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Learning by Building: Complementary Assets and the Migration of Capabilities in U.S. Innovative Firms

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Abstract

Using a sample of production-oriented start-up firms that licensed their core technology from the Massachusetts Institute of Technology (MIT) from 1997-2008, we track the growth trajectory of 150 firms and conduct in-depth interviews with senior managers of a subset of these firms to understand the critical factors in their scale-up process. Because these firms? innovations are often at the technological frontier, they generally need highly complex, advanced manufacturing capabilities that require more time and capital to scale than non-production firms. In this way, they provide an important test of the U.S. innovation ecosystem and its ability to support such firms. We find that the U.S. provides fertile ground as they prepare to enter the commercialization environment, iterating prototypes, developing pilot production facilities, and in some cases entering into commercial production. However, when these firms need to take the significant leap into larger-scaled processes, both the need for additional capital as well as the search for production capabilities pull many firms to move production abroad. This movement, which often entails the temporary relocation of key personnel with tacit knowledge, leads to the migration of key skills, capability generation and knowledge development outside of the country. We argue the migration of these capabilities has two consequences: one, expected returns to public investment in innovation are not fully realized and two, the movement offshore of vital capabilities may put at risk the

U.S.?s future capacity to innovate.

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1. Introduction

As policymakers in the U.S. debate how the economy can regain its vitality following the Great Recession, many see innovation as the key to prosperity. The U.S. excels in product, service and business model innovation, particularly where this innovation leverages technological advances. The U.S. is also one of the leading countries for venture capital financing[1], which supports the creation of many innovative start-up companies every year. While innovation by young firms is common today, it represents a relatively new economic model. Large vertically integrated firms with centralized R&D were once the primary drivers of innovation in the U.S. However, within the last thirty years, we have seen smaller, entrepreneurial firms within innovation ecosystems develop into a large source of innovative activity (Lerner 2012). This shift from large firms that moved ideas to products within the boundaries of the firm, to a model of smaller, entrepreneurial firms working in conjunction with multiple external innovators and partners to generate new inventions and technologies has become a vital source of innovation and economic growth for the country.

Given the critical role young firms play in the country's innovation engine, it is important to understand the process and pathways by which they scale their innovations and technologies. The decisions start-up firms take early on will have consequences for how and where the firm grows, if at all, in the future. Unlike large, vertically integrated firms, these smaller, entrepreneurial firms often seek out specialized complementary assets, such as distribution or manufacturing capabilities, to help them avoid sunk investments at the early stages of growth (Gans and Stern 2003; Teece 1986). The need

[1] The U.S. is second only to Israel in venture capital as a percentage of GDP (OECD 2011).

for complementary assets pushes these firms to look outside their boundaries to external actors in order to find the critical inputs they need to scale. Young firms that scale novel technology often manage loosely codified knowledge that requires significant iteration to bring a product to market. This iterative activity, which generates significant new capabilities, often occurs across firm boundaries. With whom and how does this activity occur? Does it matter? We argue the nature of this iterative activity, where most of the knowledge is at the technological frontier, is critical to the innovation process and has important implications for national innovation capabilities.

There is an extensive strategy and innovation literature that examines how young firms choose to profit from their innovations[2]. There is also an equally large economic geography literature that explores the role agglomeration and external economies play in enabling such activity[3]. While these literatures address overlapping issues, they differ in their unit of analysis, with strategy focusing on the firm and economic geography on industry clusters. There is very little scholarly work that seeks to connect firm-level decisions with long-term national competitiveness outcomes. This research brings together analysis of firm scale-up strategies with a broader perspective on innovation and economic growth, and identifies potential unintended consequences for the American innovation system.

Our research explores how innovative young firms develop and scale their novel technologies, and the critical factors that shape that process. What are the implications of firm scale-up strategies for the U.S. innovation "ecosystem" and for American economic

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[2] (Chesbrough, Birkinshaw, and Teubal 2006) give an excellent review of this work on the occasion of the 20th anniversary of Teece's seminal work on profiting from innovation.
[3] See (Delgado, Porter, and Stern 2012) for a substantive review of this literature.

growth more generally? Much has been written recently about weaknesses in the U.S. innovation ecosystem, whether from the point of view of the loss of capabilities in the "industrial commons" (Pisano and Shih 2009, 2012) or regarding the limitations of the financing model for these small, entrepreneurial firms (Lerner 2012). Building on existing theories of innovation strategy, our interviews offer empirical examples of how firm-level decisions highlight weaknesses in the present American innovation model. In particular, our research demonstrates how advanced capabilities developed over long periods of time are pulled offshore endangering future economic activity and innovative capacity in the U.S. We examine the early stages of scale up for a sample of highly innovative firms that are just entering or soon to be entering the "commercialization environment" (Gans and Stern 2003).

Our work contributes to the literature on commercializing innovation in two ways. First, we combine existing frameworks with a more nuanced understanding of product development stages. We emphasize how the search for complementary assets for complex technologies in production industries often occurs at a time when knowledge is loosely codified. Second, we extend this work into the area of economic geography by examining the consequences of firms' innovation strategies for the larger innovation ecosystem. The market for ideas as described in Gans and Stern (2003) influences firm strategy, but it also has the potential to alter future capacity for innovation across regions. While we acknowledge the robust local availability of inputs for early stage innovation that other scholars have noted (Delgado, Porter, and Stern 2012; Moretti 2012), we find evidence that foreign actors play a larger role at later stages of development. This trend disputes the conventional wisdom that the U.S. can maintain a virtuous cycle of innovation.

