan and Gambardella, 1998) or in a specific industrial sector (Gambardella and Giarratana, 2009). However, the underlying attribute of generality that GPT scholars identify can be applied to even technologies that are not necessarily pervasive across sectors of economies. I build on the core insight provided by GPT scholars that framing technological problems in more abstract or general terms can lead to solutions that are of greater applicability (Bresnahan and Gambardella, 1998). This process is applicable at even the firm level. Firms can choose to define problems very narrowly and seek specific focused solutions to those problems, or they can conceive of problems in broader and more abstract terms and seek general solutions that address a whole class of problems and which can be modified cost effectively to generate many different products. In this paper I consider the recognizable potential of the technology for the firm that creates it, rather than for the whole economy.

To complete the correspondence between my construct of general technologies and the GPT concept, one could consider a generality continuum that ranges from specific (the technology can be applied to one use and one use only) to extremely general (with minimal modification the technology can be applied to many different sectors of the economy). GPTs lie at the extremely general end of this spectrum. Indeed common examples of GPTs such as the steam engine and electricity would be illustration of technologies occupying such an extreme position. The concept of general technology, that I use in this study is however less stringent and considers all technologies as possessing some degree of generality, varying from very little to a lot. Thus, all GPT's would also be general technologies in the sense that I use the term but a technology can be general (lead to multiple different applications) without necessarily being a GPT in the sense of being pervasive across the economy.

The concept of general technology is also consistent with that of platform technologies, i.e. technologies that map into a variety of market opportunities (Kim and Kogut, 1996). Specifically previous literature has mainly referred to platform technologies for identifying – at the firm level - technologies with a broader scope while it has referred to general purpose technologies when such technologies were applied at the level of the economic system (Bresnahan and Trajtenberg, 1995) and at the industry level (Bresnahan and Gambardella, 1998). By identifying the attribute of general technology as a continuum, ranging from very general to very specific technologies, this paper provides a reconciliation of the two constructs.

The concept of general technologies stands in contrast with the concept of *specific technologies*. Specific technologies are solutions to specific problems related to a circumscribed application domain. As an illustration of the distinction between general technologies and specific technologies, consider technologies in the field of chemical science. A technology for polymer synthesis is a general technology since it can be used in different application domains: for instance, it can be used for the creation of optical films, agrichemical materials, pharmaceutical delivering systems and heat resistant separation systems. Conversely, the development of a technology in the particular domain of optical films is a specific technology, since its usage is limited to a well-defined domain (e.g. it is of no use in the domain of drug-delivery systems).

The choice between general versus specific technologies represents an important managerial decision, determining firms' strategy and having relevant implications for firms performance. For instance think about firms operating in the field of lasers. The central technology in this field deals with the stimulated emission of light. However lasers have been employed in a wide range of industries, (including electronics, graphic arts, automotive, and defense, to name just a few) and applications (including, cutting, cladding, drilling, marking, thermal processing, and welding). Yet, the type of laser, its wavelength, fiber length, fiber diameter, and power, among other operating parameters, vary according to the application (eg. cutting or welding) and the material being processed (eg. ceramic, metals, or human skin).

A firm operating in this field may choose between two strategies. First, it may invest in a specific technology, for instance focusing on a laser technology with a very short wavelength that creates less intense interaction with the platform to be treated. This choice implies that the number of downstream applications sectors that the firm may actually target is limited: in this specific case, for instance, the firm may use it only for gentle applications, for instance skin treatment. Second, the firm may invest in a general technology, for instance, a laser technology that permits laser sources and laser material processing platforms to be rapidly interchangeable and interfaceable, so that the firm could better mix and match laser power and platform characteristics to the material processing requirements of the particular application. This general technology would be usable for skin treatment, but also for cutting woods and welding metals.

Another illustration of a choice between taking a general technology approach and a specific technology approach is provided by a comparison of the strategies employed by different pharmaceutical approach in pursuit of the “flu” vaccine. Many vaccine manufacturers have historically focused on identifying the three precise variants of flu that are expected to circulate in a season and develop a vaccine against those variants. The problem however is that if the actual flu variants that circulate in a season turns out to be different the vaccine is not very effective. Against this approach some manufacturers are now investing in attacking the problem by a developing a “universal flu vaccine” that works against all types of flu (Gravitz, 2009). To develop such a vaccine researchers address the DNA of the virus thus providing a general solution to the vaccine problem.

The choice between these two strategies entails relevant managerial implications. Choosing a general technology strategy would provide both inter-temporal and intra-temporal benefits compared to a specific technology. For instance using the lasers illustration, a diversified firm using a general technology would avoid redundancy of systems within the organization, since the company would not be required to develop different laser sources to respond to the characteristics of different applications. Moreover, using a general technology strategy, a company could enter the laser material processing field with the smallest laser source and laser material processing platform and add more powerful laser sources and bigger laser material processing platforms as the business grows and the firm diversifies: a general technology would allow the firm to rapidly reconfigure the components in their line to form laser material processing systems that can process any one of a wide variety of materials with optimal performance and great efficiency. Yet, the choice between a general and a specific technology has to be carefully pondered, since there might be pitfalls in the choice of a general technology strategy too. For instance, it is likely that a specific laser technology targeted for treating skin has a better performance in the specific field of dermatology, compared to a general technology with a broader scope of application that has been adapted to be used *also* in the field of dermatology.

General technology and entrance in new product subfields

Following Penrose's work (1959), several studies have suggested that firms can sustain growth over time by the sharing of tangible or intangible resources in the creation of multiple different products (Penrose, 1959; Rumelt, 1974) through the mechanism of economies of scope. This effect is based on the logic of lower joint costs of production per unit of output. Since the cost of acquiring the resource is borne by the firm only once, employing the same resource into different applications allows to cut redundant costs.

This logic can be applied to the circumstance of a technology-based firm that use the same intangible resource – i.e. the same technology - for the introduction of different products. Once that the firm has borne the initial cost of developing the technology, employing it into different applications allows to amortize the initial R&D costs. In particular the firm may use the same technology in the same time frame, for the simultaneous introduction of multiple products (Penrose, 1959); or over time, for instance if the firm decides to withdraw a product from the market and use the same technology for new products launched subsequently (Helfat and Eisenhardt, 2004).

The choice of using the same technology for introducing new products, yet, is a complex one. On the one hand new products can provide opportunities for growth (Foster, 1986) but, on the other hand they can also reduce sales of existing products through the mechanism of cannibalization (Reinganum, 1983, Mitchell, 1989) if the products based on the same technology are very similar in terms of market niches they target and value they produce for customers. This effect has to be carefully considered since the possible loss in sales might completely wash out the benefits originating from economies of scope. Conversely, if the firm uses the technology for introducing products that solve different classes of problems for end-users cannibalization is less likely to occur.

In other words, the opportunities of using the same technology for targeting different products is conditional upon the nature of the technology itself. Suppose that the firm possesses a specific technology customized to an application area and is willing to use the same technology for introducing a new product. The flexibility of re-use of the technology is limited since every feature of the technology has been specifically designed to serve the original targeted purpose best (Arora, Fosfuri and Gambardella, 2001). The application of the technology to a domain distant from the one it was originally intended for may involve a complete redesign that is likely to correspond to a high cost of adaptation for the firm, which would dissipate the benefits of sharing the resource. Hence, new products based on the same specific technology are more likely to be introduced as incremental extensions of existing product. Conversely, the very nature of general technologies – more abstract and standardized - enables easy differentiation into different market niches reducing the risk of cannibalization. A general technology can be seen as technical knowledge on a stylized phenomenon, expressed in terms of general parameters so that, changing the parameters, the phenomenon to which the technical knowledge applies can change accordingly. In order to apply the technology to a new domain, a firm endowed with a general technology merely needs to acquire the complementary knowledge that is domain specific, i.e. it has to acquire information on the actual value of the general parameters, and modify them so that the technology can be applied to the new domain. Since the technology has been designed upfront in a way that changing parameters is relatively easy and does not need to be redesigned accordingly, adapting the technology to a distant application domain becomes a much easier and less costly task compared to the case of a specific technology.

The possession of general technologies, hence, provides firms with the potential of introducing products in different market niches and thereby expanding product scope. Indeed, efficient employment of knowledge is achieved when the knowledge of the firm matches exactly the knowledge required by the product domains of the firm (Grant and Baden-Fuller, 2004). Suppose that the firm has developed a general technology and is using it in one product. Since the general technology constitutes knowledge that might be employed in more than one applications, the possession of such a technology creates a sort of excess capacity in firm's knowledge non utilized in firm's products domains. In addition, after the first use of the technology in a specific field, the firm gains some knowledge accumulation related to the general application of the technology that originates from learning by doing (Penrose, 1959). The excess capacity in knowledge creates a motivation for market entry in order to improve the fit between the technological knowledge base and the market opportunities.

Moreover, the use of a general technology for developing products entails a very specific cost structure. Developing general technologies requires an early decision of developing the technology in a way that it can be adapted to multiple uses and in a way that subsequent costs of adaptation from one use to the other are minimized (Bresnahan and Gambardella, 1998). It is however likely that general technologies require an additional upfront cost of development relative to more specific technologies. A firm that has already borne the upfront cost C for developing the technology, faces an opportunity cost of non-entering different market niches in terms of non-amortization of R&D expenditures. This opportunity cost translates in an additional incentive for market entry in order to amortize the sunk cost of research activities. Consistent with this logic, Silverman (1999) finds that the more applicable are firms' existing technological resources to a business, the more likely it is that the firm will diversify into that business.

Hp1 The greater the generality of technology, the greater the number of new product subfields subsequently entered.

Technological uncertainty may emerge from different sources (Nelson and Winter, 1982; Rosenberg, 1996). First, uncertainty may concern whether a certain new technology is technically feasible to solve certain classes of problems, or whether its embodiment into products provide improved technical performance. Second, uncertainty may concern the uses of the technology, in that firms might be uncertain about the product categories a certain technology can be successfully applied to. For instance, some of the attributes of the technology that in principle might seems suitable for addressing certain categories of human needs may turn out useless or detrimental in those fields. Finally, uncertainty may concern the economic effectiveness of new technologies, in terms of whether the application of the technology into products can be realized in a cost effective way.

In the face of technological uncertainty, being able to enter into new product markets may be crucial for firm performance in terms of all three implications above. First, firms cannot be sure that the result of a technological investment will result in technology that meets or exceeds certain desirable performance parameters. In such a situation the targeted application may not be realized because the technology fails in addressing the desired performance levels on a key attribute. If the firm can use the technology for another application that may not need these performance levels on that attribute the firm could still benefit from the technological investment. For instance, researchers at 3M were seeking a super powerful adhesive but the final product turned out to be a fairly weak adhesive. Although this technology was a failure in its intended application the ability to convert it into a new product category, in the form of Post-It notes, enabled 3M to still benefit from the original technology.

Entrance into new product markets is also very important in order to solve the uncertainty about the best uses of the technology in relation to actual customers' preferences (Sorenson, 2000). A firm could develop a new technology that - on the basis of the predicted technical characteristics – might seem suitable for product introduction in a certain market. However, some technological features of the technology might not have been anticipated and might become evident only after its first commercial application. Some of these unanticipated features may make the technology completely inappropriate for answering to the needs of that market niche. If the firm has made a large bet on the technology in terms of financial resources invested, withdrawing the product from the market may endanger the performance of the firm since the investment made will not pay back. In this circumstance the greater the different product categories a certain technology might fit, the higher the level of insurance for the firm against the risk of product failure in each single category.

As an illustration consider the case of Corning Inc. that invented Chemcor™ (Gorilla glass), an ultra strong glass material that withstood 100,000 pounds of pressure per square inch. Although the glass was originally intended to be used for windshields but turned out to be a failure in that application, the basic technology of strengthening glass proved very useful in another incarnation, the development of cellular telephone screens (Mandel, 2009; Corning.com). “Basically if you drop it, it doesn't break....” says Corning CEO Wendell Weeks, “This is hundreds of millions of dollars of opportunity for us.” (Mandel, 2009).

Commercializing new technologies may also entail uncertainty in terms of the economic implications of the technology. A technology that develops the relevant performance attributes, and even meets with consumer preferences may still end up as a failure if its economic characteristics are inferior to other solutions of the focal problem for the consumer. However, to the extent that the technology has broader application, it may serve as the basis for a new product category in which its economics can be justified. For instance, Digital Subscriber Line technology (DSL) was originally intended to offer a video-service to telephone consumers. Yet, it proved to be prohibitively expensive for that purpose. It however found an application as a mechanism to speed up internet access for telephone-line based users of the Internet.

Compounding the problem of uncertainty in the context of new technologies is the risk of technological obsolescence. Under conditions of uncertainty indeed, firms might experience a very long period of time during which several alternative uses of the technology are explored and consumers in each subfield have not yet manifested a clear preference about whether they find a certain use valuable or not. During these periods preferences constantly shift and even if in any period some products outperform others, these differences do not persist (Sorenson, 2000). However once a certain use of the technology emerges as dominant, it is then preserved and propagated until a new discontinuous advance initiates a new cycle (Anderson and Tushman, 1990). This dynamic implies that firms have a limited time window to profit from a selected technology. After this time period the technology is rendered obsolete.

In these kinds of environments firms have two main options, i.e. postponement of commitment or exploration along a wide range of product markets. The first option corresponds to postponing entrance into any product markets until uncertainty about the best use of the technology is resolved and the firm is exactly able to identify the most profitable use of the technology. It is however likely that, once that the target application field has been identified, firms will need some time for carrying on development activities and for acquiring experience within the field before the technology can be successfully delivered into products in that area. However, if the firm has waited for uncertainty to be resolved before starting those activities, the firm's products may be launched with some delay compared to competitors. This delay is likely to correspond to a proportional loss in terms of demand and revenues with the result that firms might not be able to payback the investment made (Rumelt, 1984).

Conversely, the second option, exploration along a wide variety of alternative paths, may be a superior one in the face of technological uncertainty (Rosenberg, 1996). Firms might indeed introduce products in different subfields when uncertainty is still high and monitor how consumers in different niches react to these products. Being present in several downstream application areas for a longer period may provide firms with several benefits. For instance, monitoring consumers' preferences for a longer period may help firms in getting a clearer sense of actual customer preferences rather than being influenced by the noise of the environment (Sorenson, 2000). Moreover a longer presence in any specific application domain leads firms to acquire experience in it, with the result that, once the domain emerges as the most relevant application area of the technology, the firm may enjoy the benefit of being an experienced player in the field. Further, having different products on the market may permit firms to collect information on user preferences and their evolution in different regions of the product space. In turn this may help to identify potential emerging markets and applications for the technology.

In the face of technological uncertainty, investments in a general technology increase firms' ability to introduce products in different subfields by making available a larger number of opportunities for ongoing product diversification and by reducing the time and costs required for doing it. In the case of a general technology strategy, firms incur a higher upfront cost. However, if the same technology is utilized later on for developing different products, the firm enjoys the benefits of economies of scope (Penrose, 1959). The higher the number of entries into new product markets, the lower the marginal cost of developing each additional product for entering a new market. In the face of huge uncertainties concerning the technology, e.g. where the technology emerges as a discontinuity, this is particularly important. In the case of a specific technology, instead, the firm needs to carry on the entire costs of development each time it develops a new product category, i.e. the marginal cost of developing an additional type of product does not decrease when the firm launches a new type of product. Firms using a general technology for entering different market subfields are also likely to experience time economies (Dierickx and Cool, 1989). A general technology is indeed a technology conceived for application into different uses. Firms experience about the application of the technology increases with each additional use. Conversely, entrance through a specific technology requires a tremendous effort and a great amount of time for acquiring the relevant experience in the development of the technology into product. Reducing this time can be difficult, since this process can be subject to time compression diseconomies (Dierickx and Cool, 1989).

The overall superiority of developing products based on a general technology versus a specific technology will depend on the upfront fixed cost of developing the general technology plus the low adaptation costs from one use to the other versus the cost of carrying on the entire development costs of each specific technology into products a higher number of times. However, the higher the number of new products, the higher the likelihood that the cost of carrying out each product de novo, each requiring almost a completely new development process, is greater than the cost of developing the same number of products all originating from a unique general technology. Since a higher technological uncertainty leads firms to introduce a higher number of new products, it seems reasonable to expect that for any given R&D budget constraint the rate of new product introduction is higher if the firm has more general technologies than specific technologies.

Moreover, the higher the technological uncertainty, the greater the possible scope of applications that firms have to take into consideration for identifying the best potential use of the technology. For instance, moderate uncertainty corresponds to the case in which firms are able to accurately predict that a certain technology can be successfully used for the production of displays, however they are not able to anticipate whether the technology would perform better in mobile phone displays versus PDA displays. In case of very high uncertainty, instead, the vector of potential uses of the technology might be much wider and vary across different product subfields, e.g. from displays to optical instruments. In this latter case, the benefits of having invested in a general technology compared to having invested in a specific one are magnified since introducing new products in distant subfields is only likely if the technology is really general.

Hp2 The greater technological uncertainty facing the firm, the greater the impact of the generality of technology on the number of product subfields subsequently entered.

<u>Scientific Knowledge, Technology Portfolio Diversification and the development of General Technologies</u>

In the second part of the paper I examine the antecedent conditions that enable firms to develop more general technologies. Understanding the antecedent conditions (where do general technologies come from?) is important. If generality is an attribute of technologies that cannot be systematically explained by managerial choice variables then the competitive implications of general technologies are different than if they can be systematically explained. In this paper I pursue the idea that understanding the full significance of general technologies may require a consideration of the process that leads to the development of these technologies.

Developing general technologies implies identifying at least to some extent what the future potential applications of the technology might be and designing it in a way that makes it applicable to different domains. However, the ability to identify ex-ante different potential uses for new technologies is severely handicapped by the tendency to view them applied in the contexts the firm is familiar with (Rosenberg, 1996). In more general terms, firms tend to engage in local search (Cyert and March, 1963; Cohen and Levinthal, 1990; Stuart and Podolny, 1996), meaning that the technological content of prior searches tends to influence the context of development of new technologies. Thus, firms' innovative search takes place in the neighborhood of the technologies currently developed and innovative activities proceed incrementally (Atkinson and Stiglitz, 1969; David, 1975, Breschi et al. 2003). In other words, firms tend to be myopic in recognizing 'distant' uses of the technology (Cohen and Levinthal, 1989; Levinthal and March, 1993).Yet, in order to develop a general technology, firms need to relate the invention to different contexts, to think about potential uses for the invention in those contexts and to design upfront the technology in a way that minimize the adaptation process required to use it in those contexts. The greater the ex-ante ability of firms to see and design the invention as a solution to problems in multiple different contexts, the greater the generality of the technology.

As an illustration, suppose that there are three downstream application domains *x, y* and *z*. Suppose that in order to operate in *x* firms need knowledge input *a*, to operate in *y* knowledge input *b* is required and to operate in *z* knowledge input *c* is required. Now think about a firm that possesses knowledge input *a* and that uses it in the application context *x*. In developing new technologies, the firm will naturally tend to think about new developments of knowledge domain *a* that solve problems for the context *x*. However this tends to constraints the firm to keep operating in context *x*. In order to operate also in *y* and *x*, the firm should design technologies in knowledge domain *a* in a way that they can be applied also to context *y* and *z*. To this purpose, firms should develop technologies that embody also elements of knowledge domains *b* and *c*, besides *a*. Evidence from previous research provides support to this mechanism, by showing that the development of technology applicable to several knowledge domains is facilitated if the firm engages in distant search. For instance, Rosenkopf and Nerkar (2001) suggest that the more the firm's knowledge builds on developments within the specified technological domain, the more these developments will impact subsequent technological evolution within the domain rather than outside. Argyres and Silverman (2004) emphasize that, when R&D processes imply more distant search, the results are more likely to have a greater overall impact and influence a larger range of technological domains.

In other words creating general knowledge implies engaging in broader search processes and finding a general solution that can solve multiple local problems compared to finding a local solution for each problem. To achieve this purpose, firms can use two possible strategies: inference through deduction or generalization through induction. The first strategy relies on the logic of deduction and consists of the process of inference in which the conclusion about local settings follows necessarily from general or universal premises. Through the process of deduction the reasoning builds on established postulates and general principles and, through a series of rigorous logical concatenations, proceeds toward specific determinations linked to practical cases. The process of deduction allow firms to avoid local search, where inventors typically search incrementally, altering one component at a time, either reconfiguring it relative to the other components or replacing it with a different component.

