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ABSTRACT

This paper considers the role of Rosenbergian uncertainty (i.e., economic uncertainties that arise after successful invention) in shaping appropriability for start-up innovators. Rather than assuming that the appropriability regime surrounding an innovation is exogenous, we focus on the endogenous choice entrepreneurs face between investing in ensuring control-based appropriability versus investing in the execution and operation of their fledgling businesses. Investment in execution allows entrepreneurs to advance more quickly than competitors, while control requires delays in commercialization. Control and execution are strategic substitutes as they represent alternative paths to earning future rents. Because the size and likelihood of these rents is uncertain, entrepreneurs may be unable to rank these alternative paths in advance, and so their endogenous choice will be grounded in factors such as individual preferences, capabilities, or coherence with their overall entrepreneurial strategy. A subtle consequence is that the appropriability regime ultimately governing an innovation will be the result of the endogenous choices of the entrepreneur rather than more traditional environmental factors. Motivated by notable historical examples such as the invention and commercialization of the telephone, we explore these ideas by considering the choice of appropriability regime among a sample of academic entrepreneurs: within a sample of ventures that could have been developed by either faculty or students (or both), we find that faculty-led ventures are much more closely associated with formal intellectual property, student-led ventures are more rapid in their commercialization activities, and, relative to faculty-led ventures, student-led ventures display a tradeoff between patenting and commercialization speed.

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“...social change or economic impact is not something that can be extrapolated out of a piece of hardware. New technologies, rather, need to be conceived of as building blocks. Their eventual impact will depend on what is subsequently designed and constructed with them. New technologies are unrealized potentials that may take a very large number of eventual shapes. What shapes they actually take will depend on the ability to visualize how they might be employed in new contexts.”

Rosenberg, “Uncertainty and Technological Change,” 1994

1 Introduction

Perhaps the two most distinctive elements of technological innovation are an inherent degree of uncertainty at the time of invention and an uneven level of appropriability for inventors (Arrow, 1962; Nelson, 1959). While these defining features of innovation have long been recognized, their interplay is subtle. Specifically, when considering the degree of appropriability for an innovation, most research takes the conditions determining appropriability – such as the strength of formal intellectual property protection – to be exogenous to the innovator (e.g., Cohen, Nelson, and Walsh, 2000). When the appropriability regime is exogenous and known, innovators will choose strategies that allow them to create and capture value from their innovation, taking into account the interplay between the appropriability environment and the distribution of complementary assets (Teece, 1986; Gans & Stern, 2003).

The presence of uncertainty, however, reshapes that calculation. As emphasized eloquently by Rosenberg (1994), the uncertainty associated with technological change goes beyond the consideration of technological uncertainty (does a new technology work?) but touches instead on “uncertainties of a specifically economic nature” (Rosenberg, 1994, p. 92): conditional on success, innovation involves significant uncertainty about the overall prospects for the technology in the marketplace and in the context of specific applications. But, if innovators cannot accurately forecast the applications of their innovation, including such “details” as the size of the market or the underlying cost structure once scale has been achieved, their ability to undertake a cost-benefit analysis that compares alternative commercialization strategies will be extremely limited. More to the point, if achieving a given level of formal appropriability requires resources (e.g., the costs of patent application and prosecution), and the value of formal appropriability depends on the firm’s overall entrepreneurial strategy (i.e., its overall choices for testing ways to create and capture value), then the appropriability regime governing an innovation will depend not only on the

“exogenous” environment facing the innovator but as well on their endogenous choices in choosing the environment within which to apply their innovation.

