Resource Allocation Decision-Making in Hybrid Organizations: Evidence from University Technology Licensing[*]

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Abstract: Organizations with multiple missions (i.e., "hybrid" organizations) are on the rise, but our empirical understanding of resource allocation decision-making in these hybrid organizations is limited. In this article we study the university technology transfer office (TTO), whose dual mission of promoting the public good and private value of technological advances is complicated by the very skewed returns from academic patents. We derive predictions about the intersection of internal organizational resource allocation decision making in hybrid organizations when learning opportunities are rare. In particular, hybridity in this context may juxtapose resource allocation according to an academic "star" status logic against a commercial experience logic. We empirically test our predictions using detailed administrative records of patenting decisions and outcomes by one prominent U.S. research-based university's (PRU) TTO over a 30-year period in the context of patenting academic research inventions for commercialization. Our results are consistent with the view that TTO manager behavior skews toward the more measurable mission (private value) as compared to the harder to measure one (public value), and that there is likely overlearning from rare prior commercial successes. We discuss implications for both the academic literature and for managers in these type of hybrid organizations.

Keywords: Hybrid organizations; decision-making; university technology licensing; patents; administrative data.

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1. INTRODUCTION

Hybrid organizations—those with multiple (perhaps conflicting) missions and which combine "institutional logics in unprecedented ways" as defined by Battilana & Dorado (2010)—have become increasingly important across a number of domains. The rise of purpose-driven and environmental / socially-responsible organizations—those which are concerned with maximizing not just financial returns to shareholders, but which also have objectives of equity, economic development, and/or environmental consciousness—is capturing more attention (e.g., Eccles, Ioannou & Serafeim, 2004; Henderson, 2020). Examples abound. Consider microfinance organizations, in which economic development is prioritized alongside financial returns (e.g., Battilana & Dorrado, 2010), or corporate venture capitalists in which a financial return logic might be pitted against corporate strategic interests (e.g., Dushnitsky & Lenox, 2006).

In such hybrid organizations, there are at least two pressing managerial decisions. First, especially if the missions involve tradeoffs, managers must decide the relative weights of each mission (for example, how much financial return sacrifice would be acceptable to enable economic development or to foster strategic interests?). Second, even after managers decide on the relative weights of the pluralistic missions, how best to implement them presents a very difficult set of issues. Implementation challenges not only involve the usual issue of incentive setting and managerial oversight, but also two additional factors specific to hybrid organizations. First, measuring the social or strategic goal, both in the short and medium terms, can be particularly tricky. Second, certain hybrid organizations are sub-units inside a larger organizational context that may have its own strong cultural norms, such as corporate venture capitalists operating as a unit inside a larger organization and—the focus of this paper—technology transfer organizations (TTOs) responsible for pursuing and licensing patents within a research university context.

Unfortunately, there has been little empirical research on internal management issues within hybrid organizations.[1] At the heart of internal management of hybrid organizations challenges are resource

[1] See Battilana & Dorado, 2010 for an important exception in which the authors find that human resource acquisition, retention, and promotion strategies, together with socialization processes contribute to emergent organizational cultures inside new hybrid organizations. Similarly, the literature on university TTOs has only scratched the surface

allocation decisions. Developing a better understanding of such decisions is important both for gauging how well the organization is doing in meeting its pluralistic mission, as well as assessing how the organization is operating with regard to implementation. We therefore pose the following research question: in a hybrid organization in which there are potentially conflicting logics, which logic commands decision-makers' attention in guiding their resource allocation decisions?

Consistent with the broadening of research-oriented universities' missions since the 1980s to also include economic development, consider the following statistics of US academic technology transfer in 2018 (as reported by the Association of University Technology Managers (AUTM)): over 17,000 patent applications filed and 7,600 patents granted; 828 new products created; and over 1,000 start-ups formed. As a result, between 1991-2010, AUTM survey respondents reported nearly $10B in licensing revenue. University technology transfer and licensing operations are therefore becoming more prevalent and expansive within and across research-oriented academic institutions, and also more important economically. Alongside revenues from tuition, endowments, philanthropy, and research grants/contracts, the revenues from TTOs (typically unrestricted in use, unlike several of the other revenue categories) are becoming increasingly important for universities in financing their operations and therefore fulfilling their overall mission.[2]

Despite this promising trajectory, the aggregate licensing revenue figures reflects an extremely skewed distribution in which relatively few technologies represent the majority of the overall licensing revenue (as is true in private patent value, e.g., Gambardella, Harhoff & Verspagen, 2008). This distribution has interesting and important implications for hybrid organizational decision making, as it places the decision makers into the realm of learning from rare events.

We therefore also study hybrid organizational resource decision-making in which managers attempt to learn from rare events. Large sample empirical examination of micro-foundations is rare in both the

on these internal management topics (see Bercovitz et al., 2001 and Siegel, Waldman & Link, 2003 on TTO decision-making and organizational structures as exceptions).

[2] Recent research suggests room for further value-capture potential from such university TTO organizations, though (Hsu, et. al, forthcoming).

management of hybrid organizations literature and the learning from rare events literature. These literatures are typically either conceptually-oriented (e.g., Pache & Santos, 2010) or based on small-sample comparative case studies (e.g., Battilana & Dorado, 2010). Our approach is to conduct a statistical analysis based on in-depth administrative patenting and commercialization records inside one prominent research-oriented U.S. academic institution (hereafter, "PRU"), spanning the years 1986-2015. This design allows us to infer resource allocation decisions by TTO managers while keeping certain factors, which might otherwise vary and affect such decisions in a cross-institution analysis, constant.

Patent protection is often a prerequisite to drawing the interest of potential technology licensees, which is a necessary step to commercialization success (and associated licensing revenues). The patenting process is costly, however, and also entails foregone opportunity costs of other activities which could also help fulfill the TTO's mission.[3] The set of actors in the TTO market are the intellectual property (IP) "producers" (academic scientists and engineers), "market intermediaries" (PRU's TTO managers), and potential licensees (established firms, or less frequently, startups). In this study we focus on the second set of actors: the TTO managers. At the front end of the commercialization process, TTO managers must make judgements about allocating resources to pursue patent application filings on certain disclosed inventions from IP producers. The large majority of patents are issued only after being initially rejected and amended, sometimes many times, a potentially expensive process known as "patent prosecution." Accordingly, TTO managers must decide not only whether to file a patent application, but also how many resources to invest in its prosecution before cutting the TTO's losses by abandoning the application.

[3] Most universities in their TTO operations have a dual mission of promoting both the public good while also bringing private value. For example, MIT's licensing office mission is: "to move innovations and discoveries from the lab to the marketplace for the benefit of the public and to amplify MIT's global impact." (http://www.tlo.mit.edu). Similarly, at the University of Wisconsin (WARF), states on their website: "Most technologies/products cost WARF more money to bring to market than they recoup through licensing, which explains why most inventor groups seek WARF's professional assistance." (http://www.warf.org/about-us/faqs/facts-about-warf-s-purpose-and-functions.cmsx). They do this because of the organization's mission to "steward the cycle of research, discovery, commercialization and investment for UW-Madison."

From the standpoint of the TTO managers, we examine two logics under which they may be making their decisions to engage in patent prosecution and technology commercialization (in interfacing with the IP producers), particularly in the face of very skewed PRU patent licensing revenues (a relatively small number of patents account for the bulk of the overall revenues). First, there is the expenditure of resources along a logic of scientific and academic eminence, which is the traditional currency of merit in research universities. A second type of resource-allocation logic is the investment in producers with commercial experience, which is becoming increasingly valued in some institutions.

Our empirical analysis yields two main findings: (1) in the face of dual missions, one of which is difficult to measure (i.e., public good value), TTO managers' resource allocation behavior seems more aligned with the mission that is easier to observe and measure (i.e., promoting private value); and (2) in the face of the skewed distribution of patent outcomes, learning from successful outcomes is difficult, and there is the risk of erroneously learning from a small but influential sample of prior successful cases. These findings are important because they shed light on decision-making within hybrid organizations in general and on decisions relating to the commercialization of university research by TTOs, an understudied type of hybrid organization.