One possible way of implementing the process of deduction in inventing activities is by using scientific knowledge (Fleming and Sorenson, 2004). Science leads to the ability to predicts facts about phenomena without or prior to experimentation and observation (Nelson, 1959). It leads to a broader search process since it provides inventors with the equivalent of a map—a stylized representation of the area being searched and with a means of predicting the results of untried experiments and the usefulness of previously uncombined configurations of technological components (Fleming and Sorenson, 2004). Scientific knowledge generates innovations in two stages: at the first stage, researchers study a number of techniques; they then determine the yields of the techniques that were examined and, at the second stage, they employ the technique with the highest yield to develop the innovation (Gambardella, 1995). Having an understanding of the fundamental problem modifies the search process and lead inventors quite directly to the proper combinations of components to solve a particular technological problem (Lippman and McCall, 1976; Fleming and Sorenson, 2004).

Utilizing scientific knowledge may lead to the creation of general technologies by applying the logic of deduction. Scientific knowledge leads to a broader understanding and monitoring of the flow of information regarding the general theories and postulates that govern technological landscapes (Mowery 1981; Rosenberg 1990; Arora and Gambardella 1994). Science-based inventive activity is carried on at a more abstract level, i.e. phenomena under study are represented in terms of a limited number of essential elements rather than in terms of concrete features (Arora and Gambardella, 1994). Since the invention process is conducted at a more abstract level and without having any specific application contexts in mind, results are also likely to be more general rather than dependent on concrete situations. General rules derived in this way are more likely to be equidistant from specific technological contexts and, as a consequence, the breath of application of the technologies developed following this process is likely to increase.

Hp3 The greater the use of scientific knowledge in the inventive process, the greater the subsequent generality of the firm's technologies.

The second strategy that firms can employ for generating general solution relies on the logic of induction. Induction is the process of generalizing conclusions coming from particular instances, establishing a general law from the observation of particular cases. In this case the mechanism of problem solving can be thought as a process of search through a state space. (Newell, 1969; Newell and Simon, 1972; Holland et al. 1989). A problem is defined by an initial state, one or more goal states to be reached, a set of operators that can transform one state into another and constraints that an acceptable solution must meet. The process of generalization constists in selecting an appropriate state of operators that will succeed in transforming the initial state into a goal state through a series of steps (Newell, 1969). For instance one general method may involve 1) the comparison between the current state and the goal state and the identification of the differences; 2) the selection of an operator relevant for reducing the difference; 3) the application of the operator if possible and, if it cannot be applied, the establishment of a subgoal of transforming the current state into one in which the operator can be applied ; 4) the iteration of the procedure until all differences have been eliminated –i.e. the goal state can be reached.

In the specific context of technology development, generalization by induction can be thought in the following way: the process begins with firm's exposure to n technological application domains, each of which is characerized by concrete problems and by local technological solutions for each of them (initial states). The firm identifies a potential goal state, i.e. the creation of a technological solution that would fit for all the applications. The next step implies analysing the current solutions and detecting the differences between each specific technological application and the general solution. Then, the firm tries to minimizes the distance between the current states and the goal state. This process is iterated until all the differences have been eliminated. The result of the process is a technology which generalize the characteristics of the local solutions and that minimizes the distance between them.

Exposure to different technological domains can be achieved if the firm has created a technology portfolio. I define a technology portfolio as the allocation of the innovative activities of the firm across a vector of different technological areas (e.g. Argyres, 1996; Breschi et al., 2003). Building a technology portfolio can be thought of as the allocation of R&D resources across the development of multiple distinct technologies each of which is targeted to a specific downstream application (Nelson, 1961; Scott, 1988; Argyres, 1996; Granstrand, 1998; Gino and Pisano, 2006). The concept of technology portfolio stands in contrast with the concept of technology specialization, where all R&D activities of the firm are allocated as a unique, large bet on a single technology. For instance, a firm operating in the field of pharmacology might allocate all innovative activities to the development of neurological drugs would be an example of technology specialization. Dividing R&D resources between neurological, cardiovascular and dermatological drugs would be, instead, an example of the technology portfolio. Technology specialization and technology portfolio strategies can be thought as laying on a continuum: in the case of technology portfolio the number of distinct technologies the firm is investing in is N; in the case of technology specialization N equals one.

The creation of a technological portfolio may activate the process of induction that leads to generalization and, consequently, to the development of general technologies. The intuition behind this statement is that the diversification of R&D investment is likely to generate greater diversification in terms of 'local' knowledge inputs that firms master. This is going to increase the firm's ability to develop general technologies in two ways. First, the possession of diverse prior knowledge about technology application areas within the organization permits creative generation of the new knowledge (Cohen and Levinthal, 1990). Diversity within the firm knowledge parallels the benefits to diversity of knowledge within individuals minds, augmenting the capacity for making novel linkages and associations (Simon, 1985). Moreover by increasing the number and diversity of local knowledge inputs, the firm increases the number of different states to compare for the identification of the general parameter that minimizes the distance between them. As a consequence, the result of the process is going to be more general since it takes into account a greater variety of possible states of the world.

Hp4 The higher the diversification of firm's portfolio of technologies, the greater the subsequent generality of the firm's technologies.

METHODS AND MEASURES

Sample and Data

To test my propositions, I built a longitudinal dataset that collects information on a sample of photonics firms over a ten years period (from 1993 to 2002). Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing. I identify the sample using an industry directory that provides information on all firms active in the photonics industry in each year. I selected all US companies listed in the directories from 1993 to 2002 and obtained information on firms' product portfolios as well as their key characteristics (e.g. independence status, size, age, location) from the directories. In particular firms' products are classified into 15 products subfields which correspond to different types of photonics components. These subfields include, for instance, Detectors and Sensors, i.e. devices designed to convert the energy of incident radiation into another form for the determination of the presence of the radiation; Imaging, Cameras and Displays, e,g, devices to acquire or visualize images; Electronics and Signal Analysis devices, i.e. electronic devices for capturing and processing information acquired through the interaction of light and matter.

In order to collect data on firms' technologies I used company names and locations and matched firms' names to patent assignee's names in the NBER patents dataset. I include in the sample all firms that have created even one patent during the study period. The use of patent data creates some limitations for this study, since patents provide imperfect coverage of innovative activity, as not all innovations are patented or patentable. Yet, this potential bias is reduced given the length of my period of observation: although not all innovations are patented, it is very unlikely that a firm involved in R&D activity has not been granted a single patent over a 10 years period. Indeed, patenting is often used for strategic reasons by firms, such as signalling the value of the firm to external actors (Hsu and Ziedonis, 2007). Moreover, as pointed out by several scholars, patenting measures have the potential to allow a detailed analysis of the knowledge developed by firms (e.g. Griliches, 1990; Henderson and Cockburn, 1994; Ahuja and Katila, 2004).

Model Estimation and Econometric Issues

I use panel regression models for testing the above hypotheses. I test HP 1 and HP 2, through equation (1) and HP 3 and HP4 through equation (2) :

$$NS_{i,t} = f(GT_{i,t-1}, U_{i,t-1}, GT_{i,t-1} \times U_{i,t-1}, X_{i,t-1}, t, s_{i,t-1}, u_i, e_{it}) \quad (1)$$

$$GT_{i,t} = f(SK_{i,t-1}, TP_{i,t-1}, X_{i,t-1}, t, s_{i,t-1}, u_i, e_{it}) \quad (2)$$

where $NS_{i,t}$ is the number of new subfields (subfields the firm was not present in before) entered by the firm in year t, $GT_{i,t-1}$ is the generality of the technology (average from t-n to t-1), $TP_{i,t-1}$ is the technology portfolio diversification (average from t-n to t-1), $SK_{i,t-1}$ is the level of reference to scientific knowledge (average from t-n to t-1), $U_{i,t-1}$ is uncertainty, $X_{i,t-1}$ is the set of control variables, t are time effects, $s_{i,t-1}$ are subfields effects, u_i is a firm effect, and $e_{i,t}$ is an error term.

In estimating these equations I face a number of econometric concerns. Addressing Equation 1 I note four significant issues. First, there is the potential problem of unobserved heterogeneity. For instance, the firms vary systematically in their ability to enter new product categories because of factors that are not captured by my control variables or hypothesized effects. Second, since the dependent variable in (1) is a count variable and takes only non negative integer values, either a Poisson or a Negative Binomial Regression model would be appropriate (Hausman, Hall, and Griliches, 1984; Henderson and Cockburn, 1996), depending on the degree and nature of over-dispersion. A third issue that arises might be related to the fact that there is quite a large number of observations with zero value for the variable generality (about 20%). Fourth, there is likely to be a lag between the creation of knowledge reflected in patent data (the source of my independent variables) and the embodiment of that technology in the form of a new product used to enter a new product subfield. The lag is likely to be short given the dynamic nature of the technology in this business, but not entirely predictable. I address each of these concerns below.

To account for the problem of unobserved heterogeneity I use panel models that explicitly build in unobserved influences. I estimate the models using both Random Effects and Fixed Effects models. Both sets of models provide similar inferences, but the Hausman statistics indicate that the Fixed Effects models would be more appropriate.

Regarding the second issue I note that these data show mild over-dispersion. Over-dispersion primarily affects the standard errors of the estimates (and not the coefficient estimates themselves) by causing them to be deflated. Such deflated standard errors can be crudely corrected by multiplying the standard errors by the square root of Pearson's Chi-Square divided by the degrees of freedom (Allison and Waterman, 2002). As a basic measure I corrected the standard errors using this adjustment in the Poisson fixed effects model and found all results to be consistent with those reported below. However, for a fuller and more formal treatment of over-dispersion that leads to the understatement of the standard errors one can address the issue in three broad ways. One can make an assumption about the nature of the over-dispersion and use the negative binomial approach (Cameron and Trivedi, 1986). Alternately, one can continue to use the Poisson specification, but to allow for over dispersion, use the Poisson QMLE estimation procedure with robust standard errors[1]. Finally one can use a clustered negative binomial approach with robust standard errors. Each of these modelling strategies makes slightly different assumptions about the nature of the errors. In robustness checks I also estimate the model using these three alternative approaches.

To deal with the third issue, the presence of many "zero" values of generality, I used two distinct approaches in robustness checks. I estimated the above models

[1] The Negative Binomial allows for over dispersion, which is a common feature of count data. But this generality comes at a cost – if the specification of the conditional variance in the Negative Binomial is wrong, the parameter estimates at the condition mean are inconsistent, whereas the Poisson estimates of the conditional mean are consistent with over-dispersion. For this reason we adopt the Poisson specification. To allow for over dispersion, I use the Poisson QMLE estimation procedure with robust standard errors *(Schankerman* and *Belenzon,* 2008).

using an additional dummy variable to indicate observations with zero values of generality. I also re-ran the models after omitting all “zero” generality observations.

The fourth issue was in connection with the appropriate lag between the technology variables on the RHS and their embodiment in products on the left hand side. Two sub-issues are relevant here a) for how long should a technology be considered a viable part of a firm’s knowledge base (or in other words, beyond what period of time should technology be considered as unlikely to add value), and b) what is the time lag between the technology variables on the RHS and the introduction of new products (the LHS variable) based on that technology. To address the first issue, that of knowledge currency, I assume that the previous 5 years patents constitute the firm’s knowledge base in period t. This assumption is consistent with other work in similar dynamic industries and appropriate for this industry (Argote, 1999; Ahuja and Katila, 2002). Thus, I compute the means of the correspondent independent variable for times from t-5 to t-1. Although I report the results for t-5 through t-1 for robustness I also computed the measure using the 3 year prior period (t-3 through t-1) and the 7 year prior period (t-7 through t-1). With respect to the second issue, I note that the time lag between the development of a technology and the launch of a product in the market may take one to two years. To address this issue I use two alternative specifications. I report my primary results using a one year time lag. However, I also performed a distributed lag analysis taking into consideration two lags - a one year lag and a two year lag (Ahuja and Katila, 2001).

The dependent variable in (2) is a continuous variable that can only take values greater than zero, hence I use a Panel Tobit regression approach, where I set the lower bound equal to zero. The Tobit model does not permit a fixed effects specification so I use a Random Effects Tobit specification. For robustness, I re-estimated the models using a logged dependent variable with a linear panel regression model. Although this is not an optimal specification for the dependent variable, the results were very similar. I also used a regular Tobit model with clustered robust firm errors to test for robustness and found similar results.

Variables Definition and Operationalization

Dependent Variables

I measure the construct of **entry into new subfield** as the number of entries in year t in a subfield that the firm has not been present in before. I calculate this measure using data from the photonics directory. Photonics products fall into fifteen distinct subfields. In counting products, I only consider those products that the firms manufactured themselves and introduced on the market.

Independent variables

The core construct of **generality** of technology refers to the applicability of the technology to multiple domains. I use patent data to compute this variable. I measure it at the firm level as the average number of technological classes assigned to the firm's patents at the time of application. At the time of application, patent examiners search the patent file and assign each patent to a variable number of technological classes, depending on the domains the innovative input of the patent contributes to (Gittelman, 2008). It is reasonable to expect that patents classified into a greater number of technological classes have a greater scope of applicability, i.e. a greater generality.

The construct of **scientific knowledge** refers to the influence of science in the process of invention. To measure this construct I refer to non-patent references (Narin et al. 1997; Fleming and Sorenson, 2004). In addition to citing the prior art (previous patents), U.S. patents also cite a variety of non-patent literature, including scientific journals. Previous studies have emphasized that non-patent references provide a reasonable indicator of the influence of science (Fleming and Sorenson, 2004). I take non patent references as an indication that the inventor made use of scientific knowledge in the process of invention. I calculate this measure as the proportion of the firm's patents that referenced non patent publications on the total number of firm's patents in the years from t-n to t-1. As a robustness check I use two alternative measures: the average number of scientific references per patent made by the firm in the previous years, from t-n to t-1; a dummy variable equal to 1 whether the firm's patents in the years from t-n to t-1 made any scientific reference.

The construct of **technology portfolio** refers instead to the investment in multiple distinct technologies. I measure it as the Blau index (1- Herfindahl) of primary technological classes of the patents granted by the firm. To compute these measures I refer to US technological classification. In order to check the robustness of my results I referred both to 3 digit and 6 digit classification. Also, since patents are reclassified over time, it is very important to go back to the classification that each patent has been assigned to at the time of the invention, in order to avoid obtaining biased results. To address this concern, I use the Delphion-Derwent database to collect data on patent technological classification at the time of the invention. In order to reflect the temporal precedence of the technology being developed before the product I calculated independent variables as the average of the relevant variable from t-n to t-1. To check the robustness of these results I run different models by setting n equal to 3, 5 and 7 respectively.

Uncertainty refers to the extent to which firms are able predict the future outcomes of their technological investments. To measure this variable I use the Technology Cycle Time (TCT) indicator. This is computed at the firm level as the median age in years of the firm's patents backward citations. TCT measures the time between the previous patents upon which current patents are improving and current patents themselves (Oriani and Sobrero, 2008). Since the lower the median age, the higher the uncertainty, I transform the TCT indicator by multiplying each value by -1 so that larger values of the resultant variable measure higher levels of uncertainty.

Controls

I introduce in the analysis a set of controls that might affect the predicted relationships. I include a measure of the *firm's size*, calculated as the number of employees in year t. I control for the *firm's age*, measured as the count number of years elapsed from the firm's establishment to year t. I measure firm's *R&D intensity,* as the share of the number of engineers over the total number of employees in year t. I also control for the *firm's knowledge stock*, measured as the number of patents applied by the firm in the previous n years not including year t. I include a measure of the *product scope of the firm*, measured as the total number of product subfields the firm is active in. Finally I include in the analysis *time controls, subfields dummies* and firm's fixed effects.

Table 1 lists variables and descriptive statistics. Table 2 displays correlations between the main variables in the analysis.

Insert Tables 1 & 2 near here

RESULTS

Tables 3 shows the main results from the Fixed Effect Poisson Regression and Negative Binomial Regression estimating firm's entrance into new subfields (Equation 1). I test Hypotheses 1 and 2 in Models 1-2. Models 1a, 1b and 1c include only the main effects while Models 2a, 2b and 2c include the interaction effects between general technology and uncertainty. Results from these analyses show that the generality of the technology has a positive and significant impact on the number of new subfields entered by the firm (subfields the firm has never been active in). These results support Hypothesis 1. Moreover I find a positive and highly significant effect of the interaction term between general technology and uncertainty on the dependent variable. This suggests that when uncertainty is high, having invested in more general technologies increases firm's ability of introducing products in new subfields, supporting Hypothesis 2. The validity of these findings is supported also by the additional models ran as robustness checks, i.e. the clustered Poisson and Negative Binomial regressions with robust standard errors and the Poisson and Negative Binomial distributed lag analysis.

Insert Table 3 near here

Table 4 show the main results from the Panel Tobit regression approach, estimating the generality of the technology (Equation 2). Results from Models 3 suggest that both having been exposed to scientific knowledge and to a diversified technology portfolio influence positively and significantly the development of more general technologies. These results provide support for hypotheses 3 and 4.

Insert Table 4 near here

To check the robustness of these results I also performed additional robustness check analyses in which I used different aggregation levels for the technological classifications (i.e. 3 digit and 6 digit measures of technological classes). I also used different specifications for reflecting the temporal precedence of the technology being developed before the product is launched. Specifically, I calculated technology related measures as the average from *t-n* to *t-1* of the relevant dependent variable, where n equaled 3, 5, 7 in different specifications. All these analyses supported my hypotheses.

It is also possible that investments in general technologies may be endogenous to the outcome variable studied here, the launching of new products in new product categories. To address this potential concern I computed predicted values of generality using exposure to science as an instrument variable. I then used this instrumented value as a regressor in the second stage, where I predict entrance into new subfields as a function of generality of technology and interaction between generality and uncertainty plus the control variables (Equation 1). The results from this regression (provided in Table 5) also support the results reported above.

DISCUSSION AND CONCLUSION

This paper addresses a relevant question not answered by previous research: in the face of uncertainty, how can firms make ex-ante technological investments that prove valuable ex-post? I identify one mechanism allowing firms to deal with uncertainty ex-ante, i.e. investing in general technologies (i.e. technologies that can be adapted relatively easily to different technological domains rather than being specialized to a single domain). I explore the construct of general knowledge on two dimensions. First, I investigate how investment in general technologies may increase firms' ability to tackle technological uncertainty. Technological uncertainty concerns, for instance, whether a certain new technology is technically feasible to solve certain categories of techno-economic problems or what are the subfields that a certain technology can be most successfully applied to. I theorize that in the case of technological uncertainty, investment in a general technology increases the rate of entry into new market subfields. This constitutes a source of superior performance for the firm in allowing to launch different applications of the technology and by creating a source of protection against the risk of failure in any one of them.

Having shown that investment in a general technology opens up strategic opportunities in the face of uncertainty, I focus on understanding how firms successfully create such technologies. By relying on the fundamental premise that creating a general solution fitting different kinds of problems parallels the creation of more abstracted knowledge, I identify the cognitive mechanisms that lead firms toward the development of general technologies, i.e. deduction - the process of building on established postulates and principles to logically draw conclusions on practical cases- and induction - the process of generalizing conclusions coming from particular instances. I argue and find empirical support for the argument that deductive development as reflected by prior exposure to scientific principles, and inductive development as reflected by prior involvement in multiple distinct technologies, both enhance the likelihood of successfully creating general technologies.

My findings have important implications for research in the resource-based view, the relationship between prior experience and new business entry, and research on general purpose technologies. This paper fills an important missing component of the resource based view of the firm. The RBV fosters the idea that firms can achieve superior advantage on the product market by making early superior investments in the factor market. Yet, extant literature in this area has not provided a clear understanding on how firms, in the face of uncertainty, can identify and make superior investments ex-ante. A partial answer to this crucial question comes from literature on strategic foresight, which posits that firms are able to anticipate, at least to a certain extent, the state of the world that will eventually emerge and consequently identify and make the investments that will turn out more profitable in the future. Although research in this area has demonstrated the linkage between strategic foresight and competitive advantage (e.g. Ahuja, Coff and Lee, 2005), previous studies have not identified specific strategies that may enable firms to obtain ex post benefits from ex- ante investments.