Using a sample of 150 production-related start-up firms that licensed their core technology from the Massachusetts Institute of Technology (MIT) from 1997-2008, we track their growth trajectories. In order to understand the choices the firms made along these trajectories, we conducted in-depth interviews with senior mangers of a subset of these firms. Because these firms' innovations are often at the technological frontier, they generally need highly-complex, advanced manufacturing capabilities that require more time and capital to scale than non-production (e.g. software) firms. These firms provide an important test of the U.S. innovation ecosystem's ability to support the scaling up of firms producing innovative technologies.

Using a critical case methodology, we find the U.S. provides fertile ground as firms prepare to enter the commercialization environment, iterating prototypes, developing pilot production facilities, and in some cases entering into commercial production. Start-up firms in our sample are able to find the skills, financing and general resources they need to advance through the exploratory stages of technology development:[4] basic R&D, applied R&D and early market demonstration. However, when these firms need to take the significant leap into larger-scaled processes to prepare for commercial production, the need for additional capital coupled with the search for production capabilities or lead customers willing to be early adopters, pulls many firms to move production abroad.

This move comes at a critical stage in which much of the firm's technology and related manufacturing processes are not yet codified or fully modularized. Firms are

[4] See (Grubb 2004) for a staged typology of technology development

developing capabilities through multiple iterative steps in the technology's development over extended periods of time. We term this process "learning by building". Tacit knowledge is still critical to the development process. Tacit knowledge, as opposed to codified knowledge, requires proximity and face-to-face interactions, which makes knowledge 'sticky' and thus less mobile and harder to communicate over distances (Gertler 2003). While this stickiness has historically protected work from easily being offshored, in our interviews we find firms are now willing - or required - to move advanced technology and manufacturing processes before they are fully codified. This movement, which often entails the temporary relocation of key personnel with whom the tacit knowledge resides, leads to the migration of key skills, capability generation and knowledge development outside of the country. We argue the migration of these capabilities has two consequences: one, expected returns to public investment in innovation may not be realized in terms of economic growth and two, the movement offshore of vital capabilities may put at risk the future capacity to innovate in the US.

Each firm's decision to move technology development and related production processes abroad is based on rational criteria, at least within the realm of the economic incentives available to them in the current innovation ecosystem. However, the collective shift of these innovative firms' productive activities offshore at this critical stage of their technological and economic growth represents a loss for the country as a whole in the knowledge, skills and capability-generation that come with this next stage of scaling. Public resources are often invested in university research and early start up firms in order to foster greater innovation. Those resources are successfully encouraging new generations of innovative, entrepreneurial firms. We suggest, however, that it is not enough to start the firms in the US; we must also pay attention to how to grow them in the US. While creating incentives for individual firms to manufacture in the US has a long history that has produced mixed outcomes at best, we do believe there is a public interest in finding ways, where appropriate, to help firms to scale production in this country. While it is not realistic to keep all production in the US, the innovation ecosystem depends on continued demand for the skills and capabilities required for the new and emerging industries represented by our sample of firms.

II. Profiting From Innovation Strategies in Entrepreneurial Firms

Young entrepreneurial firms, especially those that focus on technological innovation, have a distinct set of characteristics that regularly place their long-term survival in jeopardy. In addition to the significant uncertainty that surrounds any early stage technology, new firms require capital to offset negative cash flow in starting their enterprises. They must be sensitive to protecting their intellectual property from possible imitators, including fellow start-ups that seek first-mover advantage and/or industry incumbents that seek to defend their market positions. Many scholars have studied the strategies innovative entrepreneurial firms use to address the unique circumstances that they face. In particular, there has been extensive research on the factors that determine whether new innovative companies will compete or cooperate with incumbent firms.With limited resources, young firms must decide whether to invest in upstream activities such as materials development or downstream ones like marketing and distribution.

Young firms engaged in manufacturing (generating new products) may face additional constraints including longer innovation cycle times, higher capital needs and highly complex technology. Ultimately, they must decide whether to make their own product inside the firm or contract part or all of the manufacturing externally. In other words, young firms constantly face a series of critical decisions as they move from idea to prototype to commercial production and finally distribution.

Complementary Assets

An extensive literature found on entrepreneurial strategy and the economics of innovation seeks to understand how firms profit from innovation. Teece (1986) identifies two key factors that influence entrepreneurial firms' decisions to compete or cooperate with existing firms: technology appropriability (ease of imitation) and ownership of complementary assets in production, distribution, and marketing. Following Teece's seminal work, many scholars have built on this framework to understand how young firms profit from innovation. Focusing on young technology firms, Gans and Stern (2003) note that incumbents who have incentives to expropriate the inventors' technology own many of the complementary assets sought by firms. This represents a paradox for entrepreneurs who need to disclose extensive product details to receive the highest valuation for their technology, but fear disclosing too much information to large firms who are both potential partners and potential competitors. In an environment where young firms are better at development, but incumbents control complementary assets, young firms may be better off cooperating than competing with the incumbents. To that end, young firms may seek complementary assets during the exploration (discovery) and/or exploitation (production) phases of their development[5]. They must differentiate between assets that might be generic and thus substitutable, and those that are specific and offer competitive advantages (Chesbrough, Birkinshaw, and Teubal 2006). In either case, they must decide whether investing in assets like production facilities, or marketing and distribution networks on their own risks duplicating assets held by others, leading to the inefficient use of scarce resources and potentially unreasonable sunk costs (Gans and Stern 2003).