2. BACKGROUND, LITERATURE & HYPOTHESES

Universities in 19^{th} century America did not start as hybrid organizations. As a prelude to understanding the resource allocation decisions of university TTO managers, we first discuss key events shaping the historical evolution of US research universities into modern-day hybrid organizations (section 2.1). Next, we argue that the institutional characteristics of TTOs suggest that the distribution of patent value is likely to be even more skewed for university patents than for patents in the private sector (section 2.2). We then embed our discussion of resource-allocation decisions within the literature on hybrid organizations as applied to the TTO context, and argue that managers inside the boundary organization which acts as the interface between the IP producers and the commercial marketplace will likely gravitate toward a profit-seeking logic (section 2.3). Finally, in the face of this evolving institutional environment, we position TTO licensing manager behavior and outcomes in the literature of learning from rare events, particularly given the skewed nature of commercialization outcomes (section 2.4).

2.1 TTO evolution to hybrid organizations

2.1.1 Historical background. This subsection briefly recounts the key historical events shaping universities on their evolutionary path toward technology commercialization efforts, culminating in the birth of the modern hybrid TTO organization (covered in the next subsection). Scholars agree that the period after the US Civil War was a crucial one for U.S. research universities. For example, Goldin & Katz (1999, p. 45) note: "For most of the 19th century, American institutions of higher education were centers of learning, not research. That began to change in the latter part of the 19th century with the founding of Johns Hopkins University (1876), the first dedicated research center in the US." One policy trigger was the 1862 and 1890 Morrill Acts, in which the US government transferred land to states to endow colleges and universities specializing in practical sciences such as agriculture and mechanical arts. Some 432 colleges and universities were established in the US between 1860-1899, whereas only 289 such institutions had been formed in the US in the preceding 222 years (Goldin & Katz, 1999).

While the US federal government was important in establishing these "land grant" universities, the government provided almost no funding prior to World War II for research at these institutions, a pattern which was reversed after 1945 (see Atkinsion & Blanpied, 2008 for further discussion). In that year, Vannevar Bush, a prominent science advisor who had chaired the US National Defense Research Committee and then became the chair of the US Office of Scientific Research and Development (OSRD), submitted a report to President Truman entitled, "Science—The Endless Frontier." Bush argued that funding (basic) research and science leads to general knowledge, which then provides a means of approaching a number of practical problems, and so funding science is a proper concern of government. Research efforts, which had been so important during war-time, helped develop important innovations such as radar, penicillin, and plastics, Bush argued, should also be funded during peacetime, and pushed for the formation of the National Science Foundation (which was established in 1950).[4]

With the rise of federal research funding in the following decades, the 1980 Patent and Trademark Amendments (Public Law 96-517, also known as the Bayh-Dole Act) was an important event shaping US university technology transfer. This act granted intellectual property rights to federally-funded research to entities (universities, not individual researchers) conducting the research. This Act is thought to have accelerated university efforts in establishing technology transfer and licensing offices (Henderson, Jaffe & Trajtenberg, 1998). It is starting this time period in which qualitative (Murray, 2010) and quantitative (Owen-Smith, 2003) accounts find a period of ferment in which norms and logics associated with traditional research and academia start intersecting and clashing with commercial logics. To illustrate one episode, Harvard's patent on an "oncomouse," a genetically engineered mouse for cancer studies, was exclusively licensed to the DuPont Company in 1984, which when the company imposed commercial norms (such as corporate review prior to scientific publication), led to conflict with academic researchers (Murray, 2010). During this period, social norms of the scientific field (Merton, 1968) were challenged, but the norms of academic science slowly became more accepting of commercial science (Stuart & Ding, 2006).

While potential conflicts of interest and other concerns about commercializing higher education have been forcefully articulated (e.g., Bok, 2003), others have advocated for a wider university mission beyond the traditional teaching and research ones, to also include economic development including technology commercialization. Doing so also implies associated changes in human resource management practices including revising promotion (tenure) policies to take such activities into account (Sanberg, et al. 2013). It may also involve changes in the way commercial activities are discussed, presented, and rewarded within the university.[5]

2.1.2 Modern university technology transfer offices as hybrid and boundary organizations. This historical backdrop allows us to better understand modern-day TTO manager incentives and behavior. Such

[4] For more discussion about the OSRD and an analysis of its long-run effects (on direction of US invention and location of high-tech industrial employment) of the research it supported, please see Gross & Sampat (2020).
[5] While there are differences in the apportionment of incoming licensing revenues across institutions, there is typically a split among the inventor(s), the department and/or school, and the university.

managers intermediate a dual mission of a societal benefit logic (i.e., knowledge transfer and use) coupled with a commercial return logic (i.e., licensing revenue) associated with university-owned IP. The TTO is a boundary organization in that it intermediates between the producers of the intellectual property and potential licensees, as well as interfacing with federal patent-granting authorities in the context of patent prosecution.[6]

One area within the hybrid organizations literature which has been flagged as quite underdeveloped is internal organizational design (Battilana & Dorrado, 2010). Unfortunately, the literature on university technology transfer is also sparse on this topic as well.[7] Notably, two studies in this domain (Bercovitz, et al., 2001; Siegel, Waldman & Link, 2003) both have the words "exploratory study" in their titles. Bercovitz et al. (2001) discuss variation in the way TTOs are organized (e.g., decentralized, centralized, cross-functional) as an explanatory variable for patenting and licensing behavior across three university TTOs. Such differences in organizational structure shape information processing capacity, coordination capacity, and incentive alignment. Siegel, Waldman & Link (2003) broaden this investigation to also include survey-based information not just about internal operations, but also how internal operations might interact with external potential licensees to further educate them on academic culture and develop mutual understanding.

Given that there is very limited prior literature on within-hybrid organization resource allocation decision-making, especially at the resource allocation level, we modify a framework from science policy, known as "Pasteur's Quadrant" (Stokes, 1997) to begin our analysis. This framework is contained in Figure 1, and categorizes two dimensions on which scientists choose their projects: quest for basic understanding and consideration of use. Whereas many scientists pursue either pure basic research or pure applied

[6] While the bulk of our efforts pertains to TTO managers and their resource allocation decisions, the IP producers are an important stakeholder in understanding those decisions. Potential licensees are also a key stakeholder, but the TTO organizational management-oriented resource allocation decisions associated with the demand-side of the market seem less theoretically rich. This is not to say that there are unimportant TTO marketing and contractual decisions (including negotiating sponsored research agreements, etc.), however, associated with licensees. From the standpoint of the potential licensees, these entities typically take as given the availability of university technology (leaving sponsored research aside). While we do know the licensing entities for successfully licensed technologies in our empirical sample, for the above reasons, we do not delve deeply into the demand-side for university technology here.

[7] The TTO literature has tended to concentrate on only one aspect of organizational design, namely contracting policies such as royalty revenue splits and ownership between the various stakeholders (Jensen & Thursby, 2001; Lach & Schankerman, 2008; Hvide & Jones, 2018).

researcher, some scientists conduct a “use-inspired” quest for basic understanding. For example, Pasteur sought to undertake research which was applied, but also aimed to contribute to scientific understanding in the field of microbiology, specifically in inoculation and fermentation (Geison, 1995; Stokes, 1997). While the Pasteur’s Quadrant framework is from the scientist’s perspective, we place on it a TTO manager lens to guide our conceptual and empirical exploration of how TTO licensing managers’ resource allocation behavior may respond to different types of scientists.

Scientists’ commercial experience is one important dimension that may signal to the TTO manager the presence of skills or knowledge helpful in technology commercialization. Such commercial experience may be in the domain of patenting (e.g., understanding what is likely to meet standards of patentability and IP protection, including issues such as the breadth and scope of protection) or in the realm of licensing (e.g., not only the subject matter which is likely to be demanded by the marketplace, but also possibly the most interested individuals, operations, or firms who may be potential licensees), and need not derive from time spent in industry. Scientists’ commercial experience may also reduce the (perceived) uncertainty of TTO managers that the scientist is able to self-regulate and forebear on opportunities which are less likely to have commercial significance. Without such experience, the TTO manager may be skeptical that the scientist appreciates industry demands, and so “consideration of use” in the Pasteur quadrant framework may be in doubt from the perspective of the TTO manager.