I identify investment in general technologies as one mechanism, by which firms can ex-ante develop resources that will turn out valuable ex post. By showing that investment in general technologies represents a source of superior performance for firms facing uncertain environments, I support the idea that competitive advantage does not necessarily come from specialized dedicated investments (Wernerfelt, 1984; Madhok and Tallman, 1998), but can come from flexible and general ones. In these respects, the distinction between general and specific technologies can be paralleled to the distinction between usage-flexible and usage-specific resources (Ghemawat and DelSol, 1998).

This study also raises some intriguing possibilities in terms of improving our understanding of the relationship between a firm's prior technological experience and its ability to enter and succeed in new technological areas. Studies examining the effect of prior experience on entry and success in new businesses have found conflicting results. On the one hand scholars find that having prior experience in related subfields eases entry and success in emergent subfields (e.g. Cohen and Levinthal, 1994; Klepper and Simon, 2000; Tripsas and Gavetti, 2000, Cattani, 2004). Other studies have highlighted how existing endowments can constitute a barrier to change (e.g. Levitt and March, 1988; Leonard Barton, 1992; Christensen and Bower, 1996; Christensen, Suarez and Utterback, 1998). This study contributes to this stream of research by identifying a possible conceptual link that may have been omitted in previous research in this area. I suggest that the relationship between pre-entry experience and successful new business entry may be conditioned on the use of an intermediate process by the entering firm, that of investing in generalizing knowledge. By showing that investment in a diversified technological portfolio and in scientific knowledge lead firms to develop more general knowledge - which ultimately results in a superior ability of entering into new subfields-, I demonstrate that prior endowments are relevant for firm's successful entry into new subfields to the extent that firms' are able to convert the pre-accumulated knowledge into general and higher order knowledge. It appears that a process of abstraction and generalization might be necessary to convert a pre-entry experience into an asset when a firm enters new markets.

My argument above also suggests a fascinating conjecture to be tested by future research. Past research has focused on the technological distance between the businesses that a company is present in and the businesses that it seeks to enter to predict entry or success in the new business. Yet, recognition of the need to be able to generalize (either by exposure to science or multiple different technologies) suggests that successful entry is not conditioned only on the similarity or dissimilarity of a firm's existing technology from the technology in the new business but also on the breadth of the firm's existing technological base. Broader technological bases may help firms to abstract better and thus promote successful entry into new markets. Note that this argument suggests a different causality for the classical Nelsonian hypothesis than is argued by Nelson. In the Nelsonian case diversification breadth serves as a guarantee that a new idea generated by basic research may find application somewhere in the firm. Thus it suggests that broadly diversified firms have *incentives* to do basic research, but it does not predict that such research is necessarily more *productive* in broadly diversified firms. My argument suggests that such research is also more likely to be productive (eg. lead to more new products) when conducted in diversified firms because such firms can generalize from their experiences. Although the prior literature has suggested that breadth of exposure may be related to the possibilities of cross-fertilization of knowledge across a firm's different businesses my paper suggests a specific form of cross-fertilization – abstraction and superior generalization as the basis for technological benefits for diversified firms.

The research in this paper also offers a potential contribution to the literature on general purpose technologies. Two characteristics of the literature on general purpose technologies are worth noting a) it has generally sought to identify GPT's on the basis of their *pervasiveness*, and b) it has generally focused on the *effects* of GPTs such as their role in fostering technical change and growth. Pervasiveness is an ex-post attribute and reliance on it for ex-ante identification is difficult. It also leaves the GPT literature open to criticism that any technology can be called a GPT with the benefit of hindsight (Field, 2008). Further, for GPT's to be a managerially manipulable construct understanding the origins of GPT's is perhaps as critical as understanding their effects. In this paper I try to advance the GPT agenda by addressing both these argued limitations of the GPT literature.

I begin by characterizing technologies along an underlying continuum of generality on an ex-ante basis thus identifying GPT's as one end of a conceptual spectrum from specific to general purpose technologies. Thus, technologies can vary in their degree of generality and can be fairly general without being pervasive. By providing an approach to assess the generality of a technology I provide teeth to the distinction between general and specific technologies, as the "generalness" of technologies can be measured ex-ante and lead to falsifiable predictions. Second, I explore the antecedents of generality in technologies rather than only the effects of generality. In doing so I am able to demonstrate that certain firm level investments are required to facilitate the development of GPT's; further, these facilitators (exposure to science and a broad technology portfolio) can be strategically manipulated in the sense that firms can plan and invest in developing these facilitative capabilities. I implicitly recognize firms' intentionality in the deliberate choice of investing in technologies more easily adaptable to different possible states of the world. These arguments and empirics thus provide at least prima-facie support for the feasibility of developing a general technology ex-ante. Further exploration of the relationship between managerial intent and the emergence of general technologies is then a natural task for future research.

TABLES

TABLE 1 Descriptive Statistics

	Variable	Obs	Mean	Std. Dev.	Min	Max
1	**New product subfields entered in year t**	1420	0.44	0.91	0	8
2	**Generality of the technology in year t**	1420	1.10	1.92	0	13
3	**Generality of the technology (average from t-5 to t-1)**	1420	2.37	2.21	0	12
4	**Uncertainty**	1420	-2.41	3.57	-18	0
5	**Technology Portfolio Diversification**	1420	0.63	0.41	0	1
6	**Investment in Scientific Knowledge**	1420	0.25	0.37	0	1
7	**Firm's scope**	1420	4.55	2.26	1	13
8	**Knowledge Stock (number of patents)**	1420	5.89	30.54	0	762
9	**R&D intensity**	1420	0.29	0.21	0.01	1
10	**Firm's age**	1420	22.54	19.02	2	166
11	**Firm's size**	1420	3.86	1.30	1.10	10.13

TABLE 2 Pairwise Correlations

	Variable	1	2	3	4	5	6	7	8	9	10	11
1	**New product subfields entered in year t**	1										
2	**Generality of the technology in year t**	0.05	1									
3	**Generality of the technology (average from t-5 to t-1)**	0.05	0.26	1								
4	**Uncertainty**	-0.02	-0.15	-0.42	1							
5	**Technology Portfolio Diversification**	-0.03	0.10	-0.52	0.27	1						
6	**Investment in Scientific Knowledge**	0.00	0.22	0.47	-0.41	-0.20	1					
7	**Firm's scope**	-0.15	0.03	0.08	-0.15	-0.04	0.08	1				
8	**Knowledge Stock (number of patents)**	0.02	0.18	0.12	-0.08	0.10	0.13	-0.02	1			
9	**R&D intensity**	0.02	0.06	0.05	-0.11	-0.08	0.14	0.09	-0.03	1		
10	**Firm's age**	-0.06	-0.06	0.00	0.06	0.07	-0.02	0.03	0.07	-0.35	1	
11	**Firm's size**	0.02	0.17	0.16	-0.01	0.11	0.09	0.08	0.27	-0.46	0.42	1

TABLE 3 Fixed Effect Poisson and Negative Binomial Regression

	Number of new subfields entered in year t	Number of new subfields entered in year t	Number of new subfields entered in year t	Number of new subfields entered in year t	Number of new subfields entered in year t	Number of new subfields entered in year t
	Model 1a	Model 1b	Model 1c	Model 2a	Model 2b	Model 2c
	Fixed Effect Poisson Regression	Fixed Effect Poisson Regression (Robust)	Fixed Effect Negative Binomial Regression	Fixed Effect Poisson Regression	Fixed Effect Poisson Regression (Robust)	Fixed Effect Negative Binomial Regression
Generality (average from t-5 to t-1, 6dgt)	-0.03	-0.03	0.04	0.14 **	0.14 *	0.14 **
Uncertainty	0.00	0.00	0.01	-0.19 ***	-0.19 ***	-0.11 *
Generality X Uncertainty				0.07 ***	0.07 ***	0.04 **
Technology Portfolio diversification	-0.20	-0.20	0.08	0.25	0.25	0.36
Firm's scope	-0.23	-0.23	-1.31	-0.28	-0.28	-1.30
Knowledge Stock (Number of patents)	0.00	0.00	0.00	0.00	0.00	0.00
R&D intensity	0.07	0.07	0.05	0.46	0.46	0.08
Firm's age	-0.04	-0.04	-0.02	-0.03	-0.03	-0.01
Firm's size	0.32 *	0.32	0.10	0.35 **	0.35	0.08
Time Dummies	Included	Included	Included	Included	Included	Included
Subfields dummies	Included	Included	Included	Included	Included	Included
Constant			0.32			-1.27
Number of observations	1420	1420	1420	1420	1420	1420
Log likelihood	-706.10	-706.10	-637.76	-695.61	-695.61	-634.49
Wald chi2	(29) 232.65	(29)190.57	(29)125.26	(30)248.11	(30)220.33	(30) 131.38
Prob > chi2	0	0	0	0	0	0

TABLE 4 Panel Tobit Regression

	Generality of technology in year t
	Model 3
	Panel Tobit Regression
Technology Portfolio diversification	1.57 ***
Investments in Scientific Knowledge	1.76 ***
Uncertainty	-0.07
Knowledge Stock (Number of patents)	0.01
Firm's Scope	-0.30
R&D intensity	2.25 **
Firm's age	-0.04 ***
Firm's size	0.98 ***
Time Dummies	Included
Subfields Dummies	Included
Constant	-6.67***
Number of observations	1420
Log likelihood	-1644.58
Wald chi2	(29) 92.88
Prob > chi2	0

TABLE 5 Fixed Effect Poisson and Negative Binomial Regression (Instrumented)

	Number of new subfields entered in year t	**Number of new subfields entered in year t**	**Number of new subfields entered in year t**
	Model 4°	Model 4b	Model 4c
	Fixed Effect Poisson Regression	Fixed Effect Poisson Regression (Robust)	Fixed Effect Negative Binomial Regression
Generality of the Technology	0.81 ***	0.81 ***	0.72 **
Uncertainty	-0.15 **	-0.15	-0.14 *
Generality X Uncertainty	0.12 **	0.12 *	0.12 **
Technology Portfolio diversification	-0.05	-0.05	0.06
Firm's scope	-0.24	-0.24	-1.28
Knowledge Stock (Number of patents)	0.00	0.00	0.00
R&D intensity	0.22	0.22	0.04
Firm's age	-0.04	-0.04	-0.02
Firm's size	0.30 *	0.30	0.09
Time Dummies	Included	Included	Included
Subfields Dummies	Included	Included	Included
Constant			-0.99
Number of observations	1420	1420	1420
Log likelihood	-702.27	-586.56	-635.19
Wald chi2	(30)238.12	(30) 199.67	(39) 130.02
Prob > chi2	0	0	0

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WHAT DOESN'T KILL YOU MAKES YOU STRONGER: GENERAL TECHNOLOGIES, SUPPORTING ASSETS AND FIRM SURVIVAL

ABSTRACT

Technology based firms make important decisions regarding what types of technologies to develop and how much to invest in developing the supporting assets required to commercialize those technologies. For instance, firms can choose to invest in general technologies (that solve broad classes of problems and can be used in multiple different application domains) or specific technologies (that focus on a specific type of problem and can be applied in only a narrow domain). Similarly, firms can choose to invest heavily in the supporting assets (such as manufacturing facilities) required to commercialize their technology or keep their investments in supporting assets low. In this study I examine these two features of firms' technological investments and study their direct and interactive effects on firm survival. I theorize that even though generality itself reduces the likelihood of business unit survival as does investment in supporting assets, jointly they have a positive effect. Results from the empirical test, conducted on a sample of photonics firms, support these prediction. These findings are important for both theoretical and practical reasons. Theoretically speaking, these results inform the debates on the importance of investment flexibility and supporting assets for firm survival by identifying conditions under which flexibility and supporting assets are beneficial (see Teece, 1986 and related studies). Practically, these findings provide new insights to guide future technological investments by high technology firms.

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INTRODUCTION

Technology based firms make important decisions regarding what types of technologies to develop and how much to invest in developing the supporting assets required to commercialize those technologies. For instance, firms can choose to invest in general technologies (that solve broad classes of problems and can be used in multiple different application domains) or specific technologies (that focus on a specific type of problem and can be applied in only a narrow domain). Similarly, firms can choose to invest heavily in the supporting assets (such as manufacturing facilities) required to commercialize their technology or keep their investments in supporting assets low. In this study I examine these two features of firms' technological investments and study their direct and interactive effects on firm survival. Understanding these effects is important for both theoretical and practical reasons. Theoretically speaking, studying these decisions can inform the debates on the importance of investment flexibility and supporting assets for firm survival by identifying conditions under which flexibility and supporting assets are beneficial (see Teece, 1986 and related studies). Practically, learning from these arguments can help us to guide future technological investments by high technology firms.

Several streams of research have focused on understanding the impact of making general versus specific resource investments on firm performance (for instance, Hannan and Freeman, 1977; Dierickx and Cool, 1989; Ghemawat, 1991; Peteraf, 1993). In particular, extant literature has underlined the existence of a tradeoff between these two choices, with general resource investments facilitating change by reducing commitment to any specific setting (e.g. Nelson and Winter, 1982), and specific resource investments maximizing performance in a given setting (e.g. Ghemawat, 1991). This recognition of the tradeoff between generality versus specificity has emphasized one key point: the benefits of generality are *not* costless. Yet, studies in the strategy literature have not systematically investigated the specific costs of building flexibility through general investments. This paper aims to address this important gap in our understanding of flexibility by identifying some key conditions under which 'general' resource investments are beneficial for firm performance.

Specifically this study examines the role of investing in general technologies on firm survival. General technologies are defined as higher order technologies that can be applied in multiple domains (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998; Novelli, 2009). An increasing number of studies fosters the idea that developing more general technologies is beneficial for firms since it broadens their opportunities. For instance, Gambardella and Giarratana (2009) show that when the product market is fragmented, firms with more general technologies have more opportunities to license them out to others. Novelli (2009) argues that investments in generality are helpful in launching products into different market categories as an effective mechanism to tackle technological uncertainty. Although these are important implications of general technology, by themselves they do not necessarily establish that generality leads to superior performance. For generality to be valid as a performance enhancing strategy it should be the case that investments in generality should lead to direct performance benefits such as sales or profit growth or superior survival chances.

Similarly, the literature on supporting or complementary assets has long argued that possession of such assets constitutes an advantage in commercializing technologies (Teece, 1986; Mitchell, 1989, 1991). Indeed there are celebrated case-studies that document how firms failed even after inventing high potential technologies because they lacked the supporting assets to commercialize these inventions (eg. EMI and the CT Scanner, Bartlett, 1983; Mitchell 1989, 1991; Mitchell and Smith, 1994). However, interestingly, little research has investigated the possibility that investments in supporting assets are themselves likely to be risky. Supporting assets are likely to entail a significant fixed cost component and such fixed costs will drive the breakeven point higher for firms that invest in such assets. With finite resources, a significant commitment to high fixed costs may increase the firms operating leverage and overall riskiness of the firm (Ahuja and Lahiri, 2008). Higher breakeven points may put the firm's survival at stake.

It may thus be the case that investing in supporting assets may lead to a bimodal outcome for firms. For firms that survive the higher breakeven engendered by investments in fixed cost intensive supporting assets, these supporting asset may constitute a competitive advantage. However, investing in such supporting assets may itself lead to higher failure rates for firms. If indeed the latter is true it also raises a methodological issue of relevance for the literature – investigating the impact of supporting assets on outcomes such as firm financial performance may suffer from a selection bias if the effects of such assets on organizational mortality are not controlled for. In this study I examine the impact of investing in supporting assets on the survival of a large sample of small and large firms.

To better understand the trade-offs in investing in general technologies and supporting assets I also consider the interactive effect of decisions in these two domains on business unit survival. Given that generality raises the possibility of both benefits (such as the ability to launch products in multiple categories) and risks (such as the possibility that such products are not as well suited to specific markets), it appears that generality may be a survival enhancing strategy only under specific conditions. Similarly, investments in supporting assets increase the riskiness of the business by increasing its break-even volume, but may also provide a competitive advantage. Thus, the benefits of supporting assets may also be conditional. To explore these joint conditionalities I develop a model that relates generality and supporting assets to business unit survival. I predict that by themselves investments on generality or supporting assets are likely to be risky from the perspective of business unit survival. However, investing significantly in supporting assets may enhance the viability of a generality strategy or alternately, the risks introduced by investing in supporting assets may be moderated by investing in general technologies. I find support for my contentions in that the main effects of generality and supporting assets are to reduce the survival chances of firms; however, when general technologies are also accompanied by supporting assets as is likely in large organizations, the dangers of generality are reduced. Thus, it appears that generality is better suited to certain kinds of firms or alternately, that the choices of investing in general technologies and supporting assets are complementary to each other.

The issues that I address are important from the perspective of improving our understanding of how firm's investments influence firms' performance and more specifically firm's survival. One of the key assumptions made by research investigating the determinants of firms' survival is that firms choosing between a broad versus a narrow scope strategy face a trade off: firms with a broader scope keep slack resources as a mechanism of protection against an uncertain environment; firms with a narrow scope, instead, maximize exploitation and efficiency, focusing on a narrow set of resources and markets (Hannan and Freeman, 1977; Usher, 1999). Despite the relevance of these contributions, this stream of research has mainly investigated firm's scope from a product portfolio perspective. Extant research has not looked very closely at the underlying characteristics of firms choosing one versus the other strategy and, more specifically, has not looked at the characteristics of the firms' prior investments. This paper contributes to research in this area by showing how firm's investment in technology and in supporting assets jointly affects the survival of firms.

Moreover by showing how the interaction between how upstream investments (technology) and downstream investments (manufacturing) jointly affect performance, my study contributes to research in the strategy area by supporting the idea that, in order to achieve superior performance, firms' strategic choices cannot be determined in isolation. Rather, firms need to maintain a tight coherence among their activities and identify configurations that are internally reinforcing (Levinthal, 1997; Siggelkow, 2002; Siggelkow and Levinthal, 2003). Indeed, since decisions interact with each other – i.e. the resolution of one decision affects the costs and benefit associated with the other- strategizing ultimately deals with the search for the best set of choices (Rivkin and Siggelkow, 2006). I contribute to this research stream by focusing on the choice of developing general versus specific technologies and showing that the performance of this strategy depends critically on the fit with other relevant choices of the firm, such as the investments in supporting assets.

This paper also contributes to the literature on supporting assets. Building of Teece's 1986 seminal work, research on this topic has mainly emphasized the positive effects of having invested in complementary assets, which allow innovative firms to appropriate a higher share of value from their innovations (e.g. Levin et al, 1987; Cohen et al. 2000). Other studies, however, have suggested that investment in facilities is also likely to lead to fixed or sunk costs and this way to increase the riskiness of the business proposition, especially in dynamic environments (e.g. Harrigan, 1985;1986; Ahuja and Lahiri, 2008). I contribute to research in this area by demonstrating one mechanism that firms can use to improve their ability to deal with the risk of downstream investments, i.e. investment in more general technologies. By being more easily adaptable to different contexts and applications, general technologies ease firms' search for new uses for the supporting assets reducing the risk of facilities obsolescence.

THEORETICAL BACKGROUND AND PREDICTIONS

Generality of the Firm's Technology and Firm's Survival

General technologies are defined as higher order technologies that can be applied in multiple domains (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998; Novelli, 2009) as opposed to specific technologies, solutions to specific problems related to a circumscribed application domain. An example of the distinction between general technologies and specific technologies can be drawn from the comparison of a technology for polymer synthesis versus a technology for the creation of optical films in the field of chemical science. The former is a general technology since it can be used in different application domains: for instance, it can be used for the creation of optical films, agrichemical materials, pharmaceutical delivering systems and heat resistant separation systems. Conversely, the development of a technology for optical films can be thought off as a specific technology, since its usage is limited to a more narrowly defined domain (Novelli, 2009).

Extant literature that has looked at general technologies has emphasized the benefits of developing more general technologies, identifying mainly the benefits provided by these technologies in expanding firms' opportunities. The underlying mechanism emphasized by these studies is that, since general technologies are general solutions that can solve multiple problems, firms may use these technologies in different application domains (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998; Shane, 2004; Gambardella and Giarratana, 2009; Novelli, 2009). However these studies do not investigate the effect of a general technology strategy on firms' performance and, in particular, on firms' survival. Understanding this issue would help in -addressing a relevant puzzle: if greater generality is beneficial for firms, then why do not all firms develop more general technologies?

