



## **ABSTRACT**

The Interdependence of Organizational Knowledge and Financing:  
Studies of Technological Innovation, Learning, and  
Corporate Restructuring in U.S. Medical Device Ventures

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This dissertation explores the relationships among organizational innovation, learning, and corporate restructuring in medical device ventures. The first study examines how and when private ventures' capabilities for technological innovation affect their rates of IPO versus acquisition. Exploratory search building on knowledge developed by technologically distant firms has a positive effect on IPO rates, but a negative effect on acquisition rates. The second study investigates how going public affects firm innovation. IPOs increase a firm's overall rate of innovation, the proportion of innovative search that exploits internally developed knowledge, and the rate of exploratory innovation building on public-sector knowledge.

## **EXECUTIVE SUMMARY**

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### **OVERVIEW**

The rapid pace of innovation in high-technology firms has been an important determinant of economic growth and productivity. Good ideas by themselves, however, cannot ensure continued success at innovation. A critical component of corporate research and development (R&D) efforts is access to funding. To raise the large amounts of capital required for continued growth, R&D-intensive start-ups must often turn to initial public offerings (IPOs) or takeovers by established firms. Yet, the restructuring events that are critical to continued innovation may subsequently shape the very innovative activities they are funding. These transactions are not simply short-term events that infuse capital into firms with promising innovations; rather, they delineate distinct stages in the evolution of high-tech ventures. Therefore, they have long-term effects, not only on organizational structures, but also on organizational processes, most notably the search processes that drive technological innovation. This dissertation explores this complex and recursive relationship between financing and innovation: flows of funds to firms that are intended to support R&D shape subsequent innovation efforts.

The research consists of two studies that probe these relationships among organizational innovation, learning, and corporate restructuring at different stages in the life cycles of medical device ventures. The first study focuses on the period before any liquidity event. It develops and tests theory concerning how and when private ventures' capabilities for technological innovation affect their IPO versus acquisition rates. The paper then hypothesizes that market conditions and firms' key relational resources moderate these effects. The second study investigates whether, how, and when going public affects firms' innovative activities. It proposes that an IPO fundamentally reshapes a firm's internal operations, and considers implications for the firm's overall rate of innovation and its innovation search strategies. In addition, the paper evaluates the potentially conflicting consequences of going public by examining contingencies based on firms' relational resources.

The studies assess firms' innovative capabilities in terms of both quantity and direction (firms' innovation search strategies). Firms search for new knowledge, including innovations, in part by drawing upon knowledge embodied in existing innovations. Following a stream of knowledge-based research, innovation is viewed as occurring through the recombination of existing knowledge and incremental learning. The analysis of innovative search distinguishes between

exploration and exploitation; firms are conducting exploratory search when they recombine distant or unfamiliar knowledge, and they are conducting exploitative search to the extent that they search for new knowledge by recombining proximate or familiar knowledge. Exploratory search is contrasted from exploitative search along organizational, technological, and institutional dimensions.

Together, the studies enhance understanding of how financial markets and knowledge networks intersect, thereby informing research on organizational learning, technological innovation, entrepreneurship, and organizational change. More specifically, the research contributes to literatures explaining the structures and processes associated with organizational innovation. Prior work has analyzed how firms' innovation processes differ over their life cycles, based on their age, size, and status as incumbents versus new entrants. Corporate restructuring events like IPOs and acquisitions delineate distinct stages in firms' life cycles, which they may reach as they become older, larger, and/or more established; hence, insight into the interdependence between liquidity events and firms' innovative activities provides a richer picture of how innovation and search behavior vary as firms evolve. At the same time, findings from these studies can inform unresolved questions concerning the factors driving innovation – restructuring events may well trigger some of the processes that have been attributed to age, size, or incumbency. Thus, this research advances theoretical and empirical knowledge of the dynamics of organizational innovation and, more generally, has the potential to inform work on the determinants and consequences of core organizational change. In addition, the papers are relevant to studies of financial market influence, especially those examining the ways financial relationships shape firm processes and behaviors. The analysis complements entrepreneurship research, in particular, by looking at how markets for IPOs and acquisitions relate to firm processes critical to new venture growth.