With regard to the “quest for basic understanding” dimension of the framework, the prestige conferred by scientific eminence in a traditional academic environment provides a status ordering. For this reason, tenure and promotion decisions at research universities are often tied to such scientific accomplishments. From the perspective of TTO managers, the effect of accomplished academics approaching the licensing office may come in two forms: first, their (perceived or actual) scientific merit may be higher than average and so may form the basis of differentiated technical advance which may translate into enhanced patentability and/or the potential for broader and more valuable IP. A second effect, however, may be that the TTO officer may have a harder time imposing discipline or withholding resources to the high academic status individual. The net effect of academic status is therefore ambiguous.

To mirror the "use-inspired" research of Pasteur's quadrant, there may also be interaction effects between commercial and scientific eminence in influencing TTO managers' resource allocation decisions. Individuals who patent appear not to suffer an academic productivity penalty (Fabrizio & Di Minin, 2008). Whether such individuals achieve better commercialization outcomes is an open question, and one which we will examine in the context of resource-allocation decisions in the face of a very skewed distribution of commercialization outcomes, a topic we now consider.

2.2 Skewed distribution of university patent value. With this understanding from the literature of the evolving institutional context of university research and the role of TTO managers, we now turn to the private value of university patents, since a better understanding of the value distribution will guide our discussion of TTO decision making. The average patent is worth very little, and most of the private value in the patent system is concentrated in a small percentage of patents.[8] One early study found that only 1-3% of patents yield significant financial returns (Stevens & Burley, 1997). Later, in a large sample survey of European patent holders, Gambardella, Harhoff & Verspagen (2008) found that although the median value of a patent is only 300 thousand Euros, a small proportion – about eight percent – were worth more than 10 million Euros. Representative valuation data for academic patents is also scarce, but a limited literature suggests that valuable academic patents are just as rare as valuable patents in the private sector (Sapsalis, de la Potterie, & R Navon, 2006).

Institutional characteristics of university TTOs are likely to exacerbate the skewed nature of the patent value distribution. In the private sector, patents are used for such wide-ranging (strategic and resource) purposes as cross-licensing with competitors, preventing copying by competitors, blocking technological innovation by competitors, enhancing a firm's reputation, aiding in negotiation, signaling, securing funding, preventing or defending against offensive patent litigation suits, and generating licensing revenue (Cohen,

[8] Observing the full distribution of patent values, both in the not-for-profit organization (e.g., TTOs) setting, as well as in the for-profit company arena, is rare. Typically, patent valuation is revealed only in select circumstances which are unrepresentative of the entire patent value distribution, such as in the course of patent litigation (typically only observed for highly valuable patents or those with high strategic value).

Nelson & Walsh, 2002). Accordingly, even less valuable private sector patents may nevertheless provide at least some return. Because universities typically do not directly commercialize innovation (leaving startup formation aside), however, they are effectively limited to a single avenue for generating value from a patent (i.e., licensing revenue), thereby skewing the value distribution even more than in private industry.

Making matters worse, TTO patent licenses are subject to significant transaction costs (Shane, 2002). A university TTO officer must first identify a prospective licensee. Such a task is difficult even for a private sector firm focused on a specific area of technology, which is one reason that at least half of patented technologies are never commercialized (Sichelman, 2009). Because universities typically encompass a wider range of technology which are often quite embryonic as compared to their private sector counterparts, university TTO officers are likely to be both less familiar with the technological specifics of any particular invention and the requirements for developing the technology to raise the likelihood for commercial application. Moreover, university inventions are often submitted by academic inventors with limited commercial experience and who are therefore unlikely to be helpful in securing a license.

Even after a prospective licensee is found, the university TTO officer must negotiate a license using fewer tools and with more requirements than are involved in many deals that occur in the private sector. Because the university is not itself a private sector firm, it cannot offer a cross-license, merger, acquisition, or other competitive alliance, and must instead typically negotiate for a cash or equity in the form of a license fee or royalty. In addition, the TTO officer typically negotiates for a grant back clause of some kind to allow the academic inventor to continue research along the same lines, which can create uncertainty regarding the ownership of follow-on inventions. The TTO officer may also confront a chicken-and-egg problem. Uncertain intellectual property rights hinder patent licensing deals (Gans, Hsu & Stern, 2008), but resource constraints may preclude a TTO officer from filing and prosecuting a patent application absent the promise of licensing revenue.

Finally, identifying *ex ante* which patent disclosures submitted by university inventors will prove commercially valuable is a difficult task. Private sector firms focused on particular areas of technology are generally unable to ascertain an accurate valuation, as evidenced by the presence of so many patents that are not worth the resources expended to secure them. The problem is compounded for university TTO officers who are likely to be faced with cutting edge technology submitted by academic inventors with limited commercial experience. Given the technological range of inventions produced by prominent research university, TTO officers are also likely to be unfamiliar, at least initially, with the technological specifics of any particular invention, especially since the typical university invention is often characterized as “embryonic.”

For all of these reasons, securing a profitable license, which is a requirement for achieving any financial return for an academic invention, is therefore a multistep process with many potential pitfalls. These costs are likely to render lower-value deals simply not worth the effort as compared to private sector patenting. Accordingly, the very few university patents that lead to a profitable license are likely to be quite valuable (due to technology uniqueness in the marketplace), while the vast majority are likely worth close to nothing. Collectively these observations lead to our first hypothesis, which helps sets the stage for the TTO resource-allocation environment.

> ***Hypothesis 1****: The distribution of university patent value is more skewed than the distribution of private sector patent value.*

***2.3 Public good versus private value*.** TTO officers have relatively few tools with which to further their dual mission. In securing patent protection, a TTO officer has two basic decision points. First, the TTO officer can decide whether to file a patent application for an invention submitted by an academic inventor. Second, the TTO officer can decide whether to expend resources to advance the patent application to a granted patent or instead to abandon prosecuting the patent application. After all, more than 86% of patent applications are initially rejected by the United States Patent and Trademark Office, but nearly 70% of patent applications are subsequently granted as patents (Carley, Hegde & Marco, 2015). However, the examination process can be lengthy and expensive, so the TTO officer must continually decide whether the payoff is worth the expense.

In theory, the hybrid nature of university TTOs renders the decision-making process quite difficult. How should a TTO officer decide how to allocate resources across a complex and ambiguous process of filing, pursuing, and licensing patent applications across a wide range of cutting-edge technology? In practice, however, the twin goals of a university TTO are quite different. TTOs are tasked with advancing the public good by commercializing university inventions even when such commercialization does not directly benefit the university, but success along this public good dimension is difficult to measure and therefore difficult to incentivize. The private good function of TTOs (i.e., generating licensing revenue) is not only much more readily observable but also directly benefits the university. We should therefore expect that generating licensing revenue is likely to take precedence, an argument consistent with the limited literature on TTOs (Jensen & Thursby; 2001).

If the commercial logic increasingly dominates, then the significant difficulty of evaluating the commercial viability of an idea up front coupled with the exceptionally skewed value distribution (Hypothesis 1) interact to create a powerful set of incentives for TTO officers. A TTO officer seeking to maximize the chances of securing the rare patent that will give rise to a very profitable license would do well to file applications liberally in pursuing the needle in the haystack.

At the same time, nascent technology coupled with a less selective filing strategy seem likely to lead to greater variability in patenting outcomes at the USPTO than for patents at a similarly large and experienced private sector firm. Moreover, a private firm that learns a patent application is unlikely to generate significant value and may nevertheless recoup some return on its investment by pushing the patent application to issuance, particularly when much of the cost of the patent has already been sunk, since virtually any granted patent is likely to provide at least some value to the firm. In contrast, a university TTO officer in the same situation and seeking to maximize licensing revenue would do better to cut losses and shift resources elsewhere, since a granted but unlicensed patent provides little-to-no private value for the university.