More specifically, research that has investigated the distinction between general versus specific technologies has mainly focused on one feature of technology, i.e. the breadth of domains that these technologies can target. The literature suggests that the breadth of application of general technologies is a result of the fact that the creation of a general technology implies the integration of different knowledge inputs pertaining to different knowledge domains for the purpose of generating more abstract and general knowledge (Arora and Gambardella, 1994; Novelli, 2009). The result of this process is a solution that can fit multiple problems, pertaining to different domains. Conversely, specific technologies can be thought as solutions to specific problems related to circumscribed application domains. As an illustration think about the distinction between a broad-spectrum and a narrow spectrum antibiotic. A broad spectrum antibiotic is active against a wide range of disease-causing bacteria, while a narrow spectrum antibiotic is effective against only specific families of bacteria.

However, general technologies and specific technologies differ from each other on two additional features that are relevant in determining the firm survival, i.e. their problem solving effectiveness and their underlying cost structure. The problem solving effectiveness of a technology refers to how successfully a technology addresses a given problem. A specific technology is the repository of specific problem solving information. The relevant knowledge embedded in the solution is fine tuned to the specific application that is being targeted. Conversely, the very general nature of general technologies makes them necessarily more standardized and abstract than specific problem solving solutions. Although a general technology may solve a broad number of problems, this breadth comes at the expense of the effectiveness in solving each specific problem. More precisely, a general technology - i.e. a solution for multiple problems - is reached by comparing different problems, identifying a common core, abstracting it away from the specific contexts in which it is embedded, and finding a solution that addresses the core problem rather than the specific representations of it. This necessarily requires a certain deal of compromise. As an illustration think about spectrophotometer technologies for analyzing the pureness of chemical materials. Some of these technologies are general in the sense that they cover a wider spectrum of wavelengths. However this flexibility comes at the cost of sensitivity, which is higher in spectrophotometers with a narrower spectrum.

The third distinction between general and specific technologies regards the cost structure implied by them. Developing general technologies requires an early decision to develop the technology in a way that makes it adaptable to multiple uses.

This additional cost of abstraction is likely to correspond to an additional upfront cost of development relative to more specific technologies. Moreover, to be effectively used in each application, general technologies require an additional adaptation cost (Bresnahan and Gambardella, 1998). Conversely, the creation of a specific technology does not entail a higher upfront cost for individual technologies or adaptation costs. However the opportunity of using the same technology for applications different from the intended one – and thus amortizing the initial R&D expenditures – is reduced.

The three differences between general and specific technologies outlined above – i.e. breadth of application, problem solving effectiveness and underlying cost structure – are likely to influence the survival of firms that choose to develop one technology type versus another by increasing the firm's exposure to risk for three reasons. First, the development process of a general technology is likely to be, per se, riskier. Creating more abstract solutions requires an additional effort to integrate information from different knowledge domains. This process is more complex and implies a superior capacity of abstraction, which may be the result of some preconditions such as a superior investment in scientific knowledge or a greater exposure to different knowledge domains (Cohen and Levinthal, 1990; Novelli, 2009). The complexity of the process increases the risk of failure in the sense that if firms go after more abstract solutions this may increase the uncertainty that a solution is found at all. Although some firms succeed in finding more general solutions than others, this also implies that their revealed preference to develop more general technologies rather than specific ones exposes them to a higher risk of failure in developing any solution to a problem.

Second, while being endowed with a resource with greater breadth of application is an opportunity, being able to exploit it successfully may be tricky. On the one hand, targeting multiple applications provides the firm with an opportunity to operate in multiple markets and increase its sales. In the case of firms with more general technologies this may also correspond to an increase in profits, since the costs of developing the technology may be less than proportional to the number of different markets targeted. This effect is based on the logic of lower joint costs of production per unit of output (Penrose, 1959; Rumelt, 1974). Since the cost of developing a general technology is borne by the firm only once, employing the same technology into different applications allows the firm to reduce overall costs. However, entering multiple businesses requires the firm to develop specialized market knowledge to serve customers with different preferences as well as specialized supporting assets. As suggested by Bresnahan and Gambardella (1998), this reduces the opportunity of pursuing scale economies and creates a force toward localization that may adversely affect the cost structure.

Third, by promoting multiple product launches, a general technology increases coordination uncertainty for the firm. As suggested by Barnett and Freeman (2001), the introduction of multiple products may lead the firm to experience disruptions that emerge because product innovation typically requires adjustments in various parts of the organization. For the introduction of a single new product, these accompanying adjustments throughout the organization may be straight-forward. To fully exploit general technologies however firms will generally need to launch multiple products. When multiple innovations occur, adjustments made for one change may complicate adjustments made for the others. They argue that this effect is magnified when products are interdependent from one another since interdependent products are more likely to interfere with one another (Hannan and Freeman 1984, Henderson and Clark 1990, Carroll and Teo 1996, Sorenson 1997). By increasing the interdependence between products as a result of the fact that multiple products are based on the same technology, a higher degree of general technology increases the hazard of failure for the firm. These two opposite effects create a critical puzzle for firms. Going after all the opportunities created by a general technology exposes the firm to a higher risk due to the fact that high complementary investments are also required. However, focusing on a few applications does not pay back the extra effort of having developed a more general technology and this may create some financial distress for the firm, which increases the hazard of failure.

Firms with more general technologies may also have a higher exposure to risk for another set of reasons that relate to the adaptation process required for exploiting the same general technology in multiple application domains. Even if a more general technology is more easily adaptable to any given setting than a specific technology, the adaptation process may still be problematic. For instance, using the general technology for delivering products in a setting it was not targeted for necessarily implies some compromise costs that originate from the design activity being subject to the constraints imposed by the technology (Porter, 1985). Even if the company succeeds in the adaptation process and is able to enter the targeted market, products based on the general technology may be less effective or may create less value for customers than competitor’s products, specifically targeted to more accurately meet customers demand. These arguments suggests that:

Hp1 The higher the generality of a firm’s technologies the greater the subsequent hazard of the firm’s failure.

<u>Supporting Assets and Firm Survival.</u>

Several studies in the strategy and innovation management research areas have investigated the role played by downstream investments in determining firm’s performance (e.g. Teece, 1986; Tripsas, 1997; Rothaermel and Hill, 2005). Building on Teece’s 1986 seminal work, the extant literature on supporting assets has emphasized that access to supporting assets is a key determinant of firm performance especially in the case of innovative firms, since it provides an extra layer of protection against imitation and it consequently allows firms to appropriate more value from their innovations (e.g. Levin et al, 1987; Cohen et al. 2000). Less attention has been devoted to a second important consequence of investment in supporting assets, i.e. that investment in facilities is likely to lead to fixed or sunk costs and thus increase the riskiness of the business proposition. Since all factors that increase risk for firms ultimately reflect on their survival, this issue becomes fundamental in the context of this paper.

As underlined by Teece (1986, p. 293), investment in supporting assets is risky for several reasons. First, a high investment may be necessary in order to buy or build the supporting assets, and to manage and maintain them (Teece, 1986; Jacobides, 2006). This may cause the firm to suffer a great financial or cash exposure that may increase the hazard of failure for a firm (Harrigan, 1981, 1983). Further, to the extent that supporting assets entail fixed costs such investments may increase the breakeven volume for the firm. Continued survival may then depend on substantial and stable volumes of sales. However, in an emerging technology context substantial and stable sales may be difficult. Especially for industrial products sales volumes may fluctuate with the business cycle or technology change cycle. Further, continued entry by firms as is common in high technology settings may make gaining or retaining a substantial volume of sales difficult. In such a situation the high break-even may prove dangerous to survival.

Second, higher investments in downstream assets, such as investments in plants, may reduce the flexibility of the firm in the face of a dynamic environment for both demand and supply reasons. For instance, consumer preferences may change to the extent that a certain manufacturing procedure becomes inappropriate to respond to customers' needs, or a certain market niche may disappear. However investments already made in facilities may not be adaptable to the changed market environment (Klepper and Thompson, 2006). These demand effects are intensified with supply side challenges in environments characterized by a high rate of technological change, such as in high tech industries (Harrigan, 1984, 1985; Teece, 1986; Afuah, 2001). Higher rates of technological change imply that plants and equipments become obsolete more quickly. This implies that the costs of keeping facilities up-to-date may rise exponentially..

Third, the extent of downstream investment may interfere with the innovative activity of the firm (Ahuja and Lahiri, 2008). Indeed, since accessing complementary assets inevitably changes the scope of a firm, this may entail a limitation in coming up with future innovations (Jacobides et al., 2006) as innovative behavior may become conditioned by prior manufacturing investments rather than the best technical solutions to a problem. Indeed recognizing these various limitations of investing in supporting assets the literature suggest that only if the combination of some very specific conditions occurs (e.g. the appropriability regime is weak, specialized assets are critical, imitators and competitors are better positioned and the cash position of the firm is good, integration does not reduce firm's ability to innovate.etc.) should firms invest in proprietary supporting assets (e.g. Teece, 1986; 2006; Jacobides et al. 2006). Collectively these arguments suggest:

Hp2 The greater a firm's investment in supporting assets the greater the subsequent hazard of the firm's failure.

Although investments in general technologies and in complementary assets individually may expose the firm to higher risks of failure, the combination of general technology and downstream assets may increase a firm's likelihood of survival. Investment in a more general technology improves the firm's ability to deal with the risk implied by investment in supporting assets in several ways. First, a general technology reduces the problem of asset inflexibility. Investments in complementary assets, such as investments in plants and equipment are usually targeted for certain uses of the technology that are known at the moment of the investment. If the market conditions or the preferences of demand change, the firm incurs the risk that the value of those downstream assets will decrease dramatically. In these contexts having a general technology may be an advantage. Since a general technology can be adapted to new uses it may be likely that the firm can use the same downstream assets but for serving the related product applications that have been developed from the general technology. For instance, while some production techniques and machinery may become obsolete for operating in a certain market segment (e.g. because their cutting precision has become too low for the new industry standards), it is possible that they may still retain some values for operating in another industry or segment. If the firm's technology is general, the firm can more easily find a different context to which the technology may be adapted to, wherein the firm's assets still retain their value[2].

Second, the nature of investments that firms with general technologies make in supporting assets may differ from the investments in supporting assets made by

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[2] For instance, think about advanced materials and fabrics used in contexts that require an extremely high performance and low levels of tolerance, such as the aerospace or extreme sports. These contexts are very sensitive to technological change in the sense that customers constantly look for more performing materials. However materials that become obsolete in high tech industries may still be very performing for more basic uses. Fabrics used for spacesuits or materials used for space helmets are often used later on for the production of winter jackets and motorbike crash helmets. Another example is the case of self-locking joints invented by NASA and then reused in orthopedic devices such as artificial knees.

firms with more specific technologies. Since firms investing in general technologies are likely to have a broader perspective on the applications of those technologies their choices of supporting assets may also mirror this broader perspective and lead to the development of more general purpose downstream assets. Such assets may be better positioned to withstand changes in demand preferences or specific technological applications. Similarly, firms that have invested in general technologies may have developed a more general portfolio of relationships (eg. with suppliers, distributors, and complementors) enabling them greater facility in adapting the downstream assets such as manufacturing capacity to new uses. Together, these arguments suggest:

Hp3 The effects of investing in supporting assets on the hazard of firm failure are moderated by investments in general technologies. Specifically, higher generality of a firm's technologies reduces the effects of higher investment in supporting assets on the hazards of firm failure.

METHODS AND MEASURES

<u>Sample and Data</u>

To test my propositions, I built a longitudinal dataset that includes information on a sample of photonics firms over a ten year period (from 1993 to 2002). Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation and detection to communications and information processing. I identify the sample using an industry directory that provides information on all firms active in the photonics industry in each year over this period. I selected all US companies listed in the directories from 1993 to 2002 and obtained information on firms' product portfolios as well as their key characteristics (e.g. independence status, size, age, location) from the directories. In particular, firms' products are classified into 15 products subfields which correspond to different types of photonics products. These subfields include, for instance, Detectors and Sensors, i.e. devices designed to convert the energy of incident radiation into another form for the determination of the presence of the radiation; Imaging, Cameras and Displays, e,g, devices to acquire or visualize images; Electronics and Signal Analysis devices, i.e. electronic devices for capturing and processing information acquired through the interaction of light and matter.

In order to collect data on firms' technologies I used company names and locations and matched firms' names to patent assignees' names in the NBER patents dataset. I include in the sample all firms that have created even one patent during the study period. The use of patent data creates some limitations for this study, since patents provide imperfect coverage of innovative activity, as not all innovations are patented or patentable. Yet, this potential problem is reduced given the length of my period of observation: although not all innovations are patented, it is very unlikely that a firm involved in R&D activity has not been granted a single patent over a 10 years period. Indeed, patenting is often used for strategic reasons by firms, such as signalling the value of the firm to external actors (Hsu and Ziedonis, 2007). Moreover, as pointed out by several scholars, patenting measures have the potential to allow a detailed analysis of the knowledge developed by firms (e.g. Griliches, 1990; Henderson and Cockburn, 1994; Ahuja and Katila, 2004).

Model Estimation and Econometric Issues

In order to test my hypotheses I performed a survival analysis using the technique of proportional hazards modeling presented by Cox (1972). This technique uses a logarithmic transformation of the hazard rate as the outcome variable. The Cox model assumes that the covariates multiplicatively shift the baseline hazard function. The model assumes that the hazard rate for the jth subject in the data can be represented as

$$h(t|x_j) = h_0(t)\exp(xj\beta_x)$$

where the regression coefficients β_x are to be estimated from the data. The baseline hazard, $h_0(t)$, is given no particular parametrization and is left unspecified (Cleves, Gould, Gutierrez, 2003). The advantage of using a Cox model is that it does not require any assumptions about the shape of the hazard over time (such as that the hazard is increasing or decreasing over time). This is important since incorrect parametric assumptions about the shape of the hazard function may lead to biased estimates of the effects of covariates on the hazard rate (Blossfeld and Rohwer, 1995; Cleves, Gould, Gutierrez, 2003). The Cox model does however assume that all individuals in the population have hazard rates that are proportional to each other. Since there is no theoretical reason to believe that the proportionality assumption is violated in my context this model is appropriate for my analysis As a robustness check, however, I also estimated piecewise-constant rate models, which generated nearly identical results. To allow for non-independence of the observations belonging to the same firm, I used robust standard errors adjusted for clustering at the firm level.

The equation that I used to test my three hypotheses is

$$Ln(ht)=f(GT, SA, GTxSA)$$

where GT is the Generality of the Technology and SA is the investment in supporting assets.

Variables Definition and Operationalization

Failure

In this paper I examine the effects of investing in general technologies and supporting assets on the likelihood of business unit exit from the photonics industry. Business unit exit from an industry is widely regarded as an indicator of performance (e.g. Mitchell and Singh, 1996), and specifically, exiting an industry is interpreted as business failure. Since I am interested in business unit exit as an indicator of performance, I eliminate all exits by acquisitions from my analyses as such exits may be open to ambiguous interpretations. For instance a firm may have been started with the intention of being acquired later and thus exit by acquisition might actually be a sign of success rather than failure. At the same time a firm could also be acquired when it is in danger of failing. Since I cannot separate such exits from each other and hence cannot confidently interpret the implications of such exits, I focus my attention and analyses on only the exits in which the business unit exited the industry but was not acquired by any other firm. In order to collect data on business unit exit, I first referred to the information provided by the Photonics directory itself and identified the year in which each company was not included in the directory. Then I traced the fortune of the firms in my sample triangulating from different sources of data: I checked news and press releases on Factiva dataset; I looked at corporate websites, where possible; I also used the Web Archive (www.archive.org) to browse the archived web pages of corporate website to go back to their version at the time of exit from the Photonics directory. These efforts allowed me to identify 148 cases of business exits in the data.

Independent variables

The core construct of **generality** of technology refers to the applicability of the technology to multiple domains. I use patent data to compute this variable. I use the photonics patents of firms and compute the average number of technological classes that such patents were assigned to at the time of application. At the time of application, patent examiners search the patent file and assign each patent to a variable number of technological classes, depending on the domains the patent contributes to (Gittelman, 2008). It is reasonable to expect that patents classified into a greater number of technological classes have a greater scope of applicability, i.e. a greater generality.

The construct of **supporting assets** refers to the firm's investment in downstream facilities and equipment to commercialize its technology. In order to calculate this measure I used the Photonics directory to obtain the size (in square feet) in year t-1 of the firm's photonics facilities. For specialized high technology manufacturing facilities, facility size can be interpreted to be a crude proxy of investments in manufacturing assets.

Controls

To controlling for other influences on firm survival I introduce into the analysis a set of control variables. I include a measure of the *firm's size*, calculated as the log of the number of employees in year t-1. I control for the *firm's age*, measured as the count of the number of years elapsed from the firm's establishment to year t-1. I measure the *product scope of the firm* as the total number of product subfields the firm was active in year t-1. I also include as controls, the *total number of products of the firm* in year t-1, the rate of *product introduction* measured as the number of products introduced by the firm in year t, and the *independence status* of the firm measured as a dummy variable equal to 1 when the firm was independent in year t. I controlled for the level of *competition* calculated as the number of firms active in the product segments the firm was active in year t-1. I calculated these measures using data from the photonics directory. Photonics products fall into fifteen distinct subfields. In counting products, I only consider those products that the firms manufactured themselves and introduced on the market.

I control for the *firm’s knowledge stock*, measured as the number of patents applied for by the firm in previous years. I also included a control for *uncertainty* referring to the extent to which firms are able to assess which investments in technology will yield products that can be commercialized. To measure this variable I use the Technology Cycle Time (TCT) indicator. This is computed at the firm level as the median age in years of the firm’s patents backward citations. TCT measures the time between the previous patents upon which current patents are improving and current patents themselves (Oriani and Sobrero, 2008). Since the lower the median age, the higher the uncertainty, I transform the TCT indicator by multiplying each value by -1 so that larger values of the resultant variable measure higher levels of uncertainty.

Regarding knowledge-based variables and controls (i.e. generality, firm’s knowledge base and uncertainty), consistent with other work in similar dynamic industries (Argote, 1999; Ahuja and Katila, 2001) I assume that the previous 5 years patents constitute the relevant knowledge base that the firm embeds into its products. I also include a one year lag between the technology variable and product introductions. Since the product measures included in this analysis are lagged one year from the failure outcome variable, technology variables introduced in this analysis correspond to the average from t-6 to t-2 of the relevant independent variable.

Table 1 lists variables and descriptive statistics. Table 2 displays correlations between the main variables in the analysis.

Insert Tables 1 & 2 near here

RESULTS

Table 3 shows the Cox regressions predicting business unit failure. Model 1 includes only main effects and control variables, while Model 2 also includes the interaction between General Technology and Supporting Assets. A positive β coefficient indicates that the independent variable increases the likelihood of business unit failure (hazard ratio greater than 1).

To test my first hypothesis that a higher generality of technologies increases the subsequent hazard of business unit failure I examined the coefficient of the Generality variable in model 2. The coefficient is significant and positive, supporting Hypothesis 1. Similarly, to test Hypothesis 2 that a greater investment in supporting assets increases the subsequent hazard of the business unit failure I look at the coefficient of the variable Supporting Assets, which in this case is also positive and significant, supporting Hp2. Finally, I test Hypothesis 3 that a higher generality of technologies reduces the effects of higher investment in supporting assets on the hazards of business unit failure, I look at the coefficient of the interaction variable, which is negative suggesting that firms having highly invested in both general technologies and supporting assets experience a higher survival rate.

Insert Table 3 near here

Business unit exit can imply two possible types of failures a) the organization embodying the business is dissolved (organizational death), or b) the organization continues to live but does not participate in the photonics industry anymore. In my main analyses I had included both as indicative of failure. As a robustness check, I also replicated the above analyses predicting firm's exit by dissolution only. The results of these additional analyses, reported in Table 4, are consistent with the results reported earlier that included both dissolution and industry exit as the failure events (Table 3).