## **RESEARCH SETTING: THE U.S. MEDICAL DEVICE INDUSTRY**

The U.S. medical device industry is an appropriate context for studying the relationships between firms' innovative activities and their liquidity events. Given the large amounts of capital needed to support medical device R&D, funding availability is a key factor driving product development in the industry. One important source of financing for medical device start-ups that have not yet achieved viable revenue streams has been venture capital. IPOs and acquisitions, in turn, represent the most favorable exit options for venture capital investments. The substantial numbers of private medical device firms going public and being acquired over the past two decades attest to the important roles played by IPOs and acquisitions.

In terms of innovation, medical device firms consider technological innovation to be a critical competitive dimension. Patenting is routinely practiced in the

industry and is considered a vital part of maintaining technological competitiveness. The nature of medical technology innovation also makes the industry an appropriate setting for considering questions related to exploration and exploitation. Medical devices are diverse in type, complexity, and risk. Some new products are incremental refinements of existing technologies, while others are novel, “breakthrough” devices. Furthermore, medical device innovation relies heavily on technology transfer from external knowledge sources, including public research institutions, such as universities and national laboratories, and other industries, like materials science, bioengineering, molecular biology, and information systems. Finally, the industry is highly fragmented – a few large manufacturers dominate the market, accounting for almost half of industry sales, but the most are small or emerging companies with fewer than 50 employees and annual revenues below \$100 million.

## DATA

To test the hypotheses, an original data set containing quantitative data from 1980 to 2005 on venture capital-backed firms, patents, products, U.S. Food and Drug Administration (FDA) filings, and financial transactions in the U.S. medical device industry was compiled; event-history, event-count, and panel-data models were then estimated. The time interval was selected to begin shortly after the passage of the Medical Device Amendments of 1976, which significantly increased the scope of the FDA’s regulatory authority over medical devices and initiated major changes in the way that new devices were brought to market.

Venture capital-backed firms were identified using Thomson Financial Securities Data’s *VentureXpert* database, and the *CorpTech Directory of Technology Companies* (1986-2005), the *Medical & Healthcare Marketplace Guide* (1975-2005), and the *Medical Device Register* (1981-2006) provided additional firm-level data. Only independent, dedicated companies that were *de novo* start-ups were included in the sample. Subsidiaries of diversified companies, firms for which medical devices were not the primary line of business, and firms founded through spin-offs were excluded. Thomson Financial’s *Global New Issues* and *Mergers and Acquisitions* databases were used to identify IPO and acquisition events. Other data sources included Standard & Poor’s *Compustat North America Industrial Annual* database, the Centers for Medical and Medicaid Services, the U.S. Census Bureau, IPO prospectuses, SEC filings, news articles, and company web sites.

To create variables representing firms’ innovative activities, data on pre-market approvals (PMAs) and pre-market notifications (PMNs) were obtained from the FDA’s Center for Devices and Radiological Health (CDRH) web site ([www.fda.gov/cdrh/databases.html](http://www.fda.gov/cdrh/databases.html)). In addition, a patent portfolio was constructed for each firm in the sample using U.S. patent and patent citation data from the Patent Technology Monitoring Division of the U.S. Patent and

Trademark Office's (USPTO) Office of Electronic Information Products, from MicroPatent's *PatentWeb* database, and from Delphion's *United States Patents – Granted (US)* database.