Finally, a license often gives rise to an ongoing relationship, which must be administered. Payments may be delivered as an ongoing royalty stream contingent upon one or more sales metrics, which must be monitored and evaluated. As compared to their private sector counterparts who may be able to dedicate more resources to such governance, university TTOs may be more resource constrained, due in part to the hybrid nature of the organization operating within the context of a not-for-profit university context. Knowing these downstream constraints may also elevate the threshold TTO managers impose to invest in certain types of patent applications for which they may have beliefs about ultimate commercializability and returns to justify the administration costs as compared to their private sector counterparts, leading TTO managers to abandon the prosecution of patents they deem unlikely to lead to licensing revenue. Collectively these observations lead to our second set of hypotheses.

> ***Hypothesis 2a***: *PRU's number of patent applications is increasing over time.*
> ***Hypothesis 2b***: *PRU's rate of patent application abandonment is increasing over time.*

***2.4 University patent licenses as rare events*.** As discussed, a key challenge for TTO managers is whether to pursue patent protection for a given invention disclosure given the wide diversity of technical domains typically contained in the modern research university, especially given the skewed distribution of patent value. The opportunity for learning about common characteristics which might signal patent value is extremely limited under these circumstances. Evidence from the private sector is unlikely to illuminate the situation since private firms operate under very different goals and incentives. Decisions made by other TTOs are even less likely to provide guidance since TTOs tend to operate under strict secrecy and do not disclose their decision-making processes or patenting outcomes. Accordingly, TTO officers are likely to learn primarily from the TTO's historical decisions, and particularly from the valuable but rare profitable licenses that embody one of the TTO's main objectives.

Scholars have identified two processes by which organizations construct rare events. The first process is quantitative, demarcating rare events from nonrare events using probability estimates (Lampel, Shamsie & Shapira, 2009). The central challenge with probability-based definitions is that the probability estimate for an event depends on the distribution, which can be difficult for organizations to determine (Bordo, et al., 2001; Aidt, et al., 2006). Under a probability-based view, organizations tend to invest more in learning the causes of rare events that are seen as likely to reoccur. For example, Zollo (2009) shows that organizations view successful acquisitions as rare events and focus attention on accumulating knowledge about the causes of success, which they intend to use to improve the odds for success in the future. Similarly, the TTO's entire existence is predicated on the future reoccurrence of profitable licenses, suggesting that the TTO is likely to invest considerable effort in learning the causes of previous successes.

The second process of constructive rare events is qualitative, through which organizational attention is focused through "enacted salience" (Lampel, Shamsie & Shapira, 2009). Individuals and organizations have a limited ability to deal with diverse stimuli (Weick & Sutcliffe, 2006). Organizations therefore focus their attention not necessarily on objective characteristics, but on a process of enactment through which decision makers both interpret events and influence others' interpretations (Gioia & Chittipeddi, 1991; Weick & Sutcliffe, 2006). This process of enactment is one in which an organization identifies the unusual features of a rare event and explores its meaning as the event unfolds (Beck & Plowman, 2009). The organization assigns meaning to the event in a multistage and iterative fashion that is less learning *from* rare events and more learning *through* rare events (Christianson, et al., 2009). The probability and enacted salience views of constructing rare events are not mutually exclusive, and in fact tend toward self-reinforcement – a salient event is more likely to be identified as rare in a probabilistic sense, while probabilistically rare events tend to acquire enacted salience (Lampel, Shamsie & Shapira, 2009). Profitable TTO licenses are not only rare events in a probabilistic sense but also acquire enacted salience in a slow, multi-year processes that unfold over time, from an initial invention disclosure through patent filing, grant, and licensing, and finally to the receipt of licensing revenues over an extended period.

Because rare events are by definition unexpected, they tend to generate unexpected insights (Meyer 1982). However, not all rare events result in significant organizational learning. Transformative learning is most likely to result from "[r]are events that combine a major impact on the organization with a strong match with significant organization concerns" (Lampel, Shamsie & Shapira, 2009). Successful TTO licenses which provide significant revenue meet both criteria. Nevertheless, emergent learning is subject to significant path dependencies (Cohen & Levinthal, 1994), so different organizations can learn markedly different lessons from similar rare events (Lampel & Shapira, 2001).

For all of these reasons, rare events tend to result in "overlearning." Overlearning can be conceptualized in an objective, probabilistic sense in that a model trained on an insufficient number of observations tends to be overfitted. From a more subjective perspective, enacted salience causes decision makers to overweight the characteristics of events that have particular importance to an organization (Zollo, 2009). In either case, the process of learning from rare events tends to be "shaped by selective and biased interpretation of outcomes: Success reinforces unwarranted confidence in managerial competences, and failure is attributed to unforeseen and foreseeable external circumstances" (Lampel, Shamsie & Shapira, 2009, p. 842). As applied to the TTO context, overlearning will be manifested in applying resource allocation heuristics based on past successes to a subsequent context which may not be entirely appropriate. The relevant characteristics are drawn from the IP producers as observed in the Pasteur's Quadrant framework. Collectively these observations lead to our third set of hypotheses.

Hypothesis 3a*: Characteristics of early patenting decisions by PRU will be mirrored in the filing decisions for subsequent patent applications.*

Hypothesis 3b*: Characteristics of PRU which predict patent filings do not predict future commercialization success.*

3. DATA

Our overall empirical goal is to test the above hypotheses which relate to hybrid organization managers' resource-allocation behavior when there is limited learning potential due to a very skewed distribution of patent value. To operationalize our empirical tests, in this section we cover our data sources, sample selection, key measures, and empirical strategy.

3.1 Data sources. Our data are from several sources: (1) internal patenting and licensing data from a TTO at a prominent research university (PRU); (2) the Microsoft Academic Graph (MAG); and (3) bibliographic patent data provided by the United States Patent and Trademark Office (USPTO).

The PRU data identify patent applications filed by the TTO at the PRU over a 30-year period (starting in 1986), as well as the names of inventors listed on those patent applications. Analysis of patent data is typically limited to granted patents, since data on pending and abandoned patent applications is either quite limited or not publicly available. Because they include data on pending and abandoned patent applications, the PRU administrative records therefore provide a unique perspective on PRU patenting activity. As we will show, the decision to file and later abandon a patent application seems to be a crucial component of PRU patent strategy.

Even more importantly, the PRU data also include technology and transaction-level licensing information such as whether a patent application was licensed, the number of licensing agreements, and its lifetime licensing revenue. The commercialization information, and especially the information about patented technology which remained unlicensed (and therefore yielded no revenue) is also particularly noteworthy, as it is rare to observe prices in the market for technology (at all, as such transactions are typically private), and especially in a way which is not severely selected (e.g., patents which are the subject of litigation, which are likely to be disproportionately drawn from the right tail of the value distribution).

The combination of the administrative data with the licensing information allows us to investigate decision making and performance on the patent application level, which provides a unique lens into PRU's strategy and organizational decision making. For example, whereas previous analyses of patent value have been performed at the level of the granted patent, our data allows us to evaluate the value distribution of PRU's patent *applications*, which is important since many of PRU's patent applications are abandoned prior to grant.

We rely on the MAG dataset as redistributed by Marx & Fuegi (2020) for information on inventors' publication records. The MAG dataset identifies bibliographic information such as dates, journals, authors, and journal impact factors (JIFs) for more than 160 million academic publications published since 1800 (weighting academic publications by JIF is a common way to adjust for quality). Scholars analyzing randomized samples have found that MAG provides significantly higher coverage than the better-known Google Scholar and Web of Science databases (Paszca, 2016; Hug & Brändle, 2017). Moreover, unlike the better-known Google Scholar and ISI Web of Science databases, the MAG dataset is publicly accessible under the Open Data Commons (ODC-By) attribution license.

We employ the publicly available USPTO PatentsView dataset to identify bibliographic information such as patent application filing date, patent grant date, patent citations, and inventors for granted U.S. patents. Produced by the Office of the Chief Economist of the USPTO (OCE), the PatentsView dataset provides several advantages over alternatives such as the more commonly used NBER patent dataset. Most notably, the PatentsView dataset provides comprehensive coverage for all patents granted since 1976. The PatentsView dataset also helps to resolve a longstanding challenge when working with patent data: disambiguating firms and inventors. Firms and inventors provide basic bibliographic information such as names and addresses to the patent office, but this information is rife with mistakes and ambiguities. The creators of the PatentsView dataset parse this information to assign each inventor and firm a unique identifier that can be used to track them across different patents.