Insert Table 4 near here

DISCUSSION AND CONCLUSION

In this paper I tried to understand the business survival implications of two key types of investment decisions made by firms i.e. upstream investments in technology and downstream investments in supporting assets. Looking at the firm's upstream investments in technology, I focused specifically on a firm's choice to invest in more general technologies, i.e. technologies that can be adapted relatively easily to different technological domains rather than being specialized to a single domain. Looking at firm's downstream investments, I focused on the magnitude of investments in supporting assets. I theorized that both investments in more general technologies and in supporting assets constitute risky investments that may increase firms' failure rates. However I also predicted that the combination of general technology and downstream assets may increase a firm's likelihood of survival. Since general technologies can be adapted to different contexts, investments in more general technologies reduce the problem of asset inflexibility by improving a firm's ability to find alternative uses for its facilities.

Finding support for my arguments suggests important implications for research on general technologies, supporting assets and the concept of firm strategy as a bundle of integrated choices. First, from the perspective of general technologies I show that investment in such technologies implies a tradeoff. Although general technologies permit more flexibility for firms this advantage is to some extent counterweighed by their higher risks. Specifically, extant research suggests that investments in general technologies may expand firms' opportunities, for instance by improving firm's ability to enter into new market segments (Gambardella and Giarratana, 2009; Novelli, 2009). However, generality also makes the firm vulnerable in multiple ways the sum total of which leads to higher mortality for firms investing in general technologies. Thus, investing in general technologies appears to be a high risk – high return proposition: when firms invest in general technologies they are more likely to fail, but if they survive they are more likely to be profitable. I note that my findings in this study only establish the high risk part of the above argument. Prior work has established the first part of the high return thesis – generality permits a firm to enter new market segments. Future work should examine whether such entry into multiple market segments in fact transfers to a performance benefit.

Second, this work contributes to literature on downstream assets (e.g. Teece, 1986; Mitchell, 1989, 1991). Prior literature has argued that supporting assets can be a basis of competitive advantage, by providing firms with a mechanism for appropriating the value from their innovations (e.g. Levin et al, 1987; Tripsas, 1997; Cohen et al. 2000; Rothaermel and Hill, 2005). This research conditions that view by suggesting that survivors may enjoy a competitive advantage from the ownership of supporting assets but the likelihood of survival is itself diminished when firms invest in developing supporting assets. This result raises a fundamental methodological issue for research in this area. By showing that investing in such supporting assets may lead to higher failure rates for firms, this paper points out to a potential selection bias overlooked by prior research: examining the impact of investment in supporting assets on performance without considering the effect of these investments on firm failure may lead to an overestimation of the benefits coming from downstream investments.

Most interestingly however this research contributes to our understanding of firms' strategies as bundles of complementary choices. Even though generality itself reduces the likelihood of business unit survival as does investment in supporting assets, jointly they have a positive effect. This notion of complementarity of strategic choices can also help us further in understanding research on firm ambidexterity. The literature in this area suggests that successful organizations in dynamic environments are those that are efficient in today's world, while also being adaptive enough to changes that may occur in the tomorrow's environment (Duncan, 1976;

Carlsson, 1989; Tushman & O'Reilly, 1996; Gibson and Birkinshaw, 2004). In this paper I identify one possible configuration of upstream and downstream investments that firms can use to successfully pursue an ambidexterity strategy, i.e. to simultaneously demonstrate efficiency and adaptability. By choosing to invest in more general technologies firms successfully attain adaptability to a changing environment, since these technologies can be easily adapted to new and different states of the world. Firms also improve their overall efficiency when investment in general technologies is coupled with investment in supporting assets: since general technologies can be adapted to new uses, they increase the likelihood that the same downstream assets can be employed to serve different product applications.

TABLES

Table 1 Descriptive Statistics

Variable	Description	Observations	Mean	S.D.	Min	Max
1. Generality of the Technology	Generality, average t-2 to t-6 (Photonics patents only)	2622	2.47	2.37	0	16.56
2. Supporting Assets	Log facility areat-1	2622	10.10	1.38	1.95	15.78
3. New product launches	Number of new products launched (in any cat, either existing or new) at time t-1	2622	1.58	4.67	0	133
4. Product Portfolio	Total number of products in the firm's portfolio at time t-1	2622	7.87	8.67	1	178
5. Product scope	Number of product subfields the firm is active in at year t-1	2622	4.12	2.17	0	14
6. Firm's knowledge stock	Number of patents, from t-2 to t-6 (Photonics patents only)	2622	6.33	32.43	0	767
7. Technological uncertainty	Uncertainty, average from t-2 to t-6 (Photonics pat only)	2622	-2.65	3.78	-18.00	0
8. Independence Status	Dummy equal 1 if the firm is independently held; 0 otherwise.	2622	0.81	0.39	0	1
9. Firm's age	Count of the number of years elapsed from the firm's establishment to year t-1	2622	25.56	22.05	1	201
10. Firm's size	Log of the number of employees at year t-1	2622	4.05	1.38	0.69	9.21
11. Competition	Number of competitors (sum of competitors in all the subfields the firm is present in at t-1)	2622	5283.16	2628.58	0	13523

Table 2 Pairwise Correlations

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Generality of the Technology	1										
2. Supporting Assets	0.16	1									
3. New product launches	0.01	0.01	1								
4. Product Portfolio	-0.03	0.04	0.61	1							
5. Product scope	0.01	-0.06	0.30	0.63	1						
6. Firm's knowledge stock	0.13	0.27	0.02	0.06	0.00	1					
7. Technological uncertainty	-0.44	-0.08	-0.03	-0.07	-0.08	-0.12	1				
8. Independence Status	-0.05	-0.26	-0.03	-0.06	0.04	-0.04	0.00	1			
9. Firm's age	0.03	0.49	-0.06	-0.01	-0.06	0.09	-0.02	-0.22	1		
10. Firm's size	0.19	0.87	0.01	0.05	-0.05	0.27	-0.10	-0.26	0.48	1	
11. Competition	0.01	-0.07	0.27	0.59	0.95	-0.01	-0.08	0.03	-0.07	-0.08	1

Table 3 Cox Regression predicting business unit exit and firm's death (1993-2002)

Description	Model 1 Main Effects				Model 2 Main Effects and Interaction			
	Coefficient (β)		Hazard Ratio (Exp β)		Coefficient (β)		Hazard Ratio (Exp β)	
Generality of the Technology	0.04		1.04		0.40	**	1.50	**
Supporting Assets	0.15		1.16		0.24	*	1.27	*
Interaction Generality X Supporting Assets					-0.04	*	0.97	*
New product launches	0.10	***	1.10	***	0.10	***	1.10	***
Product Portfolio	-0.09	***	0.91	***	-0.09	***	0.91	***
Product scope	-0.29	**	0.75	**	-0.28	*	0.76	*
Firm's knowledge stock	0.00		1.00		0.00		1.00	
Technological uncertainty	0.06	**	1.06	**	0.06	**	1.07	**
Independence Status	-0.11		0.89		-0.12		0.89	
Firm's age	0.00		1.00		0.00		1.00	
Firm's size	-0.10		0.90		-0.11		0.90	
Competition	0.00	**	1.00	**	0.00	**	1.00	**
Chi-square	38.46				42.48			
Log pseudolikelihood	-841.52				-840.35			
Prob >chi2	0.00				0.00			
Observations	2622				2622			
Number of subjects	649				649			
Number of failures	148				148			

Table 4 Cox Regression predicting firm's death (1993-2002)

Description	Model 1 Main Effects				Model 2 Main Effects and Interaction			
	Coefficient (β)		Hazard Ratio (Exp β)		Coefficient (β)		Hazard Ratio (Exp β)	
Generality of the Technology	0.04		1.04		0.82	*	2.27	*
Supporting Assets	0.57	***	1.77	***	0.84	***	2.32	***
Interaction Generality X Supporting Assets					-0.08	*	0.92	*
New product launches	0.10	*	1.11	*	0.11	**	1.11	**
Product Portfolio	-0.12	*	0.89	**	-0.12	**	0.89	**
Product scope	-0.27		0.76		-0.24		0.79	
Firm's knowledge stock	-0.01		0.99		0.00		1.00	
Technological uncertainty	0.08		1.08		0.09		1.09	
Independence Status	-0.29		0.74		-0.25		0.78	
Firm's age	-0.02	*	0.98	*	-0.02		0.98	
Firm's size	-0.67	***	0.51	***	-0.76	***	0.47	***
Competition	0.00		1.00		0.00		1.00	
Chi-square	35.36				41.04			
Log pseudolikelihood	-225.03				-223.21			
Prob >chi2	0.00				0.00			
Observations	2622				2622			
Number of subjects	649				649			
Number of failures	41				41			

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HOW DO INNOVATIVE SMES COMMERCIALIZE THEIR TECHNOLOGY? INVESTIGATING THE SUBSTITUTION EFFECT BETWEEN VERTICAL INTEGRATION AND COOPERATION[3]

ABSTRACT

Research on technology commercialization recognizes that firms can commercialize their technology either through vertical integration or through cooperation with other firms. However, this conceptualization ignores the tendency of firms to engage simultaneously in both types of technology commercialization practices. This paper reframes the existing conceptualization of technology commercialization by distinguishing between firms choosing a *pure* technology commercialization strategy – i.e., firms commercializing their technology either through vertical integration or alternatively through cooperation – and those following a *mixed* strategy – i.e., engaging simultaneously in both vertical integration and cooperation activities. Building on the resource-based view of the firm, this paper develops a theory of the comparative efficiency of employing a mixed strategy compared to a pure one. We then test our prediction of a substitution effect between different commercialization options using a multi-industry sample of 497 public innovative Small and Medium Enterprises in the United States. Our results show that pure technology commercialization strategies are more efficient than mixed ones.

[3] This paper has been written with Giovanna Padula and Rekha Rao

HOW DO INNOVATIVE SMES COMMERCIALIZE THEIR TECHNOLOGY? INVESTIGATING THE SUBSTITUTION EFFECT BETWEEN VERTICAL INTEGRATION AND COOPERATION

INTRODUCTION

Technology commercialization has been defined by strategic management scholars as the process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing saleable goods, and selling the goods in the product market (Mitchell and Singh, 1996). Traditional studies have identified two ways in which this process may be accomplished (e.g., Teece, 1986). First, it may be accomplished by vertically integrated firms carrying out all the activities of the value chain – from R&D to production – within their own proprietary boundaries. Second, this process may be accomplished by firms specialized in distinct stages of the value chain. In this second case, firms specialized upstream in the value chain cooperate with external partners on different types of arrangements – from licenses, to manufacturing contracts and outsourcing – for the realization of the activities located downstream in the value chain. This conceptualization of technology commercialization options mirrors the traditionally recognized make-or-buy conceptualization of the technical know-how update decisions (e.g., Pisano, 1990; Mitchell, 1991; Ahuja, 2000a). In this vein, the distinct ways in which firms commercialize their technology have actually been considered as alternative to one another.

However, recent empirical investigations have revealed a tendency of firms to engage simultaneously in both technology commercialization options (e.g., Arora, Fosfuri and Gambardella, 2001). Despite evidence of this practice, no study has so far investigated the relative efficiency of coupling versus keeping each technology commercialization option separated from the other. Understanding this issue is important for innovative firms. Although choosing a mixed technology commercialization strategy increases the number of outlets for a firm's technology and consequently its scale of exploitation, it is unclear whether this choice also corresponds to a similar increase in firms' profits. For instance, it is unclear whether there is any interaction between vertical integration and cooperation that makes the ultimate effect of coupling both options different from the sum of the effect obtained by each option separately.

This paper addresses this gap. For this purpose, it reframes the technology commercialization options available to the firms as follows. First, a firm can choose a *mixed strategy* if it couples simultaneously both vertical integration and cooperation activities. Second, a firm can choose a *pure strategy* if it commercializes its technology either through vertical integration or alternatively through cooperation. The paper then builds on the resource-based view of the firm (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993) and develops a theory of the comparative efficiency of employing a mixed technology commercialization strategy compared to employing a pure one. In particular, this paper uses the technology commercialization context to identify boundaries to two commonly presented resource-based view prescriptions.

Resource-based scholars have advocated leveraging resources across markets (e.g., Montgomery and Collis, 1995), and the building of multiple layers of competitive advantage (eg. Hamel and Prahalad, 1989). We identify possible limitations to both these prescriptions.

To test our theoretical framework, we conducted a cross-sectional analysis on a multi-industry sample of 497 public US innovative small and medium enterprises (SMEs) over the period 1996-2001. This population of firms is a particularly fruitful locus in which to investigate our theoretical framework as it shows a significant variety in the way it commercializes its technology (e.g. Hicks and Hedges, 2005). We performed a test of substitution between different commercialization practices by using two methods. We first employed an 'adoption' approach (e.g., Arora and Gambardella, 1990), an indirect test of substitution based on the criterion of 'revealed preference' of strategies. An implicit assumption underlying this methodological approach is that firms take an optimizing behavior in the decision of the commercialization practices. Since this assumption may not hold for many firms (Athey and Stern, 1998), we also checked the robustness of the findings based on the adoption approach by carrying out an additional test based on a 'productivity' approach (Cassiman and Veugelers, 2006). The 'productivity' approach relaxes the assumption of optimizing firm behavior and performs a direct test of substitution based on the assessment of the effects of technology commercialization practices on firm performance. Our results show that a pure technology commercialization strategy is more efficient than a mixed one.

These results contribute to the research on technology commercialization by providing a systematic empirical investigation of the comparative efficiency of pure versus mixed strategies of technology commercialization, an arena that had hitherto been largely neglected by extant research. Although, simple intuition might suggest that using multiple paths to commercialize your technology may be advantageous relevant to pursuing a single path, our theoretical framework and its empirical validation suggest that at least in this context more is not necessarily better.

These results also provide a twofold contribution to the resource-based view of the firm. First, the resource-based view has mostly considered the possible pitfalls of a resource leveraging strategy across different horizontally related markets, whereas this study has investigated the effects of resource leveraging across distinct vertically related markets, Second, by demonstrating a negative interdependence between *property rights* and *resource embeddedness* as sources of competitive advantage, this study reveals that the sources of competitive advantage may not necessarily be additive, a result that puts into question the traditional wisdom of resource-based view scholars who emphasize the benefits of building a competitive advantage across multiple layers (e.g., Hamel and Prahalad, 1989).

This paper is organized as follows. First, we provide an overview of the literature on technology commercialization and develop a theory of the relative efficiency of mixed versus pure technology commercialization strategies. Second, we present the data and describe the methodology chosen to test our hypothesis. Results of our analysis are then presented in the next section, followed by discussion and conclusions.

THEORETICAL BACKGROUND AND PREDICTIONS

One of the key challenges facing firms is to identify how they can profit from their innovations. Scholars examining this topic have usually investigated pure technology commercialization strategies rather than mixed strategies. The main interest of these studies has been in understanding what determines the choice of either pure strategy (e.g., Teece, 1986, 2006; Gans, Hsu and Stern, 2002; Gans and Stern, 2003; Arora and Merges, 2004; Arora and Ceccagnoli, 2006; Gambardella and Giarratana, 2008). This prominent line of inquiry reveals that vertical integration and cooperation have generally been assumed to be alternatives to each another.

Empirical evidence nevertheless shows a tendency of firms to employ a mixed strategy – coupling both vertical integration and cooperation practices – instead of employing a pure approach, especially in those industries where cooperation practices are more widespread (e.g., Arora *et al.*, 2001). However, this development has received only limited attention from scholars. For instance, Arora and Fosfuri (2003) and Fosfuri (2006) emphasize the increase in the flow of revenues obtainable when vertically integrated firms also license their technology, although they also suggest caution when considering the effects of employing a mixed strategy on profits. Following the lead of these studies, this paper undertakes a systematic investigation of the comparative efficiency of mixed versus pure technology commercialization strategies by assessing the existence of a substitution effect between vertical integration and cooperation in a firm effort to commercialize its technology.

We build upon the theory of supermodularity by Milgrom and Roberts (1990;1995) to define the concept of substitution. Two activities may be defined as being *substitutable* if doing either one of them decreases the returns of doing the other (Rothaermel and Hess, 2006; Parmigiani and Mitchell, 2007). To provide an operational definition, s*uppose there are two activities, A1 and A2. Each activity can be performed by the firm (Ai = 1) or not (Ai = 0) and* $i \in \{1, 2\}$. *A1 and A2 are substitutable if and only if:* $\Pi(1, 1) - \Pi(0, 1) \leq \Pi(1, 0) - \Pi(0, 0)$, *that is, adding an activity while the other activity is already being performed has a lower incremental effect on performance (Π) than adding the activity in isolation.* Basically the concept of substitution deals with the creation of negative synergies in performing two activities jointly and stands in contrast to the concepts of independence and complementarity (Parmigiani and Mitchell, 2007). Independence refers to the case in which the performance of doing two activities jointly does not change compared to the case in which the two activities are performed in isolation; complementarity can be identified, instead, in the circumstances in which doing more of one activity increases the value of another activity.

The Comparative Efficiency of Pure vs Mixed Technology Commercialization Strategies

The Avenues of Investigation Provided by the Resource-Based Perspective.

To investigate the comparative efficiency of pure versus mixed technology commercialization strategies, we built on the resource-based-view of the firm (e.g., Wernerfelt, 1984; Barney, 1991; Grant, 1991; Peteraf, 1993). In particular, this perspective provides two avenues of investigation that can be fruitfully applied to our study purpose.

A first avenue draws upon the resource-based reasoning about the ways in which firms can appropriate the returns for their competitive advantage (e.g., Collis and Montgomery, 1995; Grant, 2008). The literature on technology commercialization builds on the assumption that developing a novel technology does not guarantee that an innovator will gain the returns generated by that innovation (e.g., Teece, 1986; 2006). This assumption mirrors the one underlying the resource-based perspective about the profit-earning potential of a competitive advantage. According to the resource-based view, profits potentially accrue to the firms that control superior bundles of resources. However, holding a competitive advantage does not actually guarantee that a firm gains the returns of a competitive advantage. As a technical innovation is widely recognized as representing a source of competitive advantage (e.g., Thomas, 1996), especially in fast-moving industries (e.g., Teece, Pisano and Shuen, 1997), the resource-based perspective on how firms can appropriate the returns from competitive advantage may provide a fruitful line of investigation for appraising the comparative efficiency of a pure compared to a mixed technology commercialization strategy.

A second avenue for assessing the relative superiority of pure versus mixed technology commercialization strategies can be based on the resource-based debate about the profit-earning potential provided by the strategies of leveraging firm resources across distinct markets (e.g., Rumelt, 1984; Collis and Montgomery, 1995). Indeed, choosing a pure versus a mixed technology commercialization strategy has implications on the extent to which a firm actually leverages its resources across vertically distinct markets. In fact, while a pure strategy implies operating either upstream in the intermediate technology markets or downstream in the product market, a mixed strategy implies spanning across both vertically related markets. Hence, we will build on the discussion about the benefits as well as the more diffused shortcomings of the implementation of a resource leveraging strategy to assess the relative superiority of a pure versus a mixed technology commercialization strategy.

The Role of Property Rights (PR) and Resource Embeddedness

The resource-based perspective suggests at least two main mechanisms affecting the ability of a firm to appropriate the value created by its resources (e.g., Collis and Montgomery, 1995; Grant, 2008). Holding a *property right* (PR) over a resource is the first mechanism whereby a firm can appropriate the value generated by that resource. However, the strength of this mechanism varies depending on the extent to which the establishment of the PR on a firm resource is clear-cut. For instance, profits are likely to be much harder to capture from human capital resources as the boundary between the human capital owned by the employee and the know-how of the firm is particularly difficult to define. On the contrary, the definition of the PR on a novel technology may be relatively more clear-cut and this circumstance may raise the role of PR in guaranteeing the returns to a competitive advantage based on technological innovations.[4]

The *embeddedness* of a resource in a more complex set of organizational capabilities is another way in which a firm may protect itself against the risk of being expropriated of the value generated by its resources. Embeddedness spreads the source of competitive advantage from a single resource to a complex web of interactions wherein the resource gets embedded. While PR provides formal protection on the basis of the legal enforcement system, resource embeddedness provides an informal, managerial appropriation mechanism obtained by the circumstance that the embeddedness leads to a socially complex source of competitive advantage that is causally ambiguous and consequently difficult to imitate and replicate by others (Rumelt, 1984; Reed and De Filippi, 1990). Note that the resource-based view also reminds us that besides imitating and replicating, the sources of a competitive advantage – even those provided by socially complex

[4] Note that several studies outside the resource-based perspective (e.g., Teece, 1986; Levin *et al*. 1987; Ginarte and Park, 1997; Cohen, Nelson and Walsh, 2000) have argued and demonstrated that the actual effectiveness of PR in protecting technological innovations may vary depending on the strength of the appropriability regime characterizing the environment in which a firm operates. However, we do not explore this issue further since we believe that it goes beyond the boundaries of this research scope.

resources – may be substituted (Collis and Montgomery, 1995), i.e., trumped by a different set of resources. This issue implicitly suggests that the strength of resource embeddedness in guaranteeing a firm to capture profits from its competitive advantage is not absolute but dependent on the relative strength of organizational capabilities across the main competitors – provided that the organizational capabilities may be ultimately considered the most notable type of resources responsible for re-shaping the source of a competitive advantage through time (e.g., Teece *et al.*, 1997; Helfat *et al.*, 2007), hence for substituting the source of a firm's competitive advantage with another set of resources.