The objective of this paper is to explore the endogeneity of appropriability, and its connection to entrepreneurial strategy, in a more systematic way by considering the role that Rosenbergian uncertainty plays in shaping appropriability and entrepreneurial strategy. Because of its inherently exploratory nature, we will take a multi-pronged approach, including a Rosenbergian grounding in historical cases, the development of a conceptual framework, and an exploratory empirical approach for evaluating the endogeneity of appropriability in a more systematic way.⁵

We begin in Section 2 by drawing on an historical episode that vividly encapsulates the potential endogeneity of appropriability – the invention of the telephone. While the formal intellectual patent protection secured by Bell served as the cornerstone for the AT&T monopoly, the potential effectiveness of intellectual property (and the ability of an entrepreneur to compete against Western Union) was not at all clear at the time that Bell and Western Union were having to make key strategic commitments. Rather than a failure of corporate imagination, the case of the telephone highlights how economic uncertainties rendered endogenous key aspects of appropriability and linked the choice of appropriability to other elements of Bell’s overall entrepreneurial strategy.

This episode motivates the development of our core conceptual framework in which we consider the role of uncertainty in shaping the endogeneity of appropriability more fully. We consider a simple framework in which entrepreneurs must not simply invest in maximizing the level of appropriability that they can get for their innovation, but must choose how to compete, a strategic tension we frame as *Control* versus *Execution*. In contrast to a related choice of with whom to compete (see Teece, 1986; Arora, Fosfuri, & Gambardella, 2001; Gans & Stern, 2003), this choice involves what investments an entrepreneur makes to shape the nature of future competition they might face. Specifically, entrepreneurs choosing Control invest in activities

⁵ A short companion paper, Gans and Stern (2017a), outlines the key theoretical issues that arise when considering the trade-off between control and execution; this paper grounds that theoretical work in the phenomena, clarifies the crucial role of Rosenbergian uncertainty in the process of strategic choice, and provides exploratory evidence consistent with the main predictions of the theory.

designed to prevent future competition (e.g., intellectual property, non-competes, disclosure restrictions) while investing in Execution involves the development of capabilities designed to allow them to secure rents against future competition. While both paths have the same objective (the securing of future rents), these strategies involve different costs. The costs of Control are upfront, and involve delays in market entry but the benefit of a “quiet life” once control has been secured. In contrast, execution involves early market entry and learning allowing a start-up to “get ahead and stay ahead” against potential future competitors.

Rosenbergian uncertainty offers an important insight into strategic choice: while it may be possible to adjudicate the near-term costs and benefits of these alternative strategies, the overall rents to be earned (and the relative likelihood of success of each approach) is shadowed by uncertainty at the time that a choice has to be made. Consequently, rather than choice being driven primarily by the overall environment, near-term and idiosyncratic costs and benefits are influential in the choice of an appropriation path. Building on our broader agenda in entrepreneurial strategy (Gans, Stern, and Wu, 2018), we demonstrate that the choice of appropriability strategy will be linked to other elements of entrepreneurial strategy, including the identity and preferences of the founder, the choice as to whether to target a narrow early adopter customer base or the mass market, and the choice of the mix between exploration versus exploitation along technological trajectories.

We build on these insights to develop specific predictions that motivate our main empirical exercise. Our framework suggests that distinctive entrepreneurial traits may direct entrepreneurs to choose between control versus execution, even controlling for the overall type of innovation. For instance, older innovators who also have a broader agenda beyond entrepreneurship will tend to both have the patience to wait for delayed market entry and may also shy away from ongoing activity costs associated with execution (analogously, younger entrepreneurs with lower opportunity costs of time might favor execution over control even when formal intellectual property rights are available).⁶ In other words, the endogenous nature of appropriability yields some specific predictions: who the entrepreneur matters for ex-post realizations of the appropriability regime that governs the innovation.

⁶ We acknowledge that these different choices may also reflect behavioural differences that arise from differences in experience or beliefs. For example, older innovators or faculty members may simply believe that patenting is more important.