One drawback of the PatentsView dataset is that its coverage extends only to granted patents. Because many of the patent applications in the PRU patenting and licensing data were abandoned or still pending at the time of our data collection, limiting our analysis to granted patents would miss significant aspects of institutional behavior. For information on pending and abandoned applications, we turn to the publicly available Patent Examination Research Dataset ("Public PAIR"), another dataset provided by the OCE, which is described by Graham, Marco & Miller (2015).[9]

Several recent efforts, including the PatentsView dataset itself and work by Li et al. (2014), have disambiguated inventor bibliographic information to assign each inventor a unique identifier. However, for our purposes all such efforts have three drawbacks. First, they do not cross-link inventors to the PRU patenting and licensing data from which we construct our sample. Second, they do not cross-link inventors to authors in the MAG data that we used to track academic publications. Third, they do not cross-link inventors listed on granted patents with inventors listed on pending and abandoned patent applications, which form an important part of our sample. Accordingly, we conducted an extensive inventor

[9] A key advantage of the Public Pair dataset is its inclusion of data on continuity relationships. A patent application frequently includes many inventive concepts, but the USPTO limits the applicant to pursuing claims directed to a single basic idea in a patent application to avoid imposing an undue burden on the patent examiner. An applicant who wishes to pursue claims directed to multiple inventive concepts can file one or more "continuing" patent applications, effectively splitting the original application and potentially yielding multiple distinct patents that are collectively referred to as a "patent family." Accurately identifying patent families is important since they form a key component of patent strategy. Patents in the same family share inventors, descriptive material, and an effective filing date, and therefore should not be treated as independent observations in empirical analysis. Instead, the earliest patent in a family indicates the genesis of the intellectual property, while later patents indicate an effort to provide more effective and comprehensive exclusive rights.

disambiguation and matching exercise to link these datasets. We started by constructing an internally harmonized and disambiguated name for each inventor in the PRU patenting and licensing data. We then performed a similar process for inventors in the MAG data, and determined a cross-link between the PRU and MAG data inventor identifiers. Next, we repeated the process for both the PatentsView data and the Public Pair data.

3.2 Sample selection. Our sample period begins in 1986 due to data availability and ends in 2015 to allow adequate time to observe outcomes for patent applications. We start by identifying all patent applications filed by PRU during our sample period. Next, we parse the patent continuity relationships in the USPTO Public Pair dataset to create a unique identifier for each patent family. We then exclude all but the first patent application in each patent family.

As discussed in Section 3.1, continuing patents represent a special strategy to obtain broader exclusive rights, but applications nevertheless are limited to claiming concepts described in the original patent application. Because patent families are legally interdependent and are almost always licensed (or not) as a unit by PRU, treating patent families as a unified whole in our empirical analysis is necessary both to identify the effective filing date for each patent application and to avoid effectively double counting PRU patent decisions and outcomes in our regression models.

We then analyze the PRU licensing data to exclude all but the first patent application for each licensing agreement. As discussed with respect to patent families, patent applicants frequently file follow-on applications to provide broader exclusive rights to an invention. The decision to pursue follow-on applications is often a consequence of commercialization prospects, and is not necessarily indicative of distinct and independent invention. Frequently these follow-on applications are linked to the initial patent application by a priority relationship, but sometimes they are not. Accordingly, limiting our analysis to the initial patent application for each license is a conservative approach that again helps to avoid double counting decisions and outcomes.

After these restrictions, we identify a total of 1,189 initial patent applications, of which 145 are licensed. We uniquely identify all 46,580 inventors listed on any of these patent applications.

3.3 Variable definitions and summary statistics. Table 1 provides variable definitions and summary statistics for the inventor-year data sample, and Table 2 provides pairwise correlations between the variables. For each observation we identify whether the inventor was listed on a patent application filed in that year (*Filed?*). An application was filed in 4.8% of the inventor-year observations.

---- Insert Tables 1 & 2 here ----

Two variables measure patent application outcomes. The variable *Issued?* identifies those observations for which the patent application subsequently issued. Of the inventor-year observations in which an application was filed, 43.8% (i.e., 2.1% of all inventor-year observations) led to an issued patent. The variable *Licensed?* indicates whether the inventor was listed on a patent application that was subsequently issued and licensed. Of the inventor-year observations in which an application was filed, 8.3% (i.e., 0.4% of all inventor-year observations) led to licensed patents. Of the inventor-year observations in which an application was filed and issued, 12.5% led to licensed patents. A second measure of outcomes, *Lifetime Revenue*, identifies the total revenue in thousands of dollars received from all licenses with which the patent application is associated.

In accordance with the (modified) Pasteur's Quadrant framework previously discussed, we believe there are two sets of variables (and possibly their interaction effects) which may guide TTO managers' resource allocation decisions: (1) academic status, and (2) commercial experience. To the first construct, the variable *Academic Superstar?* indicates whether a JIF-weighted count of the inventor's academic publications is in the top 5.0% of all inventors for that year. For the purpose of constructing this variable, we first select all PRU academics who filed at least one patent application during our sample, and select all publications by those academics. Following Azoulay, Graff Zivin & Wang (2010), we then weight each publication by its journal impact factor (JIF). The JIF measures the frequency with which an average article in a journal is cited in a particular year, which allows us to adjust publication counts for quality. We employ an arbitrary threshold of 5.0% to separate superstars from other academics, but the results are robust to alternate thresholds as well as a continuous measure.

To measure inventors' commercial experience, we construct three variables. *Prior Applications* and *Prior Patents* count the inventor's patent applications and patents filed and issued in previous calendar years. On average, an inventor in a given year had previously filed 0.65 patent applications and been granted 0.27 patents, but some inventors are quite prolific, up to a maximum of 124 prior patent applications and 73 granted patents. *Prior License?* identifies whether the inventor was listed on a patent licensed in a previous calendar year – 7.4% of inventor-year observations were associated with previous licensing. As a control variable throughout, *Career Length* measures the time in years since an inventor's first patent application filing or academic publication, whichever is earliest.

The data reveal several crucial facts about PRU's commercialization outcomes which inform our evaluation of the hypotheses: (1) the top 15 licensing deals in the PRU data by lifetime revenue collectively account for 81% of the licensing revenue during our sample period; (2) the patents for 13 of the top 15 licensing deals were filed in the first half of our sample period, from 1986-2000; (3) 40% of the top 15 licensing deals included an academic superstar as an inventor on the initial patent application (despite the selectivity of academic superstar status – the top 5% by JIF-weighted paper publications in a given year).

3.3 Empirical strategy. For testing hypothesis 1 (on skew TTO patent distributions) and hypothesis 2 (on escalating rates of PRU patent applications and rates of patent abandonment over time) we rely primarily on graphical evidence, which we cover below. To test hypothesis 3, on learning from rare events, we employ both inventor-year and inventor-application level regression analyses. The purpose of the inventor-year level specification is to investigate the correlates of application filing over time as a function of inventor characteristics and experience. Accordingly, we construct a balanced data panel with 139,740 observations at the inventor-year level. We then divide our 30-year sample into a 15-year learning period (1986-2000) and a 15-year implementation period (2001-2015) to estimate the following equation:

$$ApplicationFiled_{it} = \beta_1 X_{it} * Post_t + \beta_2 CareerLength_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \qquad (1)$$

In equation (1), *ApplicationFiled*$_{it}$ indicates whether inventor *i* filed a patent application in year *t*, X_{it} is an explanatory variable at the inventor-year level. *Post*$_i$ indicates whether year *t* is 2001 or later. *CareerLength*$_{it}$ measures the time in years since the first academic publication or patent filing by inventor *i* as of year *t*. The variables α_i and γ_t represent inventor and year fixed effects.[10]

We then switch to an analysis at the inventor-application level to investigate whether the characteristics that are apparently used to select patent applications for filing are themselves predictive of superior commercialization outcomes. Accordingly, we created a sample at the inventor-application level, and estimate equation (2), which is similar to equation (1) apart from the change in unit of analysis.

$$Y_i = \beta_1 X_i + \beta_2 CareerLength_i + \gamma_t + \varepsilon_i \qquad (2)$$

4. EMPIRICAL RESULTS

Figure 2 compares licensing revenue for PRU patents to private patent value as reported by Gambardella, Harhoff & Verspagen (2008). The distribution of PRU licensing revenue is significantly more skewed, with some patents yielding more than \$500,000 in revenue but more than 75% yielding less than \$25,000. Figure 3 plots PRU patent value in a different way, by showing the Lorenz curve of cumulative share of lifetime revenue against the cumulative share of patent applications. If patent value were equally distributed, the data would populate the 45-degree line. If instead a small number of patents comprise the majority of overall patent value, as is the case with our PRU data, the curve “sags” well below the 45-degree line (the Gini coefficient is a statistic distributed between zero and one which quantifies the degree of inequality, with higher value associated with more inequality). Because later-filed, follow-on patents included in a license typically exhibit substantial technological overlap with the initial patent, we plot Lorenz curves both with and without these follow-on patents. The results are stark. Nearly 75% of patents

[10] The optimal model for estimating equation (1) is not entirely clear. A linear probability model provides an unbiased estimator even with two-way fixed effects, but may not be the best fit for the data. A logit model is likely to provide a better fit, but including fixed effects in non-linear panel data models can lead to the “incidental parameters” problem (Neyman & Scott, 1948). Accordingly, for robustness we estimate equation (1) using both linear probability and logit models.

generate no licensing revenue at all, and only a small fraction of patent applications (less than 5%) generate more than 75% of the licensing revenue. When follow-on patents in a license are excluded, the inequality is even more extreme. The top 1% of patents are responsible for 86% of the licensing revenue during our sample period.

---- Insert Figures 2 & 3 here ----

Although comprehensive data on private patent valuations is not generally available (and as previously mentioned, patent value datasets are typically highly selected, as in the case of those subject to litigation), the inequality illustrated in Figure 3 is far more extreme than any reported for private sector patents. For example, as shown in Figure 2, Gambardella, Harhoff & Verspagen (2008) found that the median value of their survey of European patents is 300 thousand Euros, whereas the median value of a PRU patent is zero. Figures 2 and 3 thus provide empirical support for Hypothesis 1, that the distribution of university patent value is more skewed than the distribution of private sector patent value.

Figure 4 plots patent application outcomes over time. In the second half of the sample period, after the four largest (by lifetime revenue) deals were finalized, the application filing rate increased substantially. Whereas the PRU filed fewer than 50 applications per year prior to 1995, most years from 2001-2015 saw more than 150 applications filed.

---- Insert Figure 4 here ----

Interestingly, the rate of abandoned patents climbed even more steeply, from 21.3% of patent applications filed in the first 10 years of the sample period to around 54.6% of patent applications filed in the last 10 years of the sample period. PRU's issuance rate is therefore much higher than that of all patent applications (20.8% as reported by Carley, Hegde & Marco, 2015). This suggests that the PRU TTO often abandons the prosecution of patent applications deemed to be strategically unimportant. Collectively these results provide support for both sub-predictions of Hypothesis 2, that the number of PRU patent applications is increasing over time, as is the rate of PRU patent application abandonment.[11]

[11] In addition, regression-based support for Hypothesis 2a, that patent applications are increasing over time, is visible in Table 3, column (1) in the positive estimated "Post" variable (denoting the evaluation period of 2001-15).

Table 3 presents the results of panel data models of patent application filing at the inventor-year level to evaluate the "Pasteur's Quadrant" variables. We present the results of linear probability models,[12] and all models include inventor and year fixed effects. Across all columns of Table 3, the PRU TTO is more likely to file patent applications by academic superstars than by non-stars in general, and especially so after the learning period of 1986-2000. For example, in column 3, an academic superstar in the initial learning period is 4.1 percentage points ($p<0.001$) more likely to file a patent application than a non-superstar. The correlation increases in the evaluation period—in column 3, an academic superstar is 9.1 percentage points ($p<0.001$) more likely to file a patent application than a non-superstar.

---- Insert Tables 3 & 4 here ----

In general, prior patenting experience is negatively associated with future patent application filing. In column 2, a 100% increase in prior patents corresponds to a 5.5 percentage point ($p<0.001$) decrease in the probability of patent application filing in the learning period, which drops to a 12.0 percentage point ($p<0.001$) decrease in the evaluation period. However, the decreased filing rate is almost entirely eliminated for academic superstars (column 3).

The effect of prior licensing experience is somewhat different as a measure of commercial experience. In the fully-specified column 3, previous experience with licensing a patent is associated with a 5.4 percentage point ($p<0.001$) increase in the probability of patent application filing in the learning period but this positive effect is counterbalanced with a negative effect in the on the probability of patent application filing in the evaluation period. However, in the evaluation period an academic star with previous licensing experience is 8.6 percentage points ($p<0.001$) more likely to file a patent application in a given year than a star without such experience.

One possibility for the increased probability of application filing by academic superstars, particularly those with prior commercialization experience, is that such applications fare better at the USPTO. To investigate this possibility, Table 4 reports the results of models of patent application issuance (columns 1-

[12] The signs, magnitudes, and statistical significance of the coefficients in the logit models are broadly consistent with those in the linear probability models, so we do not formally report them.

3) and lifetime revenue (columns 4-6). The unit of analysis in Table 4 is the inventor-application, so each patent application is included once for each inventor listed on that patent application. Columns 1-3 report the results of linear probability models to improve interpretability and to avoid the incidental parameters problem (Neyman & Scott, 1948), but the results are robust to a logit specification.

We find that many of the same factors which predicted patent application filing in Table 3 do not predict patent success in Table 4, and in fact are negatively related to both patent grants and lifetime revenues. Academic superstar status is negatively related to patent issuance. In column 1, for example, an application by an academic superstar is 5.9 (p<0.001) percentage points *less* likely to be issued as a patent than an application by a non-superstar academic. The magnitude of this effect is quite substantial, since as discussed above, the overall allowance rate for PRU patents is only 42.8%. Patent applications by academic superstars are therefore 13.8% less likely to be granted than those by non-superstars.

We find similarly striking results in column 2. Prior patenting experience is *positively* correlated with the likelihood of issuance, except for academic superstar inventors. A 100% increase in prior patents corresponds to a 6.1 (p<0.001) percentage point increase in the likelihood of grant for non-superstars, but a 4.4 (p<0.001) percentage point decrease in the likelihood of grant for superstars. In keeping with column 1, an academic superstar is 4.5 (p<0.05) percentage points less likely to be issued a patent. In column 3, we find that prior licensing experience is not significantly correlated with the likelihood of patent grant.

In columns 4-6, being an academic superstar is not a significant predictor of increased lifetime licensing revenue for a patent application. Interestingly, whereas prior patenting experience is positively and significantly correlated with patent application issuance (column 2), it is negatively and significantly (6.9 percentage points, p<0.05) correlated with lifetime revenue (column 5). Patenting experience thus seems helpful when preparing subsequent patent applications that will ultimately issue, but does not help to secure a license. Similarly, whereas prior licensing experience is not a significant predictor of patent issuance (column 3), the presence of a prior license is associated with a 15.6 percent (p<0.001) increase in average lifetime revenue for a subsequent patent application. However, the effect is more than eliminated for academic superstars. An academic superstar who has previously licensed a patent will on average generate 19.2 percent (p<0.01) *less* revenue for a subsequent patent than a superstar who has not previously licensed.

Overall, Tables 3 and 4 reveal several interesting patterns. First, as mentioned above, the PRU TTO seems to be learning from rare but valuable successes by filing patent applications by academic superstars, particularly those with prior patenting and licensing experience (in accordance with early successes at PRU). Second, the selection criteria apparently employed by the PRU do not seem to be predictive of future licensing successes. Thus, in keeping with the literature on learning from rare events (Zollo, 2009; Lampel, Shamsie & Shapira, 2009), the rarity of successful licensing outcomes seems to have resulted in a selective and biased interpretation of the causes of those successes. Third, we find evidence that patenting and licensing represent two distinct dimensions of experience for academic entrepreneurs, and that success at one does not predict (and is even inversely correlated with) success at the other. Collectively, the results presented in Tables 3 and 4 broadly support Hypothesis 3, that characteristics of early successes by PRU are likely to be mirrored in the filing decisions for subsequent patent applications but are unlikely to be predictive of future commercialization success.

Finally, since the count of forward citations is a commonly used measure of innovative impact, we compute a count of forward citations for each of the patents in our sample.[13] Table 5 reports OLS regression estimates of licensing outcomes as a function of forward citations. Consistent with the findings of Ziedonis & Sampat (2004), we find that forward citations are highly predictive of patent licensing (though of course forward citations are not known by the TTO manager at a time contemporaneous with our key predictor variables: inventor commercial experience and academic eminence, and so will not be of use in predicting commercialization outcomes). In column 1, a doubling of forward citations is associated with a 3.8 percentage point (p<0.001) increase in the probability that the patent is licensed, which is economically significant since only eight percent of patents in the sample are licensed. We also find that forward citations

[13] We include in the count citations made to a patent's pre-grant publication (PGPub) along with citations made to the granted patent, following Kuhn, Younge & Marco (2020). In recent years, nearly 50% of patent citations are made to PGPubs, so failing to count these citations would omit a significant portion of the data.

predict lifetime revenue – in column 3, a doubling of forward citations is associated with a 44.1% ($p<0.001$) increase in lifetime revenue. This result differs from those of Ziedonis & Sampat (2004), who find that forward citations do not predict licensing revenue; the difference may be due in part to our larger sample size and longer sample period.

5. DISCUSSION

Hybrid organizations are becoming more pervasive in the 21st century economy and society. We take a deep dive into a single prominent research university's experience in technology transfer operations over a 30-year period to better understand resource allocation decisions in an organization with a pluralistic mission (deriving social and private value from technology commercialization efforts). A unique feature of the university TTO context is that the patent value distribution is extremely skewed (the top 15 licensing transactions account for 81% of the total entire patents value), which has implications for TTO managers' ability to learn from rare events.

Our main results are that: (1) in the face of dual missions, one of which is difficult to measure (i.e., public good value), TTO managers' resource allocation behavior seems more aligned with the mission which is easier to observe and measure (i.e., promoting private value); and (2) in the face of the skewed distribution of patent outcomes, learning from rare events is difficult, and there is the risk of erroneously learning from a small but influential sample of prior successful cases.

Given the historic importance of academic status in the research university context, even before TTOs emerged as hybrid organizations in universities, perhaps it is not surprising that there is a significant association between academic superstars, especially those with commercial experience, in patent application filings at PRU. However, when we examine correlates of commercialization success, academic superstars are *negatively* associated with patent grants and uncorrelated with lifetime revenues. Indeed, academic superstars with prior patents tend to fare even worse with respect to patent grants, and such stars with licensing experience are negatively related to lifetime revenues. The fact that 40% of the top 15 most financially successful deals (with 13 of those deals occurring in the first half of the sample period – i.e., the "learning" period in our analysis) involved academic stars at PRU may have also reinforced the significant academic stars representation among patent applications – and is consistent with an overlearning phenomenon.

The relative over-representation of stars at the application stage but not at the patent grants stage may suggest two very different interpretations. First, it could be the case that academic stars, who likely command substantial power and status at the PRU, may be difficult to withhold resources from upon invention disclosure (even if TTO managers are privately pessimistic about the patent application). Under this scenario, it may be the case that TTO managers would prefer that a negative decision come from the external U.S. patent office rather than from the internal TTO. A second possibility is that the TTO managers rely on academic status as a proxy for likely commercial quality (and the managers do not have superior independent information relative to the inventors). Although we are unable to empirically distinguish these two different explanations, we put more stock in the second explanation due to both the span of embryonic discoveries covered in the typical research university (making TTO commercial potential foresight very difficult) and the high cost (including opportunity costs) in allowing the external patent office reject a patent application the TTO already knew had low potential. If that is the case, then one implication of our findings is that academic research which is at once motivated by advancing basic understanding and takes into consideration practical use (Pasteur's Quadrant) is actually quite difficult in practice. Rephrased, successful scientific hybridity may be much more difficult than specializing in either basic or applied research.

Our results also have two implications for TTO managers. First, TTO managers should be made aware that anchoring on their salient prior commercialization events may not be representative of the full distribution of possible future outcomes, and that there may be a bias in patent applications toward academic stars. Some of this TTO managerial behavior may also be somewhat unconscious, making an explicit discussion valuable. Second, there may be a mismatch between participants' objectives in commercialization efforts. Through a survey of 62 US TTOs questioned about their operations in the 1991-1995 period, Jensen & Thursby (2001) report that 71% of surveyed TTO officers stated that royalties and license fees are "extremely important" measure of licensing success, but only 41% of faculty said the same.

On the other hand, 73% of faculty said “sponsored research funds” is an extremely important measure of licensing success (versus 34% of TTO officers saying the same). This divergence, if also true at PRU, may help explain the disparity in correlates of patent application as compared to commercialization outcomes. One implication is that not only should the mission(s) of the TTO be clearly articulated, incentives for the parties should take into account possibly different objectives for the parties’ participation in the first place.

Our study, while broadening the work in the internal management and resource decision-making of hybrid organizations, also contain several limitations and domains ripe for future study. Among the highest priority domains is a better understanding of how the potential licensees factor into the resource allocation process. A second area relates to the generalizability of our findings. For example, would we see the same findings in a hybrid, for-profit organization such as a B- Corporation? Corporate venture capitalists also face a dual mission (invest in companies with both strategic value as well as offer a financial return). In addition, venture investing also has parallel characteristics of learning from rare events, as a relatively small number of investments make up the majority of overall returns in the industry. There is much work ahead for this field; we hope that this initial effort spurs others to better understand the organization and management of hybrid organizations.

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Table 1: Descriptive statistics.

Variable	Definition	Mean	S.D.	Min	Max
Year	Year	2000	8.94	1985	2015
Filed?	Was a patent application filed?	0.049	0.22	0	1
Issued?	Was a subsequently-issued patent filed?	0.022	0.15	0	1
Licensed?	Was a subsequently-issued and licensed patent filed?	0.004	0.06	0	1
Lifetime Revenue	Total revenue ($M) from filed patents	2.816	206.39	0	22,512
Career Length	Years since first application filing or paper publication	8.130	11.28	0	54
Prior Applications	Count of previously-filed patent applications filed	0.676	2.39	0	152
Prior Patents	Count of previously-granted patents	0.289	1.51	0	94
Prior License?	Has the inventor previously licensed a patent?	0.073	0.26	0	1
Academic Superstar?	In top 5% of JIF-weighted publications?	0.050	0.22	0	1
Observations		141,453			

Notes: Observations are at the inventor-year level.

Table 2: Correlation matrix.

	1	2	3	4	5	6	7	8	9	10
Year 1										
Filed? 2	0.12									
Issued? 3	0.06	0.65								
Licensed? 4	0.01	0.28	0.32							
Lifetime Revenue 5	-0.00	0.06	0.09	0.21						
Career Length 6	0.42	0.04	0.03	0.02	-0.00					
Prior Applications 7	0.24	0.18	0.15	0.04	0.01	0.31				
Prior Patents 8	0.12	0.08	0.08	0.03	0.01	0.28	0.85			
Prior License? 9	0.25	0.07	0.05	0.03	-0.00	0.24	0.26	0.17		
Academic Superstar? 10	0.00	0.09	0.06	0.04	0.01	0.37	0.21	0.15	0.09	
Year 11	1.00	0.12	0.06	0.01	-0.00	0.42	0.24	0.12	0.25	0.00

Table 3: Correlates of application filing (inventor-year observations).