We will now use these basic sources of profit appropriation to investigate the relative superiority of a pure versus a mixed technology commercialization strategy. A possible test of the comparative efficiency of a pure versus a mixed strategy in the profit appropriation mechanism perspective may be found in the appraisal of an eventual interaction between PR and resource embeddedness actually affecting the appropriation strength of either mechanism. Based on this test, a mixed strategy would be inferior compared to a pure strategy if coupling PR with resource embeddedness were to decrease the appropriation strength of either mechanism and consequently the ability of a firm to capture value from its innovation.

It is widely recognized that contracting out a novel technology and cooperating with external partners is likely to facilitate others to master the novel technology (e.g., Teece, 1986) . In a mixed strategy, besides contracting out the technology to external partners, the innovator also embodies the technology into downstream assets and consequently roots its competitive advantage in a difficult-to-imitate web of resources that may provide him with a safeguard against the risk of being expropriated of the stream of profits generated by its innovation. Yet, if those others contracting out the novel technology from the innovator also possess strong organizational capabilities, they may be in a position to substitute the innovator's socially complex source of competitive advantage with another set of resources and have some chance of outperforming the innovator in the product market. Hence, by contracting out its technology, an innovator may run the risk of generating stronger competitors. Briefly, in a mixed strategy, contracting out the technology increases the risk of the innovator being outperformed by other competitors and dissipating his rents in the product markets. Hence, coupling cooperation with vertical integration reduces the strength of resource embeddedness in protecting an innovator against the risk of being expropriated.

We now turn to examine the effects of this coupling on the strength of *PR*. While we have predicted above that contracting out the technology weakens the strength of *resource embeddedness*, at the same time we acknowledge that this latter mechanism does not provide an innovator with a full shelter against the risk of being expropriated even in the case of a firm that abstains from contracting out the technology – i.e., in the case of pure vertical integration strategy (Teece, 1986). For example, the diffusion of benchmarking practices and quality function deployment techniques (e.g., Hauser and Clausing, 1988, Griffin, 1992; Clark and Weelwright, 1993) in the last couple of decades have revealed that as competition in the product markets has intensified, so the firms have strongly engaged in a systematic search for the locus of the competitive advantage of the stronger competitors. This effort may have resulted in an explicit attention to understand and replicate a technology as far as the locus of the competitive advantage were built around the application of a technology in a firm business processes.

Whether learning about a technology embedded in an organizational context may be more difficult to achieve compared to the case of learning about a technology delivered in disembodied form, the effort of understanding a technology in its context of use – if successful – may result in a deeper and broader knowledge about that technology compared to the case of learning by exposure to a non-embedded technology. In fact, in the case of embedded technologies one can observe the interactions of that technology with the other components of the organizational context in which it is embedded, and ultimately assess the performance of the technology with respect to the production and market requirements, as well as to the requirements coming from the need of integration of that technology with other technologies as in case of products based on multiple technologies. We suggest that this deeper and broader knowledge may strengthen the ability of an imitator to get around the PR protection mechanisms, most notably the patent obtained on a novel technical idea. This line of reasoning prompts us to suggest that coupling vertical integration with cooperation may end up reducing the strength of *PR* in protecting an innovator against the risk of being expropriated.

Thus, based on this test, a pure strategy may prove to be the superior technology commercialization strategy compared to a mixed strategy.

Avoiding the Possible Pitfalls of a Resource Leveraging Strategy.

Resource-based theorists emphasize that while leveraging resources might generate the possibility of improving the profit-earning potential of a firm, there are several pitfalls that may actually exert a negative effect on the stream of profit at a firm corporate level (e.g., Collis and Montgomery, 1995; Grant, 2008).

The basic argument in favour of employing a resource leverage strategy in a resource-based perspective is provided by the benefits of exploiting the synergies among resources jointly employed across distinct correlated markets. Yet, these benefits cannot be of general validity. A first pitfall of this strategy may come from the changes that it might provoke in the market attractiveness and consequently in the profit-earning potential at a firm corporate level. We believe that this issue may apply to the case of technology commercialization strategy choices trying to exploit the synergies across upstream technology input market and downstream product market – i.e. across vertically related markets. Indeed, an innovator choosing a pure vertical integration strategy for commercializing its novel idea faces a monopolistic product market structure. If the innovator should decide to engage in a mixed strategy by stretching its technology resource and contracting it out in the technology market, it will end up facing a competitive structure – which shows much lower profit opportunities compared to a monopolist market structure – as engaging in technology trading will encourage competition in the product market (Arora et al. 2001). While the mixed strategy will multiply the channels through which a technology is commercialized, it will decrease the size of the revenues and rent flows in the product market as a consequence of the change in the product market structure from a monopolistic to a competitive one. Arora and Fosfuri (2003) predict that the transition from a monopolistic to a competitive market structure makes the rent dissipation effect larger than the benefit of doubling the sources of revenues. Hence, this test of the comparative efficiency of a mixed versus a pure vertical integration strategy would reveal the superiority of the latter over the former.

The same consequences may be obtained if we observe a vertical resource leverage strategy from upstream to downstream markets. Several reasons may explain the motivations of a innovator to move from an upstream technology specialization to a downstream vertical integration, e.g., the lack of sustainability of a technology commercialization strategy exclusively based on the royalties obtained by the licensing agreements (Fosfuri, Gambardella and Giarratana, 2007), or the several frictions that characterize technology markets (Cockburn, 2008; Padula, 2008). Yet, should these motivations arise and urge an innovator to integrate downstream, we predict that this manoeuvre will prove to be more efficient if executed through a pure vertical integration strategy rather than a mixed strategy because of the negative effects of on the attractiveness of the downstream, product markets provoked by operating in both upstream and downstream markets.

However, this issue would not arise in case of stretching a technology for possible applications into different product markets, i.e. in case of exploiting the potential for application of a technology in a variety of product applications. In their recent study on the software security industry, Gambardella and Giarratana (2008) explore this pattern of technology leverage strategy, finding that it is likely to occur through contracting out the technology and cooperating the external partners rather them integrating downstream as this technology stretching activities is likely to require huge, often irreversible commitment into many different downstream assets. This argument reminds us another critical pitfall that typically characterize a resource leverage strategy, i.e. the problem of fit between the range of knowledge required to enter into an additional market and the range of knowledge available by a firm (Grant and Baden-Fuller, 2004). Indeed, while entering into additional related markets enables a firm to extend the scale of exploitation of a resource, it also raises the need to invest into additional resources that may not be used at their full capacity unless the firm engages in a new resource leverage manoeuvre to exploit these additional resources at a fuller scale. This line of reasoning invites to acknowledge that investing downstream into different – though related – markets may lead an innovator to engage in a huge investment into downstream assets that are likely to be left largely unexploited. As a key determinant of the potential for technology stretching is the fragmentation of the downstream product markets (Gambardella and Giarratana, 2008) and as the fragmentation of market negatively affects its size – hence the scale of exploitation of downstream assets in any single product application – we suggest that when the potential for technology exploitation across a variety of markets is high, the incentives to integrate downstream even in a sole niche of application is low. Hence, in a context of technology stretching activities across distinct horizontally related markets a mixed technology commercialization strategy is likely to be less efficient compared to a pure cooperative strategy

Another possible pitfall of a resource leverage strategy is to be found in the under-estimation of the effects of de-specialization implied by this strategy. In fact, a resource leverage strategy implies that a firm broadens its scope across different markets. In the specific context of technology commercialization, a resource leverage strategy carried out through a mixed strategy implies broadening the scope of activities of an innovator across distinct – though related – vertical markets. In a resource perspective, a mixed strategy implies that a firm set of capabilities spreads across distinct stages of the value chain, from those supporting the inventive activities to those underlying the efforts of embedding those inventions into downstream assets and products. Yet, it is widely recognized that this vertical de-specialization is detrimental for firm efficiency (e.g. Arora et al., 2001; Cockburn, 2008). In fact, firms capabilities develop through the performance of activities and execution of tasks (Nelson and Winter, 1982), hence limiting the scope of the tasks accomplished by a firm may enable faster accumulation of experience and, consequently, stronger expertise in the execution of those tasks. Following a strict logic of comparative advantage, firms specialized upstream in the inventive activities would be better able to perform inventive activities while firms specialized downstream would prove to be better able to embed those inventive activities into downstream assets and products. The comparative efficiency of vertical specialization versus vertical de-specialization has been mostly investigated with respect to the relative advantage of the former over the latter in performing inventive activities. For example, Jacobides, Knudsen and Augier, (2006) argue that integrating downstream inhibits the firms' ability to innovate in the future. Hicks and Hedges (2005) find that US-based "serial innovators" – i.e., small firms with a substantial, public record of successful technical advance – are often technology specialists, while in a context of European SMEs Padula (2008) demonstrates that specialization positively affect both the rates of firm innovation and the impact of this new knowledge in shaping subsequent technological innovations by other firms.

Whereas these weaknesses have been exclusively referred to the drawbacks of vertical integration compared to vertical specialization, they may also apply – or turn to be even more serious – if referred to vertical de-specialization implied in a mixed technology commercialization strategy. In fact, in a context of mixed strategy, not only an innovator engages in both upstream and downstream activities, but it also engages in both types of activities addressed to different markets – i.e., both the upstream technology input market and the downstream product market – each responding to different rules or "best ways" of doing business. Indeed, on one hand, the profitability in the technology market depends on the technology itself as the flow of revenues in those markets is generated exclusively by selling the technology in disembodied form through contractual agreements with external partners. Hence, technology markets reward firms depending of their record of high quality innovation outcomes. On the other hand, the profitability in the product market does not depend on the technology itself but on the organizational capability of an innovator to combine that technology with complementary assets. Hence, the profitability in the product markets depends on several dimensions of performance of the firm set of resources and organizational capabilities (for a summary test to assess the ability of firms to conquer a competitive advantage and profit in a product market, see Collis and Montgomery, 1995). As a consequence, in its search of being successful on both markets as implied by a mixed technology commercialization strategy, a firm may run the risk of failing to match both the requirements to be successful in the technology markets and those to be successful in the product market, Based on this line of reasoning, a mixed strategy seems to be a less efficient technology commercialization option compared to a pure one.

Hence, all other things being equal:

Hypothesis 1 Pure technology commercialization strategies are superior to mixed technology commercialization strategies.

METHODS AND MEASURES

Model Estimation and Econometric Issues

Several empirical challenges need to be dealt with when testing substitution between organizational practices, due to the difficulty of finding appropriate measures for the values of strategies and for input prices (Athey and Stern, 1998).

Two econometric approaches have been commonly utilized in the literature to perform this test: the ‘adoption’ approach and the ‘productivity’ approach. We rely on these two methods for testing our hypothesis, which corresponds to testing substitution between different commercialization practices.

The Adoption Approach

The *Adoption* approach constitutes an indirect test of substitution. It is based on the idea of ‘revealed preference’ of strategies, i.e., if two activities are *substitutable* one would expect firms *not* to employ those activities together. Indeed, any increase in the use of one practice would correspondingly *decrease* the probability of using the other one. Therefore if two activities are substitutable, one would expect them to be *negatively* correlated, even after controlling for observable exogenous characteristics. This approach has been theoretically analyzed by Arora and Gambardella (1990); Holmstrom and Milgrom (1994), Arora (1996) and Athey and Stern (1998) and it has been implemented, using various specifications, in several management studies (e.g., Arora and Gambardella, 1990; Ichniowski, Shaw and Prennushi , 1997; Bresnahan, Brynjolfsson and Hitt, 2002; Cassiman and Veugelers, 2006).

We apply this model to our analysis by setting two separate regression models for vertical integration-based and cooperation-based activities, each having one type of commercialization activity as the dependent variable and a vector of firm and industry controls as explanatory variables. Since our dependent variables are dichotomous, we estimate these models through binomial Logit regressions. As a test for our hypothesis, we look at the pair wise correlation between the residuals of the regressions (Arora and Gambardella, 1990). Indeed, if the commercialization activities are substitutable, the covariance between these two practices, conditional upon a set of firm characteristics, should be negative; hence residuals of the regressions should be negatively correlated.[5]

The adoption approach identifies substitution between activities by looking at the *actual* commercialization *choices* of firms. The validity of this approach relies on a fundamental assumption: firms take an *optimizing behavior* in the decision of commercialization practices (Athey and Stern, 1998; Lokshin, Caree and Belderbos, 2007). This means that if two activities are substitutable, firms will tend *not* to use them jointly. It might be argued that a number of firms within the population under investigation might take *non-optimal combinations* of practices (Athey and Stern, 1998). For instance, managers may not be well informed or may face adaptation costs (Lokshin *et al.*, 2007); or their choices may be simply the results of 'managerial fads' (Bresnahan *et al.*, 2002). However, if this were the case – i.e., if the observed combination of activities were merely the results of non-optimizing behavior – the adoption approach could not provide a robust test of the substitution effect of

[5] As a robustness check, we replicate the analysis setting a *Bivariate Probit* model. This model estimates the probability of selecting cooperation-based and vertical integration-based commercialization activities through a two-equation probit model (where commercialization activities are set as the dependent variables) and provides the correlation coefficients between the two equations. Also in this case, firm and industry controls are introduced as explanatory variables.

distinct practices. Hence, to check the robustness of our analysis, we replicate the test of substitution using an alternative approach, i.e., the *productivity approach*.

The Productivity Approach

In the productivity approach, firm performance is estimated as a function of the combination of practices and of a set of industry and firm controls. The interpretation of this function is that if different commercialization strategies are substitutable for one another, the marginal performance of jointly employing these two kinds of activities (i.e., employing *mixed* commercialization strategies) will be lower compared to the performance of employing each of the two activities separately (i.e., *pure* commercialization strategies).[6] This approach constitutes a direct test of substitution and has been used in recent empirical work (e.g., Cassiman and Veugelers, 2006).

Following this approach, we tested the existence of a substitution effect by regressing several measures of firm performance on combinations of mutually exclusive commercialization activities. We created a dummy variable that indicates whether the firm engaged in *cooperation-based* activities (COOP) or pursued *vertical integration-based* activities (VERT_INT) – i.e., commercialization *practices*. From these dummy variables we constructed different exclusive categories – i.e., the commercialization *strategies* of the firms: firms that do not engage in commercialization activities (*No Commercialization*); firms that accomplish *exclusively cooperation-based* activities (*Pure Cooperation-based strategy*); firms that

[6] That is, *Π(Mixed commercialization Strategy) - Π(Pure Vertical Integration-based Strategy)* ≤ *Π(Pure Cooperation-based Strategy) - Π(No commercialization)*

accomplish *exclusively vertical integration-based* activities (*Pure Vertical Integration-based strategy*); firms that *couple both cooperation-based* and *vertical integration-based* activities (*Mixed Strategy*). The test for substitution between vertical integration-based and cooperation-based practices is:

$$\beta_{Mixed} - \beta_{Pure_c} \leq \beta_{Pure_{vi}} - \beta_{None}$$

Sample and Data

We tested our hypothesis by examining the technology commercialization strategies of US public *innovative SMEs* in the time frame 1996-2001 across all industries through a cross-section analysis. As already mentioned, innovative SMEs constitute the ideal population for testing our theoretical framework for two main reasons. First of all, the study of SMEs enables variability in the use of commercialization activities to be observed. Indeed, as noted by Teece (1986) these firms are less likely to possess the relevant specialized assets for commercializing technology through vertical integration activities, hence SMEs face a critical choice between the two categories of practices. Second, compared to large firms, SMEs are more likely to have a narrow technological scope as well as a smaller number of downstream target markets. This allows a more precise test, since the substitution effect is likely to be influenced by these factors, although we introduce several variables into the analysis as controls.

Our sample selection procedure involved four steps. First, we identified active innovation companies by selecting all firms which had been granted five or more USPTO patents during our time window of interest[7] (1996 -2001) using the NBER patent dataset. As patents are an externally validated measure of technological novelty (Griliches, 1990), they have been commonly used as a measure of firm innovativeness (e.g., Ahuja, 2000; Ahuja and Katila, 2004; Schilling and Phelps, 2007; Padula, 2008). Hence, we rely on this criterion for identifying a sample of innovative firms. Second, we tracked down subsidiaries to the parent company using the Who Owns Whom database and we excluded from our list those firms that in the above period were subsidiaries of large firms or joint ventures. Third, we matched the resulting list with company names from Compustat Research Insight. In order to avoid survival bias in the matching procedure, we matched company names in each of the years from 1996 to 2001. Even companies that met these inclusion criteria for just one year were kept in the sample. Using Compustat, we collected financial, accounting, and industry affiliation data on each of the firms. In the fourth step, we used information on firm employees from Compustat to exclude large firms from our sample. Specifically, we selected firms with 250 employees or less in 1996.[8] In this way, our sample included firms that matched our initial condition of being SMEs but that might eventually have grown, decreased or gone out of business later. This was

[7] We choose five patents as the cut-off point for inclusion in order to exclude occasional inventors from the sample. Nevertheless, a five-patent threshold was valued as sufficiently low to allow a high variability in terms of firm patent activity within the sample.

[8] For firms that were founded within the period 1996-2001 we considered the year of founding.

done because restricting our analysis only to firms which have *remained small* could have generated some biased results.

The sample selection process yielded 479 firms, operating in a wide variety of industries.[9] In order to allow comparability across different commercialization practices we excluded from the sample firms whose core business does not imply downstream integration. Hence, we excluded firms classified in the SIC codes "6794" (Patent Owners and Lessors), "7370" (Services-Computer Programming, Data Processing, etc.) and "7372" (Services-Prepackaged Software). The final sample included 439 firms.

We used this master list to collect data on firm technology commercialization activities in the period 1996-2001. Unfortunately, cross-industry data on firm commercialization practices are not readily available in public and commercial datasets, especially in the case of small and medium sized firms (Gans, Hsu and Stern, 2002). For this reason, we built a unique novel dataset collecting data on strategies using the approach followed by previous academic studies on this issue (e.g., Mitchell and Singh, 1996). Specifically, the data were collected and triangulated through an extensive search of press releases (using Factiva and Lexis-Nexis datasets), corporate reports (Security and Exchange Commission –SEC- filings, Lexis-Nexis)[10] and corporate websites.[11] This data collection process requires the

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[9] We observe that almost 80 percent of our cumulative observations are from just four 2-digit classes, namely, SIC 28, SIC 38, SIC 36 and SIC 35. These include the Chemicals, Medical Instruments, Electronics and Computer sectors. All the afore-mentioned sectors are high-technology sectors which have seen tremendous innovative activity among SMEs.

[10] The Lexis Nexis dataset collects company profiles from several sources such as: America's Corporate Finance Directory; Annual Register of Grant Support; CoreData US Institutional Database;

assumption that commercialization strategies of firms have been publicly reported. As highlighted by Mitchell and Singh (1996), this assumption is credible in a study of US public companies – which is the case of this study sample – owing to the extensive reporting of commercial information by multiple business, industry, and government sources.