Financing and the Emergence of New Sources of Complementary Assets

A critical factor in determining whether start-up firms invest in new assets is their access to capital. Technology entrepreneurs most often raise funds for their firms from providers of high risk capital—primarily independent venture capital (VC) and/or corporate venture capital (CVC) firms. While VC funds are well established as the major source of entrepreneurial finance, they are shaped by particular dynamics inherent to their business, for example, the composition and the objectives of investors that potentially limit long-term investments in young firms. Boom and bust cycles are another challenge that lead to the underfunding of novel technologies (Lerner 2012). This uncertainty, well beyond the control of young firms, may affect young firms' ability to raise capital for large fixed cost projects. Moreover, the increasing specialization of venture firms, which leads them to focus only on certain stages of a firm's development, forces founders to constantly maintain an eye on the next round of financing, unsure if current or future will accept their investment plans.

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5 See March (1991) for a discussion of exploration and exploitation.

Interestingly, multinational corporations are taking an increasingly active role in funding new firms through corporate venture capital (CVC) subsidiaries. Intel and General Electric are well known examples of historic corporate venture investors. The National Venture Capital Association reports that 2011 was the largest year for total CVC investments since the dot-com bubble of the late 1990s (National Venture Capital Association 2012). This trend is important because, unlike traditional VCs, CVCs have extensive resources including a supply chain and manufacturing network to help entrepreneurial firms commercialize a technology without investing in fixed assets. As complementary assets have become increasingly global and with the emergence of a secondary market for trading of intellectual property rights, young start-up firms are increasingly attractive to multi-national CVCs as partners. Together, these trends increase the likelihood that an upstream or downstream complementary asset holder will place more value on young technology firms.

In addition to CVC partners, national governments in emerging economies have begun to make available complementary assets to innovative American start-up firms (Chesbrough, Birkinshaw, and Teubal 2006). In an effort to seed the development of new technologies and advanced manufacturing capabilities in their country or region, foreign governments are providing direct capital for development as well as indirect capital in the form of plant, equipment and workforce training. Singapore's aggressive efforts in biotechnology, Russia's efforts in nanotechnology and China's initiatives in clean energy are salient examples of this trend.

Ultimately, where firms find complementary assets has implications for future economic activity. Whether the means are acquisition, investment, alliance or just strategic choice, the (re)location of complementary assets overseas may not be costless to the US economy of the start-up firm. As Teubal and Avnimelech (2003) show, globalization has favored the acquisition of local start-ups by foreign firms, thereby truncating the R&D leverage of downstream production and any associated economic growth.

The ability to access complementary assets is an essential ingredient for the growth strategies of many young entrepreneurial firms. In an effort to supplement new technologies and build capabilities, US start-up firms are turning to multinational firms and foreign governments that play an increasingly important role in providing complementary assets. Such partnerships, while important to the growth of the individual entrepreneurial firm, may shift investments and capability-building abroad, away from the national and local economy of the firm, with potentially negative consequences for future innovation and economic growth.

III. Research Methods and Data Collection

a) The MIT Technology Licensing Office Sample

In order to understand firm decision-making related to production in innovative start-up companies, we examine the population of firms founded on technology licensed from the Massachusetts Institute of Technology's (MIT) Technology Licensing Office[7] between 1997 and 2008. The MIT Technology Licensing Office's (TLO) mission is focused on bringing inventions from MIT laboratories into the economy, and in this

[7] In all but a few cases, the firm was created based on technology developed at MIT. In a few cases, firms licensed MIT technology after a firm was formed.

activity, it has been among the most successful bridging agents linking US university research and private industry (Di Gregorio and Shane 2003). In 2011, for example, the TLO registered 694 invention disclosures, filed 305 patents, had 199 U.S. patents issued, and facilitated the start-up of 16 firms (with a minimum of $500,000 in initial capital).

While MIT TLO firms may not be a representative sample of national technology start-ups, they offer the distinct advantage of being among the most likely advanced technology start-ups to succeed (*Ibid*). These firms consistently seek to commercialize products at the technological frontier and are well connected to academia and the venture capital industry. Given the historic role of MIT and Boston in successfully commercializing new ideas (Massachusetts is continually ranked among one of the top innovation hubs in the country[8]), we consider this to be a 'critical case'.[9] We would expect that firms within our sample should be among those start-up firms most likely to succeed at scaling up. Conversely, if firms in our sample, which enjoy extensive local resources, encounter significant challenges in reaching scale, we can only imagine how start-ups not located in the Boston/Cambridge ecosystem and not affiliated with an elite innovation-focused university might fare.