We test out these ideas in an exploratory yet hopefully instructive empirical examination. Specifically, both our qualitative evidence and model emphasize that various aspects of appropriability will be shaped not simply by the underlying exogenous environment but also by more internal factors such as the identity of the entrepreneur. To disentangle the role of the environment from the attributes of the entrepreneur, we consider an empirical setting where we can (at least in principle) separate out the “idea” from the chosen approach to appropriability: innovations whose core idea is originally disclosed in the form of an academic publication co-authored by a faculty member and student, and then subsequently serves as the foundational technology for a start-up company. “Paper-startup” pairs are quite common (e.g., Google, Genentech, Akamai), and we gather a small but informative sample of firms whose origin lies in an academic paper. We use this sample to examine whether, after controlling for attributes of the “idea” observable in the underlying paper, the identity of the founder (faculty versus student) has an influence on the subsequent approach to appropriability and time to market. The results, though exploratory, are striking: faculty-led start-ups are nearly twice as likely to obtain formal intellectual property protection for their ideas, while student-led start-ups are significantly faster in achieving key commercialization milestone such as firm founding (relative to the publication date of the paper), first financing (relative to the publication date of the paper), and even first product market introduction. As well, relative to faculty-led ventures, student-led ventures display a timing pattern consistent with a strategic tradeoff between patenting and speed. While recognizing the limitations of this exploratory dataset, our study suggests that there exist significant differences between founder types and strategic behavior among “similar” types of ventures in academic entrepreneurship. More generally, our results are consistent with the idea that, in addition to more traditional environmental factors that shape appropriability, the appropriability regime that we observe for start-up innovators is shaped by the choices and circumstances of invention and a founder’s overall entrepreneurial strategy (Gans, Stern, and Wu, 2018). As such, it may be constructive for researchers to more clearly distinguish between the role of the microeconomic and strategic environment in shaping strategy and performance versus the role that choice among uncertain alternatives plays in shaping the environment in which innovations are commercialized.

The next section motivates our study by examining the strategic impact of the Rosenbergian uncertainty accompanying the introduction of the telephone. We then use this historical episode to develop an illustrative conceptual model in Section 3 that highlights the potential for a strategic tradeoff between control and execution. Section 4 then builds on this logic by describing our small dataset of paper-startup pairs and exploring the relationship between patenting, commercialization timing, and founder identity. A final section concludes.

2 Rosenbergian Uncertainty and the Case of the Telephone

To fix ideas, let us consider an historical episode often emphasized by Rosenberg: the case of the telephone (Rosenberg, 1994; Smith, 1985). While the concept of transmitting voice communication through wires had been explored since shortly after Faraday’s initial experiments with electricity, the race to invent and commercialize the telephone did not heat up until the mid 1870s when a Boston University faculty member Alexander Graham Bell, raced with Elisha Gray of Western Electric, the key technology supplier to the dominant telegraph company Western Union. Bell famously submitted his patent application – Improvements in Telegraphy – hours before Gray’s submission of an initial patent “caveat” (what we would refer to today as a provisional patent application).⁷

However, it is not the race to the patent office that we focus on, but on the different entrepreneurial strategies pursued respectively by Bell and Gray after their initial inventive burst. While Bell was a deliberate, highly educated inventor who engaged in the majority of the research on telephony as a Professor of Vocal Physiology at Boston University, Gray was much more of a hustler who had been deeply involved in direct commercialization activities through companies he founded. Where Bell (and his initial investor (and future father-in-law) Gardiner Hubbard) focused the bulk of their energies on securing effective intellectual property around the underlying principles of telephony (but were relatively indifferent as to whether their return was achieved through cooperation or competition with Western Union), Gray was integrated deeply from the

⁷ To be clear, under the “first to invent” doctrine at that time, this race to the patent office itself had little legal consequence, but does highlight the intense race between Bell and Gray over establishing priority over the invention of the telephone.

outset into the value chain established by Western Union and the ability to scale the technology quickly by leveraging its complementary assets. Rosenberg (1994) of course emphasized in a pointed way some of the more telling aspects of this case, including (a) the refusal of Western Union to purchase the pending patent rights of Bell for \$10,000 (or \$100,000, depending on the source material), and (b) the ultimate agreement (after the patent dispute had been decided in Bell's favour) to have Bell agree to stay out of the telegraph business if Western Union agreed to stay out of the telephone business (Rosenberg, 1994, p.4).