Variable Definition and Operationalization

Technology Commercialization Practices

We created two dummy variables that correspond to the two identified practices of technology commercialization, i.e., vertical integration-based and cooperation-based. Recent studies testing complementarities between practices have followed the same approach (e.g., Athey and Stern, 2002; Cassiman and Veugelers, 2006).[12]

Directory of Business Information Resources; Directory of Trust Banking; Directory of Venture Capital Firms; Disclosure(R) Online Database-US Public Company Profiles; Experian Business Reports; Global Markets Direct Company Profiles; Homeland Security Directory; Hoover's Company Records - Basic Record; Hoover's Company Records - In-depth Records; Hoover's IPO Reports; International Business and Trade Directories; ISS Corporate Governance Quotient Profiles; ISS Proxy Research Reports; ISS Securities Class Action Services; LexisNexis(R) Corporate Affiliations(TM); Municipal Issuers Registry; Nelson's Analyst Company Coverage; Nelson's Public Company Profiles; Nelson's Research Firm Profiles; Netvention Company Profiles; OneSource(R) CorpTech(R) Company Database; Safety and Security Directory; SGA Executive Tracker Companies; Standard & Poor's Corporate Descriptions Plus News; Standard & Poor's Corporate Register; Standard Directory of Ad Agencies and International Ad Agencies (Redbooks); Standard Directory of Advertisers and Int'l Advertisers (Redbooks); The Bank Directory; The Bond Buyer's Municipal Marketplace; The Credit Union Directory(R); The Savings Directory; US Executive Compensation Database - Boards & Committees; Worldscope-International Company Profiles

[11] We aimed to collect information on firm strategies in the time period 1996-2001. In several cases corporate websites reported information on this time period in a dedicated section (e.g., history of the company). In the cases in which a 'history section' was not available, or when the website was no longer active, we used the Internet Archive's Wayback Machine to visit the past Web sites of firms in our sample (Yadav, Prabhu, Chandy, 2007).

[12] Our choice of using dummy variables to identify the use of commercialization activities was because, in order to identify the effect of substitutability, we needed measures that can identify the use of practices but that are not endogenously related to the other set of firm and industry variables

These two variables are not mutually exclusive, meaning that a firm may have employed either one, both or none of the two practices.

Cooperation-based Technology Commercialization Practice

The first dummy variable indicates whether the firm engaged in *Cooperation-based Commercialization* (COOP) within the period 1996-2001. We identified two possible practices that, following previous literature on this topic (e.g., Arora *et al.*, 2001; Gans and Stern, 2003), can be classified as such: Technology Licensing (TL) and Downstream Alliances (DA). In order to identify whether a firm engaged in Technology Licensing or Downstream Alliances, we extensively reviewed press releases, corporate reports and corporate websites. For each of the companies in our sample, we read the full texts of all the announcements and reports which mentioned the name of the firm. Our criterion for recognizing the engagement of the firm in one of these activities was the formal announcement of an agreement in one of these published media. Following Mitchell and Singh (1996), we believe that this search method allows the correct identification of most publicly reported interfirm agreements and the accurate date of signing to be assigned to them. Indeed, first, our sources included specialized industry publications which provide detailed coverage of most activities occurring within each industry, even if this information had not been deliberately released by the firm; second, many of these kinds of

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that we use in the analysis. We believe that dummy variables are more robust for this purpose than scale measures. For instance, a scale measure such as the total number of agreements that the firm finalizes may be highly related to other variables - e.g., the prestige of the firm - which are ultimately related to firm performance.

agreements are formal and legally binding, resulting in their being public knowledge; third, widespread knowledge of these kind of cooperative agreements may provide several benefits to firms, so they may tend to publicize them actively (Mitchell and Singh, 1996).

We referred to the content of the announcement for classifying agreements. Specifically, we identified as Technology Licensing agreements those cases in which the announcement: a) mentioned technology transfers from the focal firm to other businesses; b) included words such as “license” or “licensing”; or c) mentioned that the focal firm received a payment for the transfer of technology (e.g., referring to some specific licensing terms such as “royalties” or “fees”). We identified as Downstream Alliances all those agreements for which the content of the announcement explicitly referred to a collaborative agreement between two or more firms,[13] under the terms of which the focal firm provided the technology and the partner offered the use of its own downstream assets. The cross-industry perspective taken by our study required a basic measure of downstream assets which enabled comparability across all different industries. Therefore, we chose to focus on a unique type of assets, i.e., manufacturing assets. In our view, these facilities constitute the most critical assets for firms commercializing a technology, for two main reasons: first, because manufacturing facilities usually require large investments in terms of time and financial resources for acquiring or building them; second, because manufacturing assets have a high degree of interdependence with

[13] E.g., we found the words “alliance”, “collaboration”, “partnership”, “cooperative agreements”.

the technology being commercialized.[14] In almost all cases we identified the same agreements published in more than one source. This allowed us to cross-check the nature of the agreement and to correctly classify it.

Based on this search process, we built two alternative measures for the variable COOP. The first measure, COOP=TL OR DA, is a dummy variable valued 1 if the firm engaged in *at least one type* of cooperative commercialization activity (Technology Licensing OR Downstream Alliances) and 0 if the firms employed neither Technology Licensing nor Downstream Alliances. The second measure, COOP=TL AND DA, is a dummy variable valued 1 if the firm engaged in *both* forms of cooperative activities (Technology Licensing AND Downstream Alliances) and 0 if the firm employed only one or neither of them.

Vertical Integration-based Commercialization Practice

The second dummy variable indicates whether the firm employed *Vertical Integration-based Commercialization Activities* (VERT_INT) in the period 1996-2001. To identify this practice, we looked at whether the firm possessed the relevant downstream assets for commercialization in the period. Also in this case, we focused on a unique type of downstream assets, i.e., manufacturing facilities. To identify whether the firm possessed manufacturing facilities in 1996-2001, we relied on information provided in press releases, corporate reports, and company websites. We scanned these sources looking for direct information on the possession of

[14] Of course, an industry-specific perspective would allow the defining of measures of downstream assets more fine-tuned to the context.

manufacturing facilities. In many cases the corporate website provided information on the facilities possessed by the firm. In other cases we found this information in company descriptions appearing in the press articles.[15] We also found this information explicitly specified in the company's SEC filings.[16] In all cases we were able to reach a definitive decision.

Firm Performance variables

In order to test substitution using the productivity approach, we needed to identify a measure of firm productivity which could be closely related to firm commercialization practices (Athey and Stern, 1998). We introduced into the analysis several alternative measures of firm performance that are related to commercialization activities as well as being commonly adopted as measures of firm performance in studies dealing with SMEs (e.g., Qian and Li, 2003). Our first measure of firm performance, *Average Value Added,* was calculated in the following way. For each firm in each of the years within the period 1996-2001, we calculated the Value Added by subtracting the Cost of Good Sold to Total Sales. We then divided this value by the number of employees in that year. We then calculated the average for each firm for the period 1996-2001. Finally, we took the logarithm of the

[15] For example we found descriptions such as: "The company develops, *manufactures* and markets innovative disposable and limited-use protective apparel products for the industrial, clean room, medical and dental markets. The company has manufacturing facilities in Salt Lake City, Utah; Nogales, Arizona; Janesville, Wisconsin."

[16] For instance some examples of the expressions that we found are: "we *directly manufacture* our products" or "*our manufacturing facilities*"; or conversely, "We do not possess manufacturing plants. We rely on collaborators and contract manufacturers to manufacture products in both clinical and commercial quantities".

resulting value. Our second measure of firm performance, *Average Sales*, was calculated by taking, for each firm, the logarithm of the mean for the period 1996-2001 of Total Sales divided by number of employees. We also introduced into the analysis the variables *Average ROA, Average ROE* and *Average ROS,* calculated respectively as the average of Return on Assets, Return on Equity and Return on Sales for each firm in the period 1996-2001. Our final measure of firm performance was the *Average Sales Growth*, that we built for each firm included in the sample, by taking the growth of sales for each of the years between 1996 and 2001 and then calculating the mean for the period.

Controls

We defined a series of variables that we included in the analysis as a control set to account for firm, technology and industry characteristics. Concerning *firm characteristics*, we controlled for *Firm Age,* computed as the number of years elapsed from the firm's foundation year to 2001. We also controlled for the size of the firm, using the variable *Firm Size*¸ which is measured as the average number of employees recorded by the firm in the period 1996-2001. We included a measure of *Patent Propensity*, to account for the degree of innovativeness of the firm. To compute this measure, we counted the number of patents granted by the firm between 1996 and 2001 at USPTO using the NBER dataset.

The degree of substitution between commercialization practices may also be influenced by some *characteristics of the technology or of the technological portfolio* *of the firm*. One of these characteristics is the *Generality of the technology* mastered by the firm. General purpose technologies (GPT) have been defined as technologies with a high potential of application in a wide range of sectors (Bresnahan and Trajtenberg, 1995; Hall, Jaffe and Trajtenberg, 2000). If the technology is general, i.e., broadly applicable, the innovative firm may use it to develop different applications, which target different downstream markets so that they are not in competition with each other. In this case the substitution effect between cooperative and vertical integration-based commercialization practices might be weaker. To control for this effect, we introduced into the analysis the variable *Generality.* We computed this variable using the measure of generality of the technology by Trajtenberg *et al*. (1997) that can be extracted from the NBER dataset. This measure accounts for the extent to which citations received by a patent are spread across different technology classes.[17] For each firm, we took the mean of the generality measure of the patents granted by the firm between 1996 and 2001. The level of *diversification of the firm technological portfolio* may also affect the test of substitution between cooperative and vertical integration-based commercialization practices. Indeed, suppose that a firm has in its portfolio two technologies that are very different, meaning that they can be applied to very different contexts, can be used in very different applications and target very different markets. In this case the

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17 $GENINDEX_i = 1 - \sum_{k=1}^{N_I} \left(\frac{N_{citing_{ik}}}{N_{citing_i}} \right)^2$ k is the index of patent classes and N_i is the number of different classes to which the citing patent belongs.

firm might choose to commercialize one technology pursuing a vertical integration practice, while contracting out the other technology. Indeed, if the two technologies are greatly diversified there should be little – if any – interdependence between them. As a consequence, we would observe the concurrent use of different practices by the same firm: this result, although not driven by complementarity between different commercialization activities, would bias our test in the direction of complementarity. Although we believe that in the case of SMEs the level of technological diversification is a minor problem, since these firms are less likely than larger firms to carry out very different technological paths, we introduced the variable *Technological diversification* to account for this effect. We calculated this variable as 1 – the Herfindahl index of IPC technological class (at the 3-digit level) assigned to the patents granted by the firm between 1996 and 2001.

Several studies in the previous literature have shown the role played by *characteristics of the environment* in determining commercialization strategies (e.g., Teece, 1986; Gans *et al.*, 2002; Gans and Stern, 2003). We built the variable *Industry Sales* to control for industry effects at the 3-digit level of analysis. Data for calculating this variable were obtained from the US Census Bureau for the year 1997.[18] The variable was built as the logarithm of the total sales in each 3-digit industry. As an alternative control for industry effects we included in the analysis a series of *Industry Dummies.* Specifically, for each of the industries represented in our

[18] We chose 1997 since it was the year closest to the period of interest among those for which data were available at the US Census. As a robustness check we also tried different years, but results did not change.

sample (coded following 2-digit US SIC classification), we created a dummy variable taking value 1 if the firm was operating in that industry and 0 otherwise. The effectiveness of the *appropriability regime* in the industry has been identified by previous works on technology commercialization (e.g. Teece, 1986; Gans and Stern, 2003; Gans, Hsu and Stern, 2008) as one of the main factors influencing commercialization practice decisions. In some industries, the ownership of manufacturing assets may constitute *per se* the most effective form of protection against competitors (Cohen *et al.*, 2000). In these industries it is therefore probable that firms will show a tendency toward the choice of a pure, vertical integration-based commercialization strategy. In order to control for this effect, we included the variable *Effectiveness of Protection from Manufacturing Assets.* To build this variable, we referred to data from the 1994 Carnegie Mellon Survey (see Cohen *et al.*, 2000). This survey contains information at the 3-digit SIC code level on the effectiveness of different appropriability mechanisms for protecting innovation. We focused on data concerning the effectiveness of manufacturing facilities in protecting firm competitive advantage and we built an index ranging from 0 to 1, where 1 corresponds to the maximum effectiveness in protection.

Table 1 lists variables, definitions and descriptive statistics. Table 2 displays correlations between the main variables in our analysis.

Insert Tables 1 & 2 near here

RESULTS

Table 3 reports the frequency of the *commercialization practices (Cooperation-based and Vertical Integration-based practices)* and *the combination of these practices (i.e., commercialization strategies)* chosen by the firms. As can be seen from the table, the number of firms employing a mixed strategy is lower than the number of firms employing each of the two types of pure strategies. This result is confirmed using both measures of cooperation practices: Technology Licensing OR Downstream Alliances, or Technology Licensing AND Downstream Alliances. These descriptions provide preliminary support to our hypothesis that pure strategies are superior to mixed ones, assuming that firms adopt an optimizing behavior.

Insert Table3 near here

<u>Test of substitution: Adoption Approach</u>

Tables 4 and 5 present the results of the test of substitution using the *Adoption* approach. The tables report the estimates of the logit regressions with the commercialization activities as dependent variables and the vector of firm and industry controls as independent regressors. Specifically, we identified the use of *Cooperation-based* commercialization activities using the variable Technology Licensing **OR** Downstream Alliances in Table 4, whereas we used the variable Technology Licensing **AND** Downstream Alliances in Table 5. As a test for our hypothesis, we looked at the residuals of the regressions, presented at the bottom of Tables 4 and 5. Results show that the correlation coefficient between the regression predicting the likelihood of engaging in *Cooperation-based* commercialization activities and the regression predicting the likelihood of employing *Vertical Integration-based* commercialization activities are negative (i.e., the correlation between the residuals of Model 4.1 and Model 4.2 as well as the correlation between the residuals of Model 5.1 and Model 5.2). This supports our hypothesis that cooperation and vertical integration practices are substitutable for one another in innovative SMEs.[19]

Insert Tables 4 & 5 near here

Test of substitution: Productivity Approach

To test the robustness of these results we analyzed substitution through the Productivity approach. We regressed our measures of firm performances on the exclusive combination of commercialization practices using firm characteristics and industry variables which may affect the performance of the firm as controls. We ran several regression models using alternative measures of firm performance. Results are reported in Tables 7 and 8. Specifically, in Table 7 the measure of *Cooperation-based commercialization* activities that we used is Technology Licensing *OR* Downstream Alliances, i.e., whether the firm is engaged *in at least one* of these activities. For each model, we performed a joint test on the null hypothesis of equality of means and a direct test of *no* substitution (two-sided) – i.e., testing the marginal effect of adding a commercialization activity. As is shown in Table 7, the

[19] As a robustness check, we replicated the same analysis (Adoption approach) using a Bivariate Probit Model. Results, shown in Table 6, proved robust.

joint test for equality of means can be rejected only in Model 7.6 (5 percent level of significance), where we use *Average Sales Growth* as a measure of firm performance. Correspondingly, in Model 7.6 the direct test of substitution is also rejected at the 5 percent level of significance. These results provide partial support to our hypothesis. We replicated the productivity analysis by using our alternative measure to identify *Cooperation-based commercialization* activities (i.e., whether the firm is engaged in *both* Technology Licensing *AND* Downstream Alliances). Results are reported in Table 8. In this case, the coefficients indicating the difference between the mean of performances across groups is negative for all models, suggesting substitution between Cooperation and Vertical Integration-based Commercialization Practices. Moreover the direct test of substitution is rejected in Models 8.1, 8.2 and 8.3, at the 5 percent, 1 percent and 5 percent levels of significance, respectively. These results provide stronger support for our hypothesis.

Insert Tables 7 and 8 near here

The differences in the results shown in Table 7 (when the TL OR DA measure of Cooperation-based Commercialization Practices was employed) compared to those displayed in Table 8 (where the results were obtained by using the TL AND DA measure of Cooperation-based Commercialization Practices) demonstrates that the differences in the comparative efficiency between mixed and pure strategies are larger when pure cooperation strategies are based on a wider array of types of cooperation-based activities. This result may implicitly reveal that some interdependences might exist across different types of cooperation-based technology commercialization practices, as we discuss in the last section of this paper.

As a further robustness check, we replicated all the analyses (Adoption and Productivity Approach) using *Industry Dummies*, the alternative measure created to control for industry effects. Results proved robust both in terms of sign and significance and are available on request from the authors.

DISCUSSION AND CONCLUSION

This paper provides a re-conceptualization of technology commercialization strategies available to innovative firms in terms of pure vs mixed commercialization strategies. We referred to 'pure' strategies in order to identify the case in which firms commercialize their technology either through vertical integration or alternatively through cooperation-based activities. Conversely, with the expression 'mixed' strategies we referred to the circumstance in which firms simultaneously use both vertical-integration and cooperation-based commercialization practices. Specifically, this paper aims to assess the relative efficiency of pure vs mixed commercialization strategies. In fact, while we acknowledge that mixed strategies expand the firms' opportunities of leveraging their technological resources and consequently increasing their revenues, we do not have a systematic understanding of the comparative efficiency of mixed strategies versus pure ones. This paper fills this gap by investigating whether a substitution effect operates between vertical integration and cooperation-based technology commercialization activities.

The theory development of this paper builds on the resource-based view of the firm. In particular, we develop our hypothesis by extending to this study context two lines of inquiry developed within the resource-based view: first, the ways in which a firm may appropriate the returns to its competitive advantage; second, a discussion of the possible pitfalls of a resource leveraging strategy employed by a firm. We accomplished the empirical investigation of this study by using a cross section dataset on innovative SMEs. The results from the econometric analysis provide support for our hypothesis of substitution. Specifically, looking at the correlation across firms in the use of practices (i.e., *the 'adoption' approach*), we find that firms tend to employ *Cooperation-based* and *Vertical Integration-based* activities as alternative options. Moreover, the results from the *'productivity' analysis* test the robustness of this finding by showing that firms employing mixed strategies tend to have lower marginal performances than those employing pure ones. Results also show that the substitution effect is even stronger in the case in which firms engage in a wider array of contractual arrangements within the cooperation-based commercialization practices (i.e. Technology Licensing AND Downstream Alliances), rather than specializing in a more restricted set of them (i.e., Technology Licensing OR Downstream Alliances).

Results from this study have significant implications for research on technology commercialization. The recent manifestations of the increasing tendency of firms to engage in mixed strategies do not seem to be – at least "on average", across multiple industries – the ideal technology commercialization strategy according to this study's findings. In fact, our study findings must be interpreted in relation to the methodological choices employed in this paper. Indeed, our analysis employs a cross-industry perspective and shows results that demonstrate what happens "on average" across multiple industries. While this methodological choice provides a wide scope for our findings, it has the drawback of neglecting the peculiarities of specific industries. Hence, further investigations which may account for the contingency factors affecting the results at a more restricted level of investigation may be a very fruitful line of inquiry for future research.

Interesting implications for research also come from a deep evaluation of the results obtained by the employment of the statistical test based on the 'productivity' approach. In fact, the stronger effect on the differential performance of mixed versus pure strategies when we consider a wider array of cooperation-based commercialization practices may implicitly shed light on some eventual positive interactions among different types of contractual arrangements, in particular between licensing and downstream alliances. This result opens the window on a new possible line of investigation addressing the understanding of relationships – i.e., positive interdependence or complementary effects – across different types of agreements falling in the pure Cooperation-based Technology Commercialization activities.

The results of this paper also provide an intriguing contribution to the resource-based-view of the firm. Indeed, research in this area has focused on understanding how firms can leverage their resources in alternative downstream markets, expanding firms' horizontal scope (Collis and Montgomery, 1995). This paper, acknowledging the recent emergence of intermediate markets for technology, extends the investigation of this issue on a vertical dimension, by exploring the potential pitfalls of strategies aimed at leveraging technological resources into upstream and downstream markets simultaneously. In this respect, our analysis shows that these strategies need to be handled carefully since the simultaneous presence in upstream and downstream markets ultimately tends to modify the factors determining success in each of the markets.

The contribution of this paper merits the attention of practitioners. On the one hand, we confirm the idea that cooperative practices of technology commercialization represent an opportunity for small sized, highly innovative firms to appropriate the returns of their innovations. However, this paper warns managers to be cautious in the way they employ these types of strategies that, if not applied correctly, may dissipate firm sources of competitive advantage. In particular this paper shows that managers should not just look at the decision of employing (or not) each specific strategy as an isolated choice, but should rather *jointly* determine the combination of practices to be employed for an efficient novel technology commercialization.