The 1997 to 2008 time frame allows us to look at firms five to fifteen years after their founding. During this period, 189 firms started with technology licensed from MIT patents. We focused only on firms that were engaged in some form of production. We

[8] See (Information Technology and Innovation Foundation 2012)
[9] See (George and Bennett 2005) on critical case methodology.

eliminated 29 software firms and 10 firms for which we could not locate any recent data from further investigation, leaving a sample of 150 production-oriented firms[10].

By looking at firms that are between 5 and 15 years old, we cover the stages from company formation to prototype and in some cases pilot facilities and commercial production. For the older firms, many will have entered into a mass production stage in which a product is commercially produced and brought to market.

b) Methodology

For this study, we gathered historical data on financing, ownership, and operating status for all of the firms in our dataset in order to better understand the growth trajectories of these firms. In addition to data provided by the TLO, we utilized online databases from VentureXpert, Lexis-Nexis and Compustat to build a longitudinal database. Using semi-structured interviews with a subset of these firms, we developed a more in-depth understanding of how firms choose strategies to scale up by tracing the pathways from innovation to production. Together these methods allow us to understand how young technology firms make decisions about how to commercialize their innovations and move from R&D toward production.

For the interviews, we chose only firms in the sample that had demonstrated an ability to reach scale, starting with the 15 firms with over $5 million in revenue[12]. Given that firms must signal continued progress to potential investors even before they have the possibility of generating significant revenue, we also looked for firms that had received in

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[10] We were careful to include those firms that integrated software into products with the proviso that the product was specifically engineered with this software in mind. We conducted extensive checks of archival records to determine the status of the these 10 firms but were unsuccessful/

[12] Revenue of $5 million exceeds the typical amount of research funds start-up companies report as revenue.

excess of $50 million in high-risk capital as a proxy for continued market potential. This added another 11 firms to our potential interviews. From this set of 26 firms, we conducted a total of 17 interviews[13]. Not surprisingly, these highly innovative firms are predominantly located in high-skill, technology leading regions in the U.S. Of the seventeen firms in which we conducted interviews, seven firms were based in Boston, nine in the San Francisco/Silicon Valley region, and one firm was in Berlin, Germany.

------------Insert Table 1 Here: *MIT TLO Licensed Start-Ups 1997-2008*------------

c) Sample Characteristics

As seen in Table 1, of the 150 production companies, 59 percent are still active as independent firms while another 21 percent were acquired and 20 percent have closed. This survival rate is 150% higher than what Hall and Woodward find in their national study of venture-backed start-up firms (Hall and Woodward 2010). Firms in the biopharmaceutical and medical device industries make up 60 percent of our sample while semiconductor and electronics firms constitute an additional 17 percent. Geographically, 63 percent of the sample firms are headquartered in Massachusetts, 15 percent in California and the rest are spread across the country. Three percent of the firms in our sample are based overseas. The vast majority of firms had little or no revenue. As noted

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[13] See Appendix 1 for more detailed information on the companies interviewed. Interviews typically lasted between one and three hours with two or three researchers present.

above, fifteen firms had revenue over $5 million in 2011. Of these firms, three had sales over $100 million, and only one had sales over $1 billion.

IV. Innovation Ecosystem during Exploration Phase

Financing the Scale Up of Innovative Firms

Using the VentureXpert database, we identified 82 (of the 150 production) start-ups in our sample as having received VC and/or CVC capital. These 82 firms raised a total of $4.7 billion, of which 71 percent came from venture capital and 12 percent from corporate investors.[14] Some firms have raised significant capital: 33 firms raised over $50 million and of these, 14 firms raised over $100 million in investments, which suggests a strong market belief in the technology they are developing. Fifty-seven percent of the firms in our sample were still raising capital after their fifth year.[15] Of these firms, 39 percent were still raising funds after the seventh year, and 15 firms or 17 percent of the sample were able to raise high risk capital after ten years.

Almost half of the 82 venture-backed firms received a financial investment from at least one corporate investor in addition to venture capital. While strategic corporate investors represented only eight percent of total funds raised by biopharmaceutical firms (of $1.7 billion), they represented triple that amount or 21 percent of total investment ($1.1 billion) in semiconductor firms. Another way to raise significant funds for firms

[14] Of the 82 firms for which we have data, eleven closed and nineteen merged with or were sold to another firm, leaving 52 independent firms. Revenue for merged firms are not included, as unconsolidated sales figures for the acquired firms are not available. Appendix 2 contains figures of the distribution of funds raised by the 52 operating firms.

[15] Venture funds are traditionally structured as partnerships, with the active fund manager serving as general partner and investors as limited partners. Most partnerships are structured with a seven-year investment cycle.

seeking to scale up is to sell shares to the public through an initial public offering. Only nine firms of the 82 in our sample followed this path. Of these nine, eight were in the biopharma or medical device industries (the exception was a battery manufacturer). On the whole, the data demonstrate that these young start-up firms have had little trouble raising significant amounts of capital during the exploration stage of their technology development even when this phase has taken place over an extended period of time.

Thick Labor Markets and Network Nodes

Rapid access to diverse talent is the critical input for these young entrepreneurial firms, particularly in the early stages of growth. It is at this point that iterations between lab and production are taking place, road blocks in developing the technology may appear, and new strategic directions might evolve based on what can and cannot be done with the technology. "High intellect" talent, as described by one semiconductor executive, is essential at this stage. One firm estimated that salary for these highly skilled employees represented 70 percent of its budget. Firms locate in or close to labor markets where they can find diverse yet specialized sets of skills.

The ability to hire quickly is important. One firm, which needed equipment engineers, process engineers, device engineers, and a MEMS (micro-electromechanical systems) device team, hired 25 people almost over night. This need to draw from a diverse set of skills and to hire a workforce in a relatively short period of time drives these firms to locate near educational institutions with strong track records for graduating well-trained engineers or in regions with reservoirs of engineering talent from previous rounds of industrial creation. This was true for all five of the semiconductor companies we interviewed on both the East and West Coasts. The situation was similar with the biopharmaceutical firms we interviewed in Boston as well.

The importance of connecting start-up firms to networks of capital, human resources, potential strategic partners, and early adopters and customers has been studied extensively in the literature on entrepreneurship[19]. In the small, innovative firms we studied we usually found that there was at least one individual playing a critical role in the initial formation of the firm as well as in connecting the firm to resources, talent and partners. These unique individuals, who have deep industry knowledge and experience, as well as strong local networks, are especially important at three points in the firm's development: firm formation, testing market viability and integrating novel technology into existing systems.

In several cases, a venture capitalist saw the potential for a new technology and pooled the IP from different universities, assembled the initial team, and formed a firm. The individuals acted in these cases as visionaries who understood the potential for a particular type of technology and assembled the right intellectual property and team to help build a firm. In one medical device company case, this involved assembling IP from five different universities and funding a team that would ultimately build a billion dollar firm.

After the firm is formed this unique individual might be a person who is intimately connected to a particular industry and who can make important introductions to potential funders or partners. Within each of the industries we studied there are several critical people who had worked in a particular industry for years, participated in building

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[19] See (Powell et al. 2005) for an excellent discuss of the role networks play in innovation ecosystems

several firms, and had achieved great respect in both the national industry and regional innovation networks. These individuals guide firms as they test the market viability of their technology and help to identify the most appropriate capital providers. In one case, this key actor arranged to have a major potential customer from Asia come to MIT to see the prototype. Based on the potential customer's enthusiasm for the product, the team went forward, created the firm, and began hiring a team and raising money.

In the early stages of scale up, as a firm decides how to integrate its technology into incumbent systems, a key agent is represented by seasoned industry executives who have deep knowledge of the prevailing industry production architecture, understand how new technology can be incorporated into it, and are familiar with specific facilities that are best suited for introducing the technology. For one set of firms, these individuals were retired production executives of large integrated petrochemical firms who understood what plants had the managerial and technical ability to successfully integrate a new technology. They also could bring in experienced production engineers on an as needed basis to ensure that the technology could be inserted into existing larger production lines, without the sort of disruptions that have scuttled other previous projects.

Our sample firms' ability to access networks through these individuals appeared integral to their success. While not limited necessarily by distance, these networks are often enhanced by proximity and encourage firms to locate in places where there are dense networks within their specific industry.

Thick Supplier Markets

While these firms draw on a deep and specialized talent pool, they are also drawing on a range of suppliers for certain products, services and skills. The firms in our sample are engaged in complex engineering and manufacturing. One medical device firm that has successfully scaled production has a product with 10,000 components, and 300 suppliers of custom pieces, 65 percent of which are provided by local suppliers. When start-ups begin product development, they are more concerned with speed and quality as opposed to cost. Being located near a strong supplier base that can turn around product very quickly is a priority.

Initial prototypes often come out of the university lab in rough form and need iteration, either within a lab setting, or in partnership with suppliers. This process, while time-consuming and labor-intensive, must emphasize speed and quality. Thus, firms like to have their suppliers near at hand. In the case of one East Coast semiconductor firm, the loss of control and time that came with working with a third-party semiconductor fabricator in the U.S. pushed them to build their own fabrication plant. They did not consider going offshore because of the expense both in time and money of transferring people and technology, as well as the fact that the novel work they were doing would have required 18 months to transfer the process offshore. It took two years to get their prototype to be a fully functioning product. During this process, they benefited significantly from the proximity of talent and suppliers.

In the case of another semiconductor equipment firm on the West Coast, they built a prototype in four months and continued to iterate it every six months for three years before they were ready to ship product to a potential customer. This is consistent with other semiconductor firms located in the Silicon Valley area; these firms could find a relatively strong local supply chain during the prototype stage. One firm described how they kept eight machine shops busy for two weeks at full capacity in order to ship a prototype system to a potential customer.

V. Financing and Capabilities Migration at an Inflection Point

The findings discussed above paint a picture of a very robust regional innovation ecosystem for new firms that are in the exploration phase. For these firms, finding advanced skills across a wide range of disciplines, suppliers that can help them iterate prototypes, networks that can provide contacts with both funders and potential customers, and most importantly, early stage capital to support the firm's growth, are all readily available. This ecosystem helps incubate the early development of the technology and allow the firms to focus on quality and speed to market.

However, the local ecosystem falters as firms seek to scale production from the pilot stage to a commercial scale. To help explain this stage of growth, we have adopted a framework for the development of novel technologies from Lester and Hart (2011 – see Figure 1). As firms move from the exploration phase toward the exploitation phase they are both demonstrating the viability of their product while also building it at scale. The two activities are inseparable - as is often said in bioprocessing, "the process *is* the product." We call this space the "inflection band" to convey both the critical nature of this stage for the firm and the fact that, rather than a point in time, this stage can last for a relatively long period of time, up to several years.

-------------Insert Figure 1:Inflection Band Here----------------------

Financing

During the early stages of development, the innovative companies we interviewed were able to raise significant amounts of risk capital over extended periods of time. However, as they moved into pilot and demonstration phases of their technology, they needed a new influx of significant capital to finish codifying their technology processes and bring it to commercial scale. Traditional venture capitalists, who invest in the earlier stages of the company, do not typically fund at this stage and at these levels (anywhere from $15 to $40 million) so these companies must look elsewhere for funding. We find that during this inflection band, the money often comes from corporate investors (MNCs) or national investment funds of emerging economies. For example, an advanced materials firm that had withdrawn an earlier IPO received a $30 million investment from an Asian multinational firm twelve years after founding. At this stage, "venture investors [in the firm] look for certainty; they are willing to trade upside for certainty. The investors understood the possibility of acquisition by a foreign firm when they took the money [from the Asian multinational firm] in the last round"[20].

In another case, the CEO of an advanced materials company said, " the VC model does not work for manufacturing companies. VCs cannot make any money on something that costs $100 million and takes at least 10 years to build. The technological risk is high

[20] Interview—CEO, advanced materials firm 4/25/12

and there is a high burn rate. They are much more comfortable with a software deal that will cost them $20 million. They have to pull away at what is a critical time for the company – just as [the company] is trying to finalize the product and get it ready for commercial production… eventually people won't start companies like this because they can't get financing." Ultimately, the company raised $40 million from an emerging economy government investment fund with a *quid pro quo* that some R&D and manufacturing would be set up in that country.

Those rare firms that went public offer a counterpoint to this pattern. A senior manger at one firm, an integrated surgical device manufacturer, stated that having the money from an IPO allowed them to get through an extended stretch to develop their technology for the market, after they had consumed most of the $125 million they had raised in venture funds. The tendency of the board was to sell the firm, "98% of the conversations in Silicon Valley are around an M & A exit, not an IPO"[21]. The firm remained independent, however, which may be the result of a product that fell 'in a crack' between the diagnostics and interventional equipment industries as well as the willpower of management to resist the board of directors' desire to sell.

Life sciences as an industry seems more likely to follow this pathway. Eight out of the nine firms in the TLO sample that went public were in the life sciences sector. These companies benefited from an IPO, raising capital that has helped fund their long development cycles. For these firms, the complexity of the early stage scale up of their products and the close interface with R&D teams leads them to develop capabilities in-house, even while they might work with a contract manufacturer on clinical production.

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[21] Interview--CEO, integrated surgical device manufacturer 4/25/12

Capabilities Migration

While the firms we interviewed could find the skills and capabilities they needed during the initial phases of scale up, they had greater difficulty finding the know-how and capabilities for production at scale. As described earlier, the knowledge being developed within the inflection band is not yet codified, and will only become standardized through future iteration over months and years. To find the capabilities required at this stage to both iterate the technology and develop it at scale, the TLO firms sought out partnerships to provide the complementary assets required. Whether for reasons of a lack of skills ("in certain industries, a whole generation of engineers is missing" according to the CEO of a nanotechnology firm), pull from an industry where the center of gravity has moved abroad, and/or market demand that is growing faster outside the U.S., more often than not, the TLO firms developed partnerships to scale production offshore. These factors, combined with financial resources, make the pull to scale abroad very compelling.

For example, in one biomedical device company we studied, we learned that it needed to design a product that could be manufactured at high volumes (involving precision injection molded plastics and rubber components). First, the company tried to partner with small firms in the US to develop this capability but ended up with a very low yield rate (less than 10%). Then it turned to large U.S. chemical and electronics companies. However, the product the start-up produced was so different from conventional technologies, the large companies had little interest. One called it "really stupid", another a "fool's errand," while a third wanted $5 million for a feasibility study. After a global search for manufacturing capabilities at scale, the company settled on Singapore because it offered three things: capital ($30 million investment from the government), a willingness to draw on their semiconductor experience to build the right capabilities, and intellectual property protection. The company was one of the first to move its production to Singapore and others have followed, creating a center of capabilities in biomedical manufacturing. The company has since gone public.

For several of the companies we interviewed, almost all of their future customers are in Asia. One company, a semiconductor equipment firm founded in 2007, has only 10 potential customers in the world for its product, and five of them (the most important) are all in Asia. Volume is low for these high margin systems and commercial production would represent approximately 100 units a year. They chose their first partner for testing the equipment carefully since some of these players are considered aggressive and would "eat you alive"[22]. Their plan at this stage is to support the customer in the field during the testing phase. The six months after completing the prototype are critical, so the CEO will be moving to Asia for a couple of months. They will have two to three people on site and set up an office next to the customer. Their partner has spent two years already evaluating the technology and paid $1million up front for the demonstration phase. The pilot will cost $30 million and a full commercial production facility will cost $150 million. They expect to engage the customer for the investment going forward.

Suppliers as well as capital draw firms into overseas partnerships. In another case, a manufacturer of devices utilizing specialized silicon inks was only able to survive by working with suppliers who had a long -term incentive to develop their technology

[22] Interview—CEO-semiconductor equipment company 4/26/12

together. The CEO says, "The only reason we are alive is because of several strategic partnerships".[23] They work with one Japanese company and one American company. The easiest way to ramp up the process is to find equipment that already fits with what they do, even if it is designed to work on a different process. The Japanese company they partner with has resources abroad for manufacturing, and it is cheaper for them to build a large-scale plant in Japan (although they haven't done so yet). The CEO doesn't see a choice when it comes to building a 50 billion-unit plant; it will have to be in Asia. The CEO further states that he believes this is common for many production related companies due to the complexity of the technology coupled with the capital needs to develop it, "When they transition from the normal VC model, there is no other model to jump to, so they go abroad. They end up offshore 99% of the time. M&A deals happen at that point. The partner thinks 'we're going to manufacture this stuff, so why not acquire the company instead of being a partner?' Both manufacturing and technology companies go abroad looking for partnerships because it is easier for investors".[24]

VI. Discussion and Implications

The emergence of the high-tech entrepreneurial firm has created a new model for innovation in which these firms, trying to both scale novel technologies and enter the global marketplace, must seek out complementary assets. The nature of the US innovation ecosystem for these new technology firms, in terms of financing, demand from growing markets and customers overseas, and the lack of capabilities for scaling production in the US, creates momentum for these companies to find these

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[23] Interview—CEO, silicon ink device company 6/14/12
[24] Ibid

complementary assets offshore at a critical point in their scale up process. The aggressive pull of emerging economies seeking to build capabilities in advanced technology reinforces this behavior. Of course, in a global marketplace, we would not expect all investment and all parts of a supply chain to be located within the U.S. The firms are acting rationally and taking advantage of a global economy that prizes innovation. But it is the crucial point in these firms' development that raises concerns about important capabilities migrating offshore.

While some might argue that the iterative process of innovation that we describe is not critical to the U.S. as long as the country continues to drive the idea generation and early stage research and development, we believe this is a mistaken view of the risks and stakes involved. The transfer or sharing of this advanced knowledge across national borders, which often took years to develop, risks the potential loss of the national competitive advantage these capabilities have created in three ways. First, the loss of this learning by building deprives the country's innovation ecosystem of new learning and thus reduces the accumulation of knowledge and capabilities, ultimately diminishing the potential for future and as yet unknown innovation. The "industrial commons" is made poorer for it. Second, as we have seen in other industries, it increases the movement of the center of gravity for established and new industries away from the country, with implications for future industry growth. As underscored by others, where process innovation goes, product innovation follows (Pisano and Shih 2012). Finally, it limits the benefits the country could gain from the economic growth generated by the downstream activities these firms will create with scaled production in terms of investments and jobs.

Independent of whether the company preferred to scale in the U.S. or not, these companies have little choice but to go overseas to continue the commercialization process. While they are acting in the firms' best interest, as Teubal and Avnimelech (2003) observe, "there is no a *priori* reason for the market solution to be optimal or adequate to the country" (p. 37). The loss of the capabilities generated by these leading edge companies creates ripple effects for the country over time. Chesborough et al. (2006), discussing a similar phenomenon, state, "it is open to debate whether local policymakers should have invested more in helping to create the complementary assets to allow *in situ* development.' (p. 1098). Given the outcomes we observe in our research, we would agree that there is a case to be made for both private and public interventions to create complementary assets within the country that will enable more scaling locally.

We see four possible areas for exploration in terms of interventions: 1) increasing financing options for later stage development, 2) creating institutions and incentives that provide opportunities for firms to build capabilities in advanced manufacturing in the country ("learning by building"), 3) changing the contours of market demand through state procurement or standard setting, and 4) continuing efforts to encourage firms to raise capital through initial public offerings.

We believe initiatives in all four of these areas will extend the time and capital available for these firms to cross the "inflection band" and do so within their local economy. Given the country's focus on and investment in the early growth of innovative companies (university and company research grants, seed capital, tax incentives, etc.), we believe there should be an equal focus on the later stage scaling of these companies and how to encourage more of it to take place in the country. Likewise, many of these firms have benefited from U.S. R&D programs, whether in research grants, shared production facilities or tax treatment. It is reasonable to ask whether the country should care how those investments pay off in the long run.