### **DOING THE RIGHT THING AT THE RIGHT TIME: THE ROLE OF ORGANIZATIONAL INNOVATION IN THE LIQUIDITY EVENTS OF HIGH-TECHNOLOGY VENTURES (STUDY A)**

IPOs and acquisitions by established firms are two important restructuring opportunities that many privately-held growing ventures must eventually consider. For R&D-intensive start-ups with limited options for raising the substantial amounts of funding necessary to support continued R&D efforts, this decision often marks a critical turning point in their life cycles. Liquidity events are more than just short-term financial transactions that provide infusions of capital or mark new stages of growth; IPOs and acquisitions by other companies involve transformational change that affects core organizational structures and processes. Moreover, although IPOs and acquisitions both represent preferred liquidity options from the perspectives of initial investors like venture capital (VC) firms, the choice is much more critical from the viewpoints of entrepreneurs and the firms themselves. While both types of liquidity events may be financially lucrative, they yield significantly different outcomes: a start-up will cease to exist as an independent legal entity post-acquisition. Therefore, the choice between going public and being acquired has important implications for firm evolution.

The scant research examining firms' choices between going public and being acquired concentrates on factors external to firms, such as market conditions and VC investor characteristics, and thus offers little guidance towards the identification of potential firm-specific antecedents. This study sheds light on this restructuring choice from an organizations perspective by focusing on the relationship between firms' technological resources and their liquidity events. It develops and tests theory concerning how and when private ventures' capabilities for technological innovation – both their stocks of knowledge assets and the search activities that produced these assets – influence their rates of going public and being acquired. Specifically, the paper posits that the rates at which firms go public or are acquired are associated with: 1) the strength of their knowledge bases, 2) the breadth of innovative activity, 3) competitive crowding in their technological areas, and the degree to which they build on 4) internally developed knowledge, 5) knowledge developed by technologically distant (rather than technologically proximate) firms, 6) public-sector knowledge, and 7) existing products. The first three constructs represent stocks or structures, while the remaining four denote innovative search processes along different dimensions – organizational, technological, institutional, and product. Both sets of factors – structure and process – contribute to a firm's growth potential and hence to its ability to go public or be acquired. In addition, environmental factors and relational resources play crucial roles in liquidity events and the impact of firms'

innovative capabilities on IPO and acquisition rates depend on conditions in the equity markets, VC investment, and alliances.

To model the determinants of IPO and acquisition rates, a sample of 1,143 VC-backed medical device firms that received their first rounds of funding between 1980 and 2005 and were founded after 1976 was constructed. Each firm in the sample was tracked from its first year of VC funding through the first year it went public, was acquired (100%), or failed. Firms that remained private and operating were observed through the end of 2005. The event histories of each firm were broken into one-year spells (resulting in 8,437 spells). Of the 1,143 firms in the analysis, 219 experienced an IPO event during the period studied, 233 were acquired, and 194 failed. Mean firm age in the sample was 8.7 years. For the 219 firms that went public, the mean age at IPO was 6.6 years. The mean age at acquisition for the 233 firms that were acquired was 7.9 years. The hypotheses were tested by estimating competing-risks hazard-rate models with two possible destination states: IPO and acquisition. The assumption in these models is that in any given year, each VC-backed, privately-held start-up is subject to two competing hazards, IPO and acquisition, with separate mechanisms leading to each. Maximum-likelihood estimates were obtained using the statistical package TDA.

Findings from the analysis show that the set of internal, firm-specific factors that are conducive to an IPO differ from those that are conducive to an acquisition. Specifically, the strength of a firm's technological knowledge base increases IPO rates, while the strength of a firm's product knowledge base increases acquisition rates. Exploratory search across technological boundaries (building on knowledge developed by technologically distant firms) has a positive effect on IPO rates, but a negative effect on acquisition rates. Results also demonstrate that institutional exploratory search (building on public-sector knowledge) increases IPO rates only, product-based exploitative search increases acquisition rates only, and product-based exploratory search increases both types of liquidity event rates. In addition, the analysis suggests that context matters – favorable medical device equity market conditions heighten the effects of both the strength of a firm's knowledge base and exploitative search. While VC investment appears to strengthen the impact of firms' stocks of innovative capabilities on IPO rates, alliances appear to weaken their influence. Finally, VC investment weakens the effect of exploratory search along technological and product-based dimensions on acquisition rates; alliances do not appear to moderate the relationship between innovative search and acquisition rates.

This study makes both substantive and theoretical contributions. The outcomes studied – the transformation from private venture to public company or wholly-owned subsidiary of another organization – are major, yet relatively unexplored, transitions in the life of any organization. Most prior research has considered either IPO or acquisition outcomes separately; of the few studies that look at both outcomes simultaneously, the majority focus on factors external to the firm or

treat IPOs and acquisitions as a single type of outcome – a liquidity event. Insight into why some start-ups go public while others get acquired can inform theories of firm evolution. By analyzing whether and in what context different firm-specific forces are responsible for different liquidity event outcomes, this research enhances understanding of how organizational structures and processes evolve in entrepreneurial companies.

The study further asks whether innovative search across different dimensions vary in their effects on different performance-related outcomes (IPO versus acquisition). In doing so, the paper delves into the role of innovation in firms' life cycles and probes how firms reach different growth stages. It therefore also complements the organizational learning and knowledge-based literatures that examine tradeoffs between exploration and exploitation. While much prior research has assessed the impact of exploratory and exploitative search on innovation quality and innovative productivity, few published studies have directly examined the effects of innovation search strategies on firms' financial performance. Furthermore, previous empirical work looking at the consequences of firm-level innovative search has focused primarily on exploration and exploitation as internal firm processes. By investigating contextual factors as potential moderators of the innovation-liquidity event relationship, this paper addresses broader questions relating not only to whether, but also to when, exploration and exploitation are more or less likely to influence the evolution of organizational structure in start-ups. How exploration and exploitation are managed may produce very different performance outcomes in varying contexts.

Beyond the theoretical contributions to the entrepreneurship, strategy, and organizational learning literatures, this paper also offers broader practical implications for firm strategy in medical device and other high-tech industries. Findings from this study could inform the decisions of entrepreneurs and other practitioners in organizations considering restructuring and growth options. Liquidity events are not only major transitions in the lives of organizations, but also represent important initial indicators of success for entrepreneurial companies, especially those in high-tech industries. When developing innovation strategies, entrepreneurs and managers of growing ventures may need to recognize that, in addition to the more widely recognized trade-offs involving short-term profitability and long-term growth, an exploratory or exploitative search strategy may put their firms on paths towards very different outcomes – IPO or acquisition, respectively. At the same time, managers should keep in mind that the effects of these innovation search strategies on firm outcomes may change depending on external factors, including equity market conditions and VC investor commitment.



## **DOES MONEY COST TOO MUCH? THE EFFECT OF GOING PUBLIC ON INNOVATION IN HIGH-TECHNOLOGY FIRMS (STUDY B)**

An IPO represents a broad transformation with long-term impact, not only on organizational structures, but also on organizational processes. As a firm adapts to the pressures of the public market environment, there are likely to be changes in its key internal operating processes and strategic activities, including technological innovation. Recent work has characterized IPOs as “transformational” events likely to trigger significant changes in core organizational features. Few empirical papers, however, have examined the effects of going public on firms’ long-term operating processes. This study begins to fill this research gap by developing and testing theory concerning whether, how, and when going public affects firm innovation. It draws on concepts from the organizational learning, institutional theory, and corporate governance literatures and also builds on previous empirical research looking at technological innovation, organizational change, and agency theory.

The study proposes that an IPO influences both the quantity and direction of a firm’s innovative activity. First, four mechanisms underlying an IPO may have opposing effects on overall innovation rates: increased financial resources, increased legitimacy, internal organizational change, and increased institutional pressures to manage shareholders’ earnings expectations. The first two mechanisms represent advantages of going public that are likely to increase a firm’s rate of technological innovation, while the latter two denote potential disadvantages that may disrupt innovation. The net effect of an IPO depends on the relative magnitudes of these consequences.