We would, however, take this analysis further to highlight a few key puzzles of this episode. First, while the refusal of Western Union to purchase the Bell patent has often been highlighted as a failure of corporate imagination on the part of an incumbent (Smith, 1985), it is equally and perhaps even more noteworthy that Bell and Gardiner were willing to sell the patent in the first place. To be concrete, their offer (which presumably could also have been negotiated) represents their assessment of the possible value to be captured from the innovation at the time; even if they placed only a modest probability on successfully securing the key patent (say 50%), that implies that their valuation of the prospects of the Bell System at the time of invention were many orders of magnitude below what the realized return on the innovation would be. Second, as emphasized in the longer treatment in Smith (and commentary by, for example Malki, 2015), the key point of contention between the president of Western Union William Orton and Bell was not so much the overall value of telephony but instead whether Bell's patent-oriented appropriation strategy was worth anything. According to a potential investor Chauncey Depew who was dissuaded from investing in Bell by William Orton, Orton simply emphasized that "if there was any merit to the thing, the Western Union owned the Gray patents and would simply step in, superseding Bell, and take the whole thing away from him" (Malki, 2015). Indeed, rather than simply ignoring Bell, Western Union undertook a vigorous program of moving forward rapidly with significant improvements in telephony (including hiring Thomas Edison to develop a work-around to subvert the Bell monopoly) and, most importantly, leveraging the complementary assets of Western Union to simply overwhelm the nascent American Telephone and Telegraph through implementation and scale (Smith, 1985). Simply put, by bringing the telephone to market quickly by leveraging their existing complementary assets. the refusal by Western Union to license the patent at an early point

in time was perhaps less a failure of corporate imagination than a bet on an alternative (and, indeed, quite Teecean) strategy.

We aim to highlight three key insights from this important (and perhaps not so unique) episode of nearly simultaneous invention followed by the pursuit of alternative entrepreneurial strategies. First, the case of the telephone highlights the process by which the process of successful invention inevitably and inherently ushers in a new type of “uncertainties of a specifically economic nature” and that, rather than reducing the level of ambiguity in the environment, successful invention is the moment at which it becomes feasible to contemplate alternative applications and markets for a new technology in a meaningful (yet still highly uncertain) way.

Second, at the time of successful invention, it is possible for innovators and entrepreneurs to conceptualize multiple alternative paths towards successful commercialization, and importantly only a subset of these rely on either traditional tools for appropriation such as patents or alternatively reliance on the leveraging of existing stocks of complementary assets. In the case of the telephone, Bell focused on an approach emphasizing independent invention and the securing of intellectual property rights (with the degree of cooperation with Western Union to be determined later), while Elisha Gray focused on an approach that was premised on collaboration with Western Union (with patents as a useful tool that nonetheless was not central to the strategy). Importantly, at the time that the decision-makers were making choices, they had available to them information about the relative near-term costs and benefits of individual decisions (e.g., the costs of obtaining the patent, the cost of beginning to build out a commercial salesforce), but had little ability to assess the long-term impact of the innovation (neither Bell nor Western Union believed the Bell patent to be worth more than \$100,000).

Finally, though the appropriate counterfactual is of course difficult to establish, the telephone case does suggest that rather than simply being alternative elements of an overall approach, the Bell and Western Union approaches were substitutes (at least on the margin) in terms of where resources and attention were allocated. If Western Union had appreciated the likely strength of Bell’s patent, then they surely would have been willing to purchase it at an earlier stage, and at the same time, Bell’s investments in control over his innovation seems to have come at the expense of his ability to compete quickly and adeptly with Western Union from 1877 through 1879.