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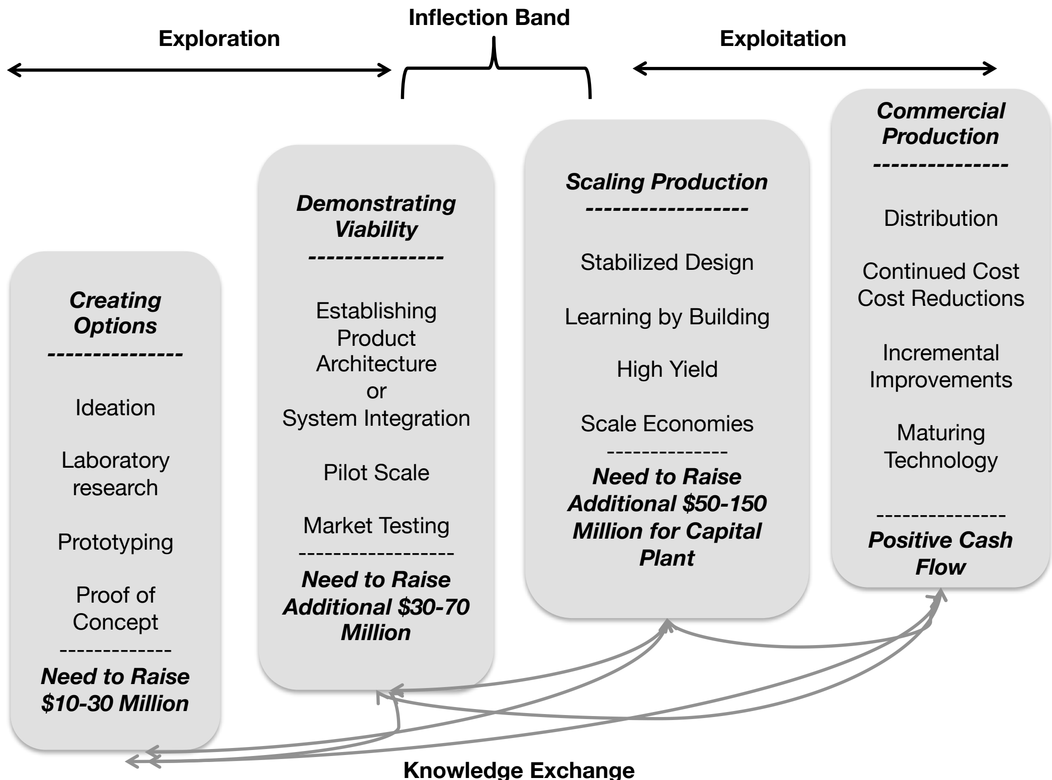
Tables & Figures

Table 1: MIT TLO Companies 1997-2008

Industry	# of Firms Started	% of Total	% Receiving Venture Capital*	% Operating^	% Closed	% Merged
Advanced Materials and Energy	15	10%	33%	73%	27%	0%
Biopharma	58	39%	59%	55%	26%	19%
Medical Devices	31	21%	52%	65%	3%	32%
Robotics	5	3%	0%	60%	20%	20%
Semiconductors and Electronics	26	17%	85%	62%	19%	19%
Other	15	10%	33%	47%	27%	27%
All Production Companies	150	100%	55%	59%	20%	21%

*Reported by VentureXpert
^-As of June 2012

Figure 1: Inflection Band During Scale-Up Process



Adapted from Lester Hart (2011)

Appendix 1: MIT TLO Companies Interviewed

Firm	Year Founded	Industry	Revenue	Public	SBIR	Exploration	Exploitation	Foreign Corporate or (State) Investor	Amount Raised ($M)	Motivation for Offshore
A	1997	Medical device	Yes	Yes	Yes	CA	US/Mexico	No	56	Low-cost production of low-value parts
B	2001	Biomedical	Yes	Yes	Yes	CA-R & D Prototype	Singapore	Yes (Singapore)	216	Capital, Capabilities, Cost at Scale
C	2001	Semiconductor	Yes	No	No	CA-R & D Prototype	Japan	Yes	77	Capital, Supplier, Cost at Scale
D	2001	Semiconductor	No	No	No	MA-Prototype, Pilot	MA, Asia, Europe	Yes (Russia)	108	Capital
E	2001	Biopharma	Yes	Yes	Yes	MA-Pilot	Multi-National Supply Chain	Yes	120	Capital, Distribution Marketing
F	2001	Biopharma	Yes	No	No	Germany	N/A	Yes	117	
G	2001	Medical device	Yes	No	Yes	MA	MA	No	74	N/A
H	2002	Battery Manufacturing	Yes	Yes	Yes	MA	Asia/US	Yes	243	Capital, Capabilities, Cost at Scale
I	2002	Biopharma	Yes	Yes	Yes	MA-Pilot, US-Clinical	N/A	Yes	100	N/A
J	2003	Advanced materials	Yes	No	Yes	CA/Ohio	South Korea--production?	Yes	95	Capital, Capabilities, Customers
K	2004	Advanced materials	No	No	Yes	MA-Prototype	US-Bulk, Taiwan-Application	No	55	Capital, Customers
L	2004	Semiconductor	No	No	No	CA	Taiwan	Yes	153	Capital, Suppliers
M	2006	Biotech	Yes	No	Yes	CA	N/A	No	<10	N/A
N	2006	Geothermal Drilling	Yes	No	No	CA	N/A	No	<10	N/A
O	2007	Semiconductor	Yes	No	No	MA	N/A	Yes	46	Capital
P	2007	Semiconductor	No	No	No	CA-Prototype S.Korea-Pilot	Asia	Yes	75	Capital, Capabilities, Customers
Q	2007	Advanced materials	No	No	No	CA-R & D Prototype	US/Russia	Yes (Russia)	36	Capital, Natural Gas Supply

Appendix 2: Venture Funding Of TLO Operating Firms (52)