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THE EFFECT OF TECHNOLOGICAL COMPLEXITY ON INNOVATION PERFORMANCE, EMPLOYEE ENTREPRENEURSHIP AND MOBILITY: THREE ESSAYS

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Technological innovation, knowledge diffusion and employee entrepreneurship and mobility are closely related phenomena. Multiple literature streams in strategy, entrepreneurship and technology management focus on explaining them. However, relatively little is known about the micro-level variation in technological tasks as their driver. I examine how the complexity of the technological problems that employees solve affects innovation performance and employees' choices about entrepreneurship and mobility. The dissertation highlights a new driver of innovation patterns, knowledge flows and employee entrepreneurship and mobility with implications for firm performance and competitive dynamics.

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DISSERTATION

University of Illinois
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EXECUTIVE SUMMARY

Technological innovation, knowledge diffusion and employee entrepreneurship and mobility are closely related phenomena. Multiple literature streams in innovation management, strategy and entrepreneurship focus on explaining them.

Understanding what drives successful innovations became a central concern of an eclectic body of research. Many scholars, dating back at least to Schumpeter, propose to conceptualize innovations as novel combinations of existing resources or knowledge. The more recent work on complex adaptive systems examines innovation by focusing on the process of searching for novel combinations. The complexity scholars theorize that innovations emerge from bounded, iterative, trial-and-error searches for novel combinations of existing building blocks over a complex search space. Such a conceptualization of the innovative process is appealing since it provides an important counterpart to neoclassical economics models that may not capture real life dynamics due to the assumptions of equilibrium and strong rationality.

The notion of innovation is closely related to entrepreneurship. For instance, entrepreneurial ideas frequently originate within existing firms. An extensive body of work examines both antecedents and consequences of employee entrepreneurship. Employee entrepreneurship has been heralded as a driver of innovation, a critical source of new capabilities

and heterogeneity in performance and an impetus to the creation and growth of industries and regional clusters.

Exploiting ideas identified while working within incumbent firms through employee entrepreneurship can be seen as a form of knowledge transfer. Similar to employee entrepreneurship, scholars have long recognized intra-industry employee mobility (i.e. post-exit joining of another firm within the industry) as a powerful engine for knowledge diffusion between established firms as well as between incumbents and startups.

At the heart of the issues above are questions that relate to the underlying drivers. *What factors affect the value of innovation, whether innovations are exploited or not and in which organizational setting*? *Are there any common drivers that affect all these phenomena*? Answering such questions in a coherent framework is important due to the inherent linkages between the creation and exploitation of knowledge that connect multiple levels of analysis. To investigate the possible common drivers of innovation performance, exploitation of ideas within incumbent firms, employee entrepreneurship and mobility decisions, as well as the associated knowledge flows, I examine the role of technology.

The nature of innovation and knowledge required to solve technological problems may affect choices individuals make about how they exploit the knowledge. This may have important consequences for patterns of knowledge diffusion and competitive dynamics. The main focus of my dissertation is to contribute to a better understanding of how technology affects innovation patterns and the origins of employee entrepreneurship and mobility. More specifically, I study an area which has received relatively little attention - how the micro-level variation of the technological context affects innovation performance and how it shapes employees' entrepreneurship and mobility decisions. The prior studies suggest that technologically more

advanced firms generate more entrepreneurs and that underexploited technological opportunities may lead to employee entrepreneurship. Additionally, there is abundant anecdotal evidence revealing that employees often quit after their technological ideas are rejected by parent firms. However, whether and how technology matters at a "finer grain" and how it affects employees' decisions to exploit their knowledge is less clear.

The key underlying driver of innovation performance and employee entrepreneurship and mobility decisions that I examine is the technological complexity of inventors' prior patenting activities within the incumbent firm. The technological complexity - being one of the key determinants of innovation performance dynamics - should also affect patterns of employee entrepreneurship and mobility.

Technological complexity affects characteristics of knowledge at multiple levels. Technological complexity may not only affect the innovative dynamics within incumbent firms but also influence how such knowledge diffuses across firms. For instance, solving technologically complex problems may lead to breakthroughs but knowledge necessary to solve such problems is more tacit and the solution outcomes may be more uncertain. At the same time, complexity may affect frictions in decision-making and increase the likelihood of idea rejections at the parent firm. As a result, technological complexity appears to be a viable driver affecting not only innovations but also employee entrepreneurship and mobility decisions.

In the three essay of my dissertation, I study how technological complexity affects the performance of innovations and how the innovations are exploited. In the first essay, I examine the question of what is the best approximation of innovative process. The traditional approach of neoclassical economics often assumes full rationality and thus provides a polar opposite to the agent-based models that assume very limited rationality. Whether simplifying human behavior

towards more rationality as in neoclassical models or less rationality as in agent-based models is more appropriate should be decided on the basis of the predictive powers of the respective models. To contribute to this discussion, I model the innovative process as an iterative experimentation using an agent-based model. The main question that I address is whether such approach is a valid approximation of the technological problem-solving. In particular, I use the NK model for predicting innovation performance.

The findings of the first essay underscore the difference between the search in biological evolution, which is "blind" and driven by mutations, and technological search, which is driven by human cognition and its heterogeneity. Consistent with the notion that technological problem-solving can be approximated with an iterative and adaptive search of boundedly rational agents, I find that, on average, inventors face difficulty when solving complex technological problems and are unable to capture opportunities present in complex technological domains. For an average inventor, performance declines with high problem complexity. However, in contrast with such a view of the innovative process, I find that variance of achieved performance increases with complexity. In a "biological" view of the innovative process represented by the iterative search of boundedly rational agents, all inventors are assumed to have identical search capabilities. In practice, inventors are heterogeneous in their ability to recognize and exploit opportunities. Even though an average inventor faces difficulties when solving complex problems (and iterative experimentation and luck aren't sufficient to ensure discovery of the best solutions), some inventors may have the required abilities to discover and exploit such opportunities. The findings of the essay thus emphasize that the applicability of the simple agent-based models to human processes may be valuable but must be taken with caution and with attention to boundary conditions.

The essay has important implications for the following two essays. It justifies the use of the iterative and adaptive search of boundedly rational agents as a reasonable approximation of the technological problem-solving process, and it shows that technological complexity has a significant impact on patterns of innovation performance. It also informs the theory in essay 3 by suggesting that innovation outcomes become more varied with highly complex problems even as average performance declines. The opportunities in complex technological domains are more abundant but only some inventors are able to exploit them. Further, the study develops and validates a novel measure of technological complexity that allows the examination of the empirical relationships between complexity and employee entrepreneurship and mobility in essay 3.

Importantly, technological complexity matters at multiple levels. It affects whether opportunities are present and the ability of inventors to discover them. As a result, it may also affect how the opportunities are exploited. In the second essay, I rely on the notion that iterative and adaptive search of boundedly rational agents is a valid approximation of technological problem-solving. I use an agent-based model to examine the relationship between technological complexity and idea rejection within parent firms. My main question is what attributes of the underlying technological problems affect idea rejection within parent firms. These are factors that are driven by the technology itself and are separate from agency costs, asymmetric information or resource constraints - factors that have been examined in the prior literature. The core objective of developing the agent-based model is to isolate the effects of technological attributes like problem difficulty and technological breadth and show that rejection of profitable ideas may occur even in the absence of factors associated with asymmetric information, contract incompleteness or resource constraints. Could technological tasks that employees solve serve as

an independent driver of idea rejection? What attributes of the tasks are relevant and what are their effects on idea rejection? Answering these questions is important since idea rejection is frequently assumed to be a precursor to employee entrepreneurship. The empirical evidence suggests that employees frequently leave existing firms to start their own firms after they disclose ideas to their parent firms and these are rejected, they implement knowledge they encounter within parent firms, and, more specifically, they have knowledge which is underexploited within these parent firms.

Technological complexity affects performance of innovations and whether these innovations are exploited from within the firms they originate. However, technological complexity also influences the characteristics of knowledge that is required for solving such tasks. Does it have implications for the ability of employees to transfer their knowledge and ideas and implement them outside of the incumbent firm? How important is the organizational setting of the recipient organization? Answering these questions is critically important for determining not only knowledge flows and mobility patterns but also competitive dynamics and industry structure. If more complex knowledge embodies more opportunities then who exploits them? Which firms are best positioned to absorb such knowledge and thus compete with the parent firm?

In the second essay, I find that rejection of profitable ideas may be driven purely by the attributes of the underlying technology without the presence of agency considerations, asymmetric information or resource constraints. The idea rejection in the model is driven by attributes of the task that is being solved (complexity, breadth, volatility of the environment) and their interaction with the bounded search abilities of inventors who solve this task. Even though inventors are assumed to be homogeneous in terms of quality they have different expertise.

Further, their expertise is a subset of the dimensions of a given problem, which necessitates collaboration. The model predicts that the likelihood of idea rejection increases with problem complexity and with the size of technological shock; there is a negative interaction between problem complexity and technological shock size; and project rejection has an inverted U-shaped relationship with problem breadth. Assuming that idea rejection is a precursor to the emergence of an employee founded startup, the model suggests that technology can provide an independent driver of employee entrepreneurship.

The mechanics of the model developed in essay 2 informs the theory in essay 3 that connects technological complexity with employee entrepreneurship and mobility decisions. More specifically, the model emphasizes that knowledge originating from more complex technological domains may embody underexploited opportunities – viable ideas which are rejected by the incumbent firms.

In the third essay, I examine how technological complexity affects the ability of employees to transfer and replicate their knowledge in other organizational settings. I theorize that complexity affects underexploited opportunities that are embodied in knowledge carried by employees and also their ability to transfer such knowledge to other organizational settings. Such dynamics, in turn, affects employee exit choices.

I develop the theory along the tension that more complex knowledge not only contains underexploited ideas but may be also be more embedded within the parent firm structures and be more difficult to transfer to other organizational settings. In particular, I develop a theory connecting the technological complexity of employees' prior innovations with their decisions to engage in employee entrepreneurship and mobility while also examining some of the contingencies like target firm size and team movements. I find that, after controlling for the

value of innovations within incumbent firms and the attractiveness of the technological domain, technological complexity affects whether inventors exit and the destinations of their moves. The likelihood of joining a rival firm decreases with technological complexity of inventors' prior work. Conditional on mobility to rivals, complexity increases the likelihood of joining a larger firm. However, conditional on exit, the technological complexity increases the likelihood of founding a startup relative to joining a rival firm. Further, I find that the likelihood of team founding relative to individual founding increases with the technological complexity.

The results show that characteristics of knowledge not only determine whether inventors may transfer such knowledge outside of the incumbent firm but also its destination. Complex knowledge that potentially embodies valuable opportunities is more likely to flow through employee moves to startups relative to established firms. If it does flow to existing rival firms it is transferred to those firms that are sufficiently large to provide necessary slack resources for exploratory activities leading or that have the ability to absorb such knowledge. These findings have important implications. It may explain why employee entrepreneurship is so prevalent in early phases of industry evolution when firms possibly generate more knowledge than they utilize. It may also explain why, in some settings, startups outperform other firms. The results also imply that nature of technology affects industry structure. Complex technological domains favor entrepreneurship and perhaps lead to a more volatile competitive environment in which incumbent firms are frequently displaced by new entrants.

The dissertation opens rich venues for future research. A particularly relevant question connecting all three essays relates to the cross-industry differences in how technological complexity affects innovation performance, employee entrepreneurship and mobility patterns. For instance, the cross-industry differences in the nature of complementary assets may affect

how technological complexity affects inventors' exit decisions. In the semiconductor industry that I study in essay 3, the entrants were predominantly non-manufacturing firms. This is consistent with the standardization of core designs and transition towards the "fabless" business model. In such a context, the complementary assets are in the knowledge domain and are embedded in the highly mobile human assets. However, in some other industries the linkages between the intangible and tangible assets may be tighter, and necessary complementary assets may be embedded within incumbent firms. This may interact with technological complexity and affect inventors' exit choices. The broader related question is how industry context affects creation and exploitation of knowledge. The differences in the nature of complementary assets and characteristics of knowledge may affect studied phenomena through different drivers than the ones explored in this dissertation.

Similarly, characteristics of knowledge may interact with firm strategies in their effect on inventors' incentives and exit choices. For instance, parent firms may design strategies to protect their intellectual property or rely on outside legal mechanisms. Such potential interactions underline the necessity to examine these phenomena in a coherent framework.

Critical questions that emerge in both essays 2 and 3 relate to the post-exit performance of employee entrepreneurs and mobile inventors. Do inventors successfully exploit opportunities embodied in complex knowledge? What are the contingencies? Based on findings of essay 1, it may be the case that average performance is low in very complex technological domains while the variance of performance is high. Founding a startup that exploits a complex technological knowledge may thus represent a high-risk-high-return strategy.

The questions related to post-exit performance also have an international dimension. The existing literature shows the performance premium experienced by startups founded through

employee entrepreneurship relative to other startups. With the increasing importance of international mobility, the question is how knowledge characteristics and knowledge transfer affect performance of inventors moving across national borders. Disentangling these contingencies and performance implications is an important project for future research.

The findings in essay 3 suggest that technological complexity affects industry structure by shaping the likelihood of entrepreneurial entry. This has potential implications for overall technological evolution, competitiveness and turbulence of a given industry. How exactly knowledge structure affects industry structure is another important question. Examining the role of technological complexity may provide a meaningful contribution to this discussion.

Another overarching question connecting all three essays relates to the drivers of technological complexity, its changes over time and the cross industry differences in its patterns. Does technological complexity increase over time? If yes, in what settings? Why does it change over time and what are the implications? These questions go beyond the scope of my dissertation but are nevertheless important in improving our understanding of drivers of innovation, firm and industry performance. My dissertation provides a first step in the examination of these fascinating phenomena.

The dissertation contributes to technology and innovation management literature, complexity literature and literatures on employee entrepreneurship, employee mobility and knowledge diffusion.

In the first essay, I contribute to innovation and complexity literatures by showing that the innovation process can be successfully modeled as an iterative search of boundedly rational agents. I develop a novel measure of patent-level technological complexity and show that it improves the fit of the NK model over prior studies with important theoretical implications.

The second essay contributes to employee entrepreneurship literature by focusing on factors that condition the emergence of employee entrepreneurship. The paper connects employee entrepreneurship literature with the technology management literature by providing a first model that explicitly links technology with employee entrepreneurship. The model also contributes to complexity literature by extending the NK models with cognitive search by incorporating team interaction.

The third essay contributes to the employee entrepreneurship literature by empirically documenting that the nature of technology is an important contingency in the emergence of employee entrepreneurship. The study contributes to the literature on employee mobility and knowledge spillovers by showing that the nature of technology may affect the ability of employees to transfer and replicate knowledge in other organizational settings.

In conclusion, the study shows that knowledge creation and exploitation are inherently connected. Common drivers like technological complexity may affect creation and exploitation of knowledge at multiple levels, which underscores the value of examining these phenomena within a joint framework. The study thus provides a unique opportunity to shed new light on an important contingency, opening rich pathways for continued research.