Second, going public is also likely to influence firms’ innovative search strategies, specifically their predilections for exploratory and exploitative search. Three mechanisms – internal organizational changes, increased external pressures on time horizons, and shifts in risk preferences – may lead to increases in exploitative search over exploratory search. The paper distinguishes between exploratory and exploitative search along organizational, technological, and institutional dimensions because going public, in addition to having broad impact on innovative search, may lead to consequences specific to each dimension; while the three dimensions are logically related, they are also conceptually distinct.

Third, the impact of an IPO on a firm’s innovative activities is likely to depend on firm-specific contingencies. Firms’ relational resources – ties to external, yet potentially influential shareholders – may moderate the relationships between IPOs and firm innovation. Different types of external stakeholders may have varying goals, time horizons, and risk preferences; these relations may thus strengthen or weaken the various underlying mechanisms by which going public affects innovation. The study focuses on the roles of two stakeholder groups: alliance partners and institutional shareholders. The two types of relational

resources attend to two of the key IPO effects – increased legitimacy and increased external pressures on time horizons. Assessing *when* IPOs are more or less likely to influence innovation rates and innovation search strategies sheds additional light on *how* they affect firm innovation.

To model the effects of going public on firms' innovative activities, longitudinal data from 1980 to 2005 on a sample of 770 VC-backed medical device firms that received their first rounds of funding between 1980 and 2004 and filed at least one patent during the observation period were compiled. The innovative activities and other characteristics of each firm in the sample were tracked from its first year of VC funding through the end of 2005 (or until the year it failed or was acquired). By the end of the observation period in 2005, 403 of the 770 firms had exited the sample (149 failed and 254 were acquired by other companies). The resulting dataset included 8,072 firm-year observations. Of the 770 firms in the sample, 216 (28.1%) experienced an IPO event during the period studied. Four dependent variables were used to investigate the hypotheses: overall rate of technological innovation, proportion of innovative search exploiting internally developed knowledge, technological similarity of external knowledge sources, and level of exploratory search building on public-sector knowledge. The innovation rate variable relied on patent data and the three innovative search variables were operationalized using patent citation data, conditional on firms having filed patents. Inverse probability of treatment and censoring weights were used to account for self-selection into IPO and the presence of time-dependent confounders; estimates represented population average treatment effects.

Findings from the analysis show that overall rates of innovation increase after firms go public. Going public also increases organizationally exploitative search (the proportion of innovative search that exploits internally developed knowledge) and the rate of exploratory innovation that builds on public-sector knowledge. Thus, concerns based on anecdotal evidence that going public may have detrimental effects on innovation in technology-based ventures are only partially justified. Overall levels of innovation may actually increase following an IPO. The direction of that innovation, however, may shift towards exploitative, rather than exploratory innovation; this shift has implications for the long-term viability of firms. In addition, results demonstrate that alliances moderate the impact of going public on exploratory search along the technological dimension. Finally, in terms of institutional ownership, given that a firm has gone public, analysis of panel data on 561 medical device firms with IPOs between 1980 and 2005 suggests that innovation rates increase with institutional shareholdings. On balance, these findings lend some support to the conjecture that increased legitimacy and increased external pressures on time horizons are two key mechanisms by which going public influences firm innovation.

This study complements research looking at the dynamics of organizational innovation. Insight into how going public affects firms' innovative activities provides a richer picture of how innovation and search behavior vary as firms

evolve, and can also inform unresolved questions concerning the factors driving innovation dynamics. More generally, this paper is relevant to studies of the consequences of organizational change and to corporate governance literature assessing the ownership-performance/strategy relationship. As highlighted above, an IPO often involves substantial changes to core organizational features. A large body of research has examined the destabilizing effects of such fundamental changes on organizational performance and survival. Scholars have only recently, however, begun to explore the mechanisms that produce these disruptive effects. This study enriches recent work on core organizational change by investigating another important outcome: innovation. In addition, previous research has considered the impact of ownership and governance structure on various innovation-related outcomes, including R&D spending, innovative outputs like patents and new products, and corporate innovation strategies. Given that an IPO represents a significant change in ownership structure, this paper also contributes to the literature focusing on the effects of ownership on firm performance and corporate strategy.