	(1)	(2)	(3)
Career length	-0.002^{***}	-0.002^{***}	-0.001^{***}
	(0.0001)	(0.0001)	(0.0001)
Post	0.081^{***}	0.084^{***}	0.085^{***}
	(0.002)	(0.002)	(0.002)
Academic Superstar (AS)	0.102^{***}	0.054^{***}	0.041^{***}
	(0.005)	(0.005)	(0.006)
Prior patents	-0.110^{***}	-0.055^{***}	-0.066^{***}
	(0.003)	(0.004)	(0.005)
Has Licensed	0.034^{***}	0.064^{***}	0.054^{***}
	(0.003)	(0.009)	(0.009)
Post * Academic Superstar (AS)		0.084^{***}	0.050^{***}
		(0.006)	(0.006)
Post * Prior patents		-0.065^{***}	-0.061^{***}
		(0.004)	(0.004)
Post * Has Licensed		-0.033^{***}	-0.032^{***}
		(0.008)	(0.008)
AS * Prior patents			0.042^{***}
			(0.006)
AS * Has Licensed			0.086^{***}
			(0.010)
Observations	141,453	141,453	141,453
Adjusted R^2	0.087	0.090	0.091

Sample includes all inventor-year observations from 1986-2015. All models include inventor fixed effects. *Career length* counts years since first patent application filing or paper publication. *Academic Superstar* indicates whether the inventor was in the top 5% for prior publications, weighted by journal impact factor, for that year. *Prior applications* and *Prior patents* are logged. Two-tailed tests in parentheses ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

Table 4: Correlates of patent outcomes (inventor-application observations).

	Issuance			Lifetime revenue		
	(1)	(2)	(3)	(4)	(5)	(6)
Career length	0.002^{**}	0.0005	0.001^{*}	0.001	0.003	-0.0004
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Academic Superstar (AS)	-0.059^{***}	-0.045^{*}	-0.066^{**}	0.009	0.039	0.071
	(0.017)	(0.020)	(0.021)	(0.039)	(0.046)	(0.048)
Prior patents		0.061^{***}			-0.069^{*}	
		(0.014)			(0.032)	
AS * Prior patents		-0.044^{**}			-0.006	
		(0.017)			(0.038)	
Has Licensed			0.018			0.156^{***}
			(0.017)			(0.039)
AS * Has Licensed			0.008			-0.192^{**}
			(0.030)			(0.067)
Observations	8,388	8,388	8,388	8,388	8,388	8,388
Adjusted R^2	0.091	0.093	0.091	0.039	0.041	0.041

Sample includes all inventor-application observations for applications filed from 1986-2015. All models include year fixed effects. *Career length* counts years since first patent application filing or paper publication. *Academic Superstar* indicates whether the inventor was in the top 5% for prior publications, weighted by journal impact factor, for that year. *Prior applications* and *Prior patents* are logged. Two-tailed tests in parentheses ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

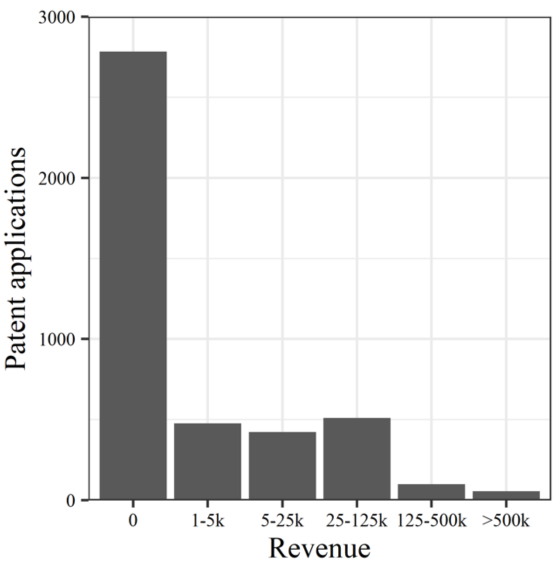
Table 5: OLS models predicting licensing outcomes from patent citations.

	Licensed? (all patents)	Lifetime revenue (all patents)	Lifetime revenue (licensed patents)
	(1)	(2)	(3)
Forward citations	0.038***	0.220***	0.441**
	(0.008)	(0.038)	(0.144)
Constant	0.007	0.174	5.221**
	(0.101)	(0.468)	(1.909)
Observations	1,189	1,189	145
Adjusted R^2	0.081	0.084	0.039
F Statistic	4.470***	4.617***	1.225

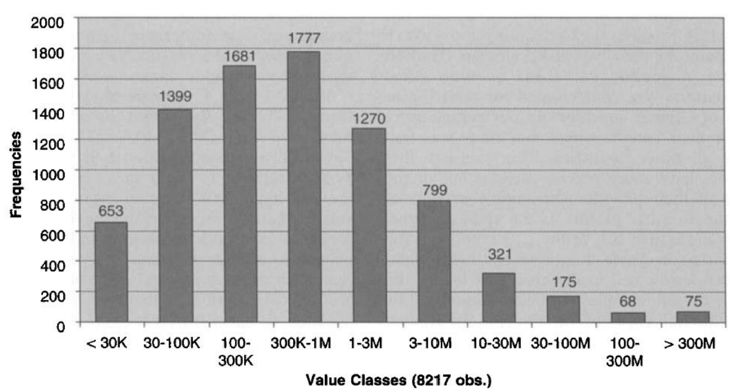
Sample includes all original patents filed from 1986-2015. All models include year fixed effects. *Forward citations* and *Revenue* are zero-inflated and logged. Two-tailed tests in parentheses ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$).

Research is inspired by:		*Consideration of use?* No	Yes
Quest for basic understanding?	Yes	Pure basic research (Bohr)	Use-inspired research (Pasteur)
	No		Pure applied research (Edison)

Figure 1: Pasteur's Quadrant (reprinted from Stokes, 1997, p. 73).



(a) PRU licensing revenue



(b) PatVal-EU (reproduced from Gambardella et al., 2008)

Figure 2: Distributions of patent value.

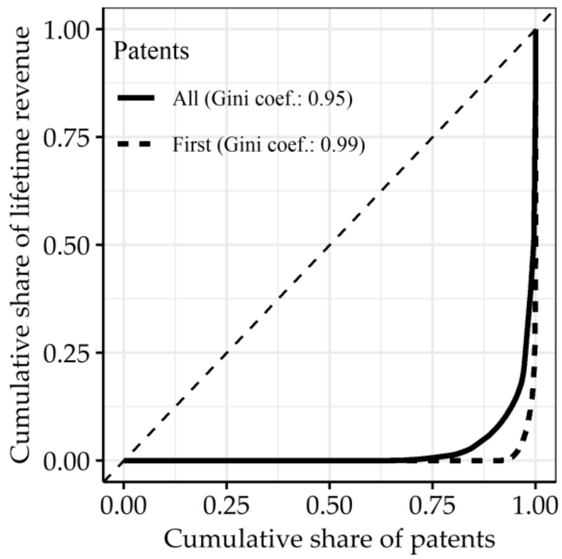


Figure 3: Lorenz curve of revenue distribution across patent applications at PRU. The "First" curve limits the data to the first-filed patent associated with each license.

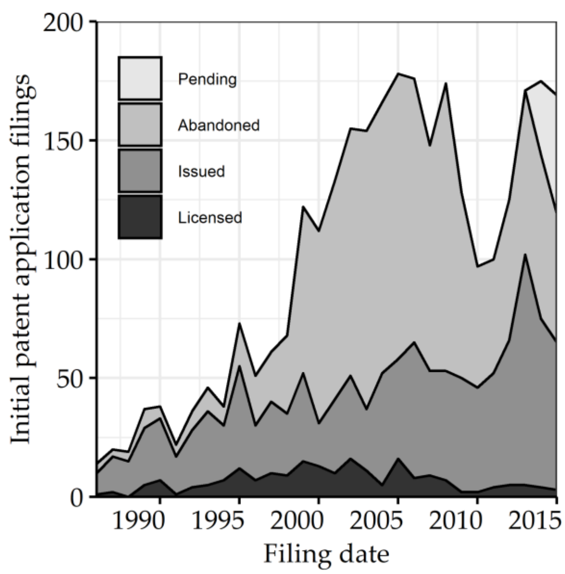


Figure 4: Patent applications by outcome at PRU.