This study also has some limitations. First, it reveals the existence of a substitution effect between technology commercialization practices at the corporate level. It may be argued that firms might employ different strategies of commercialization for each type of technology developed, with the results that, at a firm level, we could observe the concurrent use of diverse strategies. However, if this is the case, we would expect this limitation to bias our results toward complementarity, while we observe substitution. Hence, the validity of our results is not compromised.

Finally, this work provides a cross-section perspective for the issue of technology commercialization. While we emphasized the existence of two distinct, alternative approaches adopted by the firms to commercialize their technology, it would be interesting to bring a *longitudinal perspective* to this analysis and observe whether and how the firm business model changes over its life-cycle and how this change affects firm performance.

TABLES

TABLE 1

List of variables and descriptive statistics							
Variables	Acronym	Type and Description	Mean	S.D.	Min	Max	Source
Commercialization Practices							
Cooperation-Based Commercialization Practice							
Technology Licensing	TL	Dummy variable valued 1 if the firm has entered into (one or more) licensing out agreements within the period 1996-2001, 0 otherwise	0.52	0.50	0	1	Press Releases (Factiva, Lexis-Nexis), Corporate Reports (SEC Filings, Lexis-Nexis), Corporate Websites, Internet Web Archive
Downstream Alliances	DA	Dummy variable valued 1 if the firm has entered into one or more production agreements on production within the period 1996-2001, 0 otherwise.	0.29	0.46	0	1	
Technology Licensing OR Downstream Alliances	TL_OR_DA	Dummy valued 1 if the firm uses at least one of the following cooperative activities: Technology Licensing, Downstream Alliances; 0 if the firms does not use either TL or DA	0.64	0.48	0	1	
Technology Licensing AND Downstream Alliances	TL_AND_DA	Dummy valued 1 if the firm uses both cooperative activities (Technology Licensing, Downstream Alliances); 0 if the firm uses only one of these activities or neither of them	0.17	0.37	0	1	
Vertical Integration-based Commercialization Practice							
Internal Manufacturing	DI	Dummy variable valued 1 if the firm possesses Internal Manufacturing facilities within the period 1996-2001, 0 otherwise.	0.54	0.50	0	1	
Performance variables							
Average Value Added	VA	Logarithm of the Mean in the period 1996-2001 of Value Added divided by number of employees of each firm (Value Added=Sales-Cost of Goods Sold)	4.63	1.14	-1.79	7.36	Compustat
Average Sales	SALES	Logarithm of the Mean in the period 1996-2001 of Sales divided by	2.01	0.33	0.63	4.58	

		number of employees of each firm					
Average ROA	ROA	Mean of Return on Assets of each firm in the period 1996-2001	-53.32	99.35	-1450.95	25.58	
Average ROE	ROE	Mean of Return on Equity of each firm in the period 1996-2001	-124.96	481.56	-8865.54	198.99	
Average ROS	ROS	Mean of Return on Sales of each firm in the period 1996-2001					
Average Sales Growth	SALES_GR	Mean of sales growth of each firm in the period 1996-2001.	2.10	7.44	-1	106.83	
Control variables							
Patenting Propensity	PAT_PROP	Logarithm of the count of firm patents granted in the period 1996-2001	2.57	0.71	1.79	4.99	NBER Patent Dataset
Generality of the Technology	GEN INDEX	For each firm, mean of the GENINDEX of the patents granted between 1996 and 2001. $GENINDEX_i = 1 - \sum_{k=1}^{N_I} \left(\frac{N_{citing_{ik}}}{N_{citing_i}} \right)^2$ Extent to which citations received by a patent are spread across different technology classes. *k* is the index of patent classes and *Ni* is the number of different classes to which the citing patent belongs.	0.2	0.17	0.00	0.80	NBER Patent Dataset
Technological Diversification	TDIV	1-Herfindahl index of IPC technological class (3 digits) of firm's patents granted between 1996 and 2001.	0.41	0.25	0.00	0.88	NBER Patent Dataset
Firm Age	AGE	Logarithm of the count of the number of years elapsed since firm's foundation to 2001.	2.59	0.50	1.10	4.41	Corporate Reports (SEC Filings, Lexis-Nexis), Corporate Websites, Internet Web

Firm Size	SIZE	Logarithm of the mean of the number of employees between 1996 and 2001.	4.62	0.84	1.33	7.03	Archive Compustat
Effectiveness of Protection from Manufacturing Assets	APPR_MANU	Index measuring the strength of protection guaranteed by the ownership of Downstream Manufacturing Assets in each industry	0.56	0.04	0.31	0.70	Carnegie Mellon Survey
Industry Affiliation (2_dgt dummies)	SIC_13 - SIC_99	For each of the 2-digit US SIC codes, dummy variable is valued 1 if the firm falls into the corresponding 2-digit SIC code, 0 otherwise			0	1	Compustat
Industry Sales	IND_SALES	Log (Total Industry Sales in 1997 at the US SIC 3-digit level)	9.54	1.14	6.33	11.31	US Census Bureau

TABLE 2

Pair-wise correlation between variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. TL	1.00																	
2. DA	0.07	1.00																
3. TL_OR_DA	0.77	0.48	1.00															
4. TL_AND_DA	0.43	0.70	0.33	1.00														
5. DI	-0.38	-0.16	-0.40	-0.19	1.00													
6. VA	0.03	0.06	0.07	0.03	0.09	1.00												
7. SALES	0.04	0.03	0.05	0.02	0.06	0.61	1.00											
8. ROA	-0.08	0.01	-0.09	-0.01	0.13	0.33	-0.03	1.00										
9. ROE	-0.05	0.01	-0.05	0.01	0.11	0.08	-0.04	0.38	1.00									
10. ROS	0.02	0.03	0.03	0.02	0.02	0.22	0.08	0.18	0.02	1.00								
11. SALES_GR	0.06	0.07	0.07	0.08	-0.12	-0.11	-0.12	-0.06	-0.02	-0.09	1.00							
12. PAT_PROP	0.10	-0.01	0.05	0.05	-0.07	-0.04	-0.21	0.10	0.04	0.03	0.01	1.00						
13. GEN INDEX	-0.13	0.07	-0.07	0.00	0.11	0.04	0.03	-0.08	0.03	0.03	-0.01	-0.01	1.00					
14. TDIV	0.05	-0.05	0.02	-0.02	0.03	0.05	0.02	0.09	0.10	0.10	-0.01	0.01	0.05	1.00				
15. AGE	-0.17	-0.04	-0.16	-0.08	0.24	0.15	0.06	0.25	0.12	0.05	-0.18	-0.12	-0.03	-0.03	1.00			
16. SIZE	0.04	0.04	0.01	-0.02	-0.06	0.31	-0.47	0.41	0.15	0.14	0.04	0.32	0.01	0.01	0.11	1.00		
17. APPR_MANU	0.02	-0.02	0.01	-0.02	0.03	0.03	0.04	0.03	-0.06	-0.02	-0.01	0.11	0.01	-0.06	-0.16	-0.04	1.00	
18. IND_SALES	0.21	0.14	0.25	0.13	-0.26	-0.05	0.05	-0.06	-0.05	0.01	0.06	0.00	-0.23	0.00	0.07	-0.10	-0.06	1.00

TABLE 3

Frequency of Commercialization Practices and Strategies

Commercialization Practices (NON EXCLUSIVE CATEGORIES)		**Frequency**
Cooperation-based Commercialization Practice	Technology Licensing	229
	Downstream Alliances	128
Vertical Integration-based Commercialization Practice	Internal Manufacturing	236

Commercialization Strategies (EXCLUSIVE CATEGORIES)	**Frequency**
Cooperation-based Practice = Technology Licensing **OR** Downstream Alliances *Vertical Integration-based* Practice = Internal Manufacturing	
Mixed Commercialization Strategy	111
Pure Commercialization Strategy (Cooperation-based)	172
Pure Commercialization Strategy (Vertical Integration-based)	125
None	31
Total	439

Cooperation-based Commercialization Practice = Technology Licensing **AND** Downstream Alliances Vertical Integration- based Practice = Internal Manufacturing	
Mixed Commercialization Strategy	24
Pure Commercialization Strategy (Cooperation-based)	50
Pure Commercialization Strategy (Vertical Integration-based)	212
None	153
Total	439

TABLE 4

Test of Substitution- *Adoption* Approach:
Logit Estimates of *Cooperation-based* and *Vertical Integration-based* Commercialization Practices

Dep. Variable: Commercialization Practices	(4.1) *Cooperation*: Technology Licensing **OR** Downstream Alliance		(4.2) *Vertical Integration*: Internal Manufacturing	
Patent Propensity	0.02		-0.18	
	(0.14)		(-1.11)	
Generality of the Technology	-0.03		0.27	
	(-0.05)		(0.38)	
Technological Diversification	0.01		0.51	
	(0.02)		(1.12)	
Firm Age	-0.75	***	1.20	***
	(-3.10)		(4.70)	
Firm Size	0.17		-0.02	
	(1.18)		(-0.17)	
Effectiveness of Protection from Downstream Manufacturing	-1.03		3.74	
	(-0.38)		(1.38)	
Industry Controls (Industry Sales)	0.52	***	-0.54	***
	(4.60)		(-4.68)	
Intercept	-2.8		0.55	
	(-1.28)		(0.25)	
Obs	373		373	
Prob > chi2	0.00		0.00	
Pseudo R2	0.07		0.10	
Log likelihood	-225.84		-231.78	

Test of Substitution- *Adoption* Approach:
Correlation among the residuals of the regressions

Commercialization Practices	*Cooperation*: Technology Licensing **OR** Downstream Alliance	Vertical Integration: Internal Manufacturing
Cooperation: Technology Licensing OR Downstream Alliances	1.00	
Vertical Integration: Internal Manufacturing	**-0.31*** **	1.00

Notes: Coefficients significant at 1%***, 5%**, and 10%*; z value in parentheses

TABLE 5

Test of Substitution- *Adoption* Approach: **Logit Estimates of Cooperation-based and Vertical Integration Commercialization Practices**				
Dep. Variable: Commercialization Practices	(5.1) Cooperation: Technology Licensing **AND** Downstream Alliance		(5.2) Vertical Integration: Internal Manufacturing	
Patent Propensity	0.19		-0.18	
	(0.94)		(-1.11)	
Generality of the Technology	0.69		0.27	
	(0.80)		(0.38)	
Technological Diversification	-0.56		0.51	
	(-1.02)		(1.12)	
Firm Age	-0.44		1.20	***
	(-1.46)		(4.70)	
Firm Size	0.07		-0.02	
	(-0.40)		(-0.17)	
Effectiveness of Protection from Manufacturing Assets	-2.78		3.74	
	(-0.85)		(1.38)	
Industry Controls (Industry Sales)	0.39	***	-0.54	***
	(2.63)		(-4.68)	
Intercept	-2.8		0.55	
	(-1.02)		(0.25)	
Obs	373		373	
Prob > chi2	0.10		0.00	
Pseudo R2	0.03		0.10	
Log likelihood	-168.09		-231.78	

Test of Substitution- *Adoption* Approach: **Correlation among the residuals of the regressions**		
Commercialization Practices	Cooperation: Technology Licensing **AND** Downstream Alliance	Vertical Integration: Internal Manufacturing
Cooperation: Technology Licensing **AND** Downstream Alliances	1.00	
Vertical Integration: Internal Manufacturing	**-0.18*****	1.00

Notes: Coefficients significant at 1%***, 5%**, and 10%*; z value in parentheses

TABLE 6

Test of Substitution- *Adoption* Approach:
Bivariate Probit Estimates of Cooperation and Vertical Integration-based Commercialization Practices

Dep. Variable: Commercialization Practice	(6.1) Cooperation		(6.1) Vertical Integration		(6.2) Cooperation		(6.2) Vertical Integration	
	Technology Licensing **OR** Downstream Alliance		Internal Manufacturing		Technology Licensing **AND** Downstream Alliance		Internal Manufacturing	
Patent Propensity	-0.00		-0.11		0.12	*	-0.10	
	(-0.01)		(-1.04)		(1.08)		(-1.07)	
Generality of the Technology	-0.04		0.12		0.37		0.12	
	(-0.10)		(0.29)		(0.78)		(0.28)	
Technological Diversification	0.01		0.32		-0.32		0.31	
	(0.04)		(1.19)		(-1.03)		(1.12)	
Firm Age	-0.47	***	0.71	***	-0.25		0.72	***
	(-3.14)		(4.78)		(-1.52)		(4.81)	
Firm Size	0.11		-0.03		-0.05		-0.02	
	(1.22)		(-0.29)		(-0.53)		(-0.28)	
Effectiveness of Protection from Manufacturing Assets	-0.60		2.29		-1.82		2.28	
	(-0.37)		(1.43)		(-0.99)		(1.40)	
Industry Controls (Industry Sales)	0.32	***	-0.32	***	0.22	***	-0.32	***
	(4.64)		(-4.73)		(2.76)		(-4.73)	
Intercept	-1.70		0.35		-1.47		0.37	
	(-1.27)		(0.26)		(-0.98)		(0.28)	
ρ12	**-0.53**	***			**-0.32**	***		
	(-7.26)				(-3.40)			
Obs	373				373			
Log likelihood	-438.60				-394.84			

Notes: Coefficients significant at 1%***, 5%**, and 10%*; z value in parentheses

TABLE 7

Test of Substitution- Productivity Approach: OLS Regressions on Firm performance (Huber White sandwich estimator) Cooperation =TL OR DA

	(7.1)	(7.2)	(7.3)	(7.4)	(7.5)	(7.6)
Dep. Variable: Performance	**Average Value Added**	**Average Sales**	**Average ROA**	**Average ROE**	**Average ROS**	**Average Sales Growth**
Cooperation and Vertical Integration Practices	0.66 **	0.18 **	-0.45	38.85	20.21	0.24
	(2.20)	(2.37)	(-0.05)	(0.79)	(1.26)	(0.32)
Cooperation Only	0.51 *	0.12	-10.66 *	-50.74	3.58	1.75 *
	(0.09)	(1.61)	(-1.13)	(-0.67)	(0.20)	(1.71)
Vertical Integration Only	0.36	0.12 *	2.73	32.19	-11.88	1.45
	(1.14)	(1.41)	(0.30)	(0.59)	(-0.34)	(1.36)
Patent Propensity	-0.21 ***	-0.02	-0.82	16.85	-2.67	-0.16
	(-3.06)	(-1.35)	(-0.23)	(0.80)	(-0.74)	(-0.27)
Generality of the Technology	0.33	0.08	-43.29 *	111.87	39.01	1.58
	(0.82)	(0.73)	(-1.76)	(0.68)	(0.81)	(0.56)
Technological Diversification	0.07	0.03	14.63	211.61	67.87	-0.45
	(0.29)	(0.39)	(0.97)	(1.36)	(1.12)	(-0.37)
Firm Age	0.26 **	0.07 **	28.68 ***	106.29	12.92	-2.73 **
	(2.19)	(2.12)	(4.49)	(1.51)	(0.98)	(-2.25)
Firm Size	0.50 ***	-0.18 ***	39.82 ***	93.68 ***	31.66 *	0.86 *
	(5.43)	(-4.73)	(5.43)	(3.70)	(1.69)	(1.90)
Effectiveness of Protection from Manufacturing Assets	2.04	0.39	39.75	-401.13	18.35	-5.88
	(1.44)	(1.17)	(0.46)	(-0.50)	(0.32)	(-1.45)
Industry Controls (Industry Sales)	-0.02	0.00	-5.16	-0.32	5.13	0.62 *
	(-0.35)	(0.04)	(-1.63)	(0.03)	(0.59)	(1.80)
Intercept	0.66	2.36 ***	-274.76 ***	-769.62 ***	-298.05	1.366
	(0.49)	(7.22)	(-4.43)	(-2.99)	(-1.38)	(0.32)
Obs	367	367	373	366	367	358
R2	0.16	0.24	0.26	0.06	0.04	0.05
Model	F(10,356)= 4.58***	F(10,356)=6.69***	F(10,362)=5.01***	F(10,355)=2.68***	F(10,356)=1.21	F(10,347)=1.50
SubstitutionTest: $\beta_{Mixed}-\beta_{Pure_c} \leq \beta_{Pure_{vi}} - \beta_{None}$						
F test (Ho: Equality of Means)	F(1,356)=0.41	F(1,356)=0.47	F(1,362)=0.36	F(1,355)=0.48	F(1,356)=0.74	F(1,347)=4.55**
t test (Ho: No Substitution)	-0.22 (t=-0.64)	-0.06 (t=-0.68)	7.48 (t=0.60)	57.40 (t=0.69)	28.51 (t=0.86)	-2.96 (t=-2.13)**

Notes: Coefficients significant at 1%***, 5%**, and 10%*,;T statistics in parentheses.

TABLE 8

Test of Substitution-Productivity Approach: OLS Regressions on Firms' performance (Huber White sandwich estimator) : Cooperation = TL AND DA

	(8.1)	(8.2)	(8.3)	(8.4)	(8.5)	(8.6)
Dep. Variable: Performance	**Average Value Added**	**Average Sales**	**Average ROA**	**Average ROE**	**Average ROS**	**Average Sales Growth**
Cooperation and Vertical Integration Practices	0.05	0.00	-8.71	92.77	27.29 **	-1.12
	(0.27)	(0.06)	(-0.43)	(1.46)	(2.12)	(-1.41)
Cooperation Only	0.40 **	0.10 **	25.68 ***	128.43	24.82 **	0.62
	(2.21)	(2.30)	(2.61)	(1.58)	(2.00)	(0.41)
Vertical Integration Only	0.20	0.08 *	20.74 **	113.71 *	5.64	-0.43
	(1.28)	(1.86)	(2.60)	(1.85)	(0.27)	(-0.62)
Patent Propensity	-0.22 ***	-0.02	0.29	19.36	-2.34	-0.24
	(-2.97)	(-1.32)	(0.08)	(0.87)	(-0.62)	(-0.40)
Generality of the Technology	0.30	0.07	-43.56 *	107.89	39.45	1.30
	(0.74)	(0.67)	(-1.86)	(0.66)	(0.80)	(0.47)
Technological Diversification	0.11	0.04	14.12	212.31	68.59	-0.31
	(0.44)	(0.52)	(0.94)	(1.38)	(1.14)	(-0.25)
Firm Age	0.24 **	0.06 *	28.60 ***	105.34 ***	11.37	-2.66 **
	(1.99)	(1.94)	(4.56)	(3.73)	(0.97)	(-2.19)
Firm Size	0.51 ***	-0.18 ***	39.68 ***	94.99 ***	32.96 *	0.79 *
	(5.41)	(-4.66)	(5.42)	(3.73)	(1.67)	(1.82)
Effectiveness of Protection from Manufacturing Assets	2.06	0.38	21.79	-434.381	18.25	-5.27
	(1.45)	(1.14)	(0.24)	(-0.53)	(0.31)	(-1.33)
Industry Controls (Industry Sales)	0.0	0.01	-4.96	-1.26	6.41	0.56
	(0.00)	(0.38)	(-1.59)	(-0.11)	(0.64)	(1.65)
Intercept	0.79	2.39 ***	-284.73 ***	-827.61 ***	-317.81	3.31
	(0.61)	(7.85)	(-4.45)	(-3.21)	(-1.39)	(0.75)
Obs	367	367	373	366	367	358
R2	0.16	0.24	0.28	0.07	0.03	0.05
Model	F(10,356)= 4.43***	F(10,356)=6.84***	F(10,362)=4.92***	F(10,355)=2.99***	F(10,356)=1.18	F(10,347)=1.52
SubstitutionTest: $\beta_{Mixed} - \beta_{Pure_c} \leq \beta_{Pure_{vi}} - \beta_{None}$						
F test (Ho: Equality of Means)	F(1,356)=4.77**	F(1,356)=7.22***	F(1,362)=6.47**	F(1,355)=2.58	F(1,356)=0.02	F(1,347)=0.71
Two-tailed t test (Ho: No Substitution)	-0.55** (t=-2.18)	-0.18*** (t=-2.69)	-57.13** (t=-2.54)	-149.37 (t=-1.61)	-3.17 (t=-0.16)	-1.31 (t=-0.84)

Notes: Coefficients significant at 1% ***, 5%**, and 10%*; T statistics in parentheses

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