Indeed, the generous terms of the Bell-Western Union Patent Agreement of 1879 (where Western Union received a 40% equity share in Bell in addition to their willingness to foreclose future activities in telephony) reflects the recognition that whereas Bell had “won” control over the technology, it was nonetheless the case that Western Union had established a much greater presence at that point in the market. Together, these considerations point towards a more general if speculative conclusion: rather than simply reflecting appropriate strategies and tactics within an exogenous and known appropriability regime, the appropriability regime that was ultimately established for the telephone depended critically on the endogenous choices and idiosyncratic circumstances of the innovators and commercializers of the technology itself.

3 How to Compete: Control Versus Execution

Since Teece (1986), the study of appropriability has centered largely on why and when innovators would generate sustained profits from their innovation, with a particular focus on the interplay between the appropriability regime and the distribution and specialization of complementary assets.⁸ By and large (and with some important exceptions as noted below), the large literature spawned by Teece (1986) takes the appropriability regime as (at least for a specific innovation) exogenous, in the sense that an individual innovator (and certainly an entrepreneur) chooses a strategy conditional on the appropriability regime governing the innovation rather than the main focus being the choice of appropriability regime itself. By linking strategy to innovation through this important insight, Teece (1986) triggered a wide-ranging yet structured exploration of the connection between firms’ strategies, innovation, and appropriability.⁹

⁸ By appropriability, we simply refer to the degree to which a firm captures the value created when it introduces innovations. For example, in “weak” appropriability regimes, innovators would need to rely on “co-specialized assets” to protect their innovation from imitation and protect their innovation rents. On the other hand, in strong regimes, firms could rely on licensing and other contractual arrangements to extract rents from their innovation without access to such assets. Building on the seminal Teece framework, scholars have developed a broad and influential range of work on research and practice (see Winter 2006 for a review).

⁹ This agenda is quite broad and includes important contributions and insights into transaction cost economics, evolutionary economics, and law and economics. For example, it is this framework which underlies the significant literature developed over time into the conditions supporting a market for technology and the factors shaping the boundaries of innovating firms (Arora, Fosfuri, & Gambardella, 2001, 20014; Cassiman & Veugelers, 2002; Gans & Stern, 2003).

We build on this but argue (consistent with Gans, Stern, and Wu (2018)), that, for many entrepreneurs, there are multiple paths to creating and capturing value. In particular, entrepreneurs face a choice in *how* to compete with a focus here on the ability to compete through control over an underlying idea versus execution of that idea (perhaps at the expense of control). While it may be the case that for some innovations, methods for control (e.g., intellectual property protection) may be unavailable or imitative competition may be so strong that execution is insufficient to generate rents, often both paths will exist and the entrepreneur can choose which direction to invest in. That they must choose arises because entrepreneurs both have limited resources for such investments and cannot easily grapple with embarking on two paths to the same end in a way that makes their strategic choices coherent. Hence, they will be faced with a choice between one path or the other.¹⁰

A key feature of the choice that makes it a difficult one for entrepreneurs is the presence of uncertainty. And not just the usual uncertainty but uncertainty that is of what we term “Rosenbergian Uncertainty.” Rosenberg (1994) focuses on explicating uncertainties of a “specifically economic nature” (page 92). In so doing, he clarified other dimensions of uncertainty, including that on the technological improvement (and use), the need for complementary technologies, and the identification of market needs. Their existence highlights how innovators cannot precisely forecast the impact of their innovations or the level of appropriability they will enjoy, even after pure technological uncertainty has been resolved.

Scholars have built on this theme in articulating how the uncertain nature of innovations lends to the immense difficulty for entrepreneurs to identify the market opportunities available. For example, in Shane’s (2000) study of the commercialization of a technology (three-dimensional printing) developed at MIT, of the eight entrepreneurs who sought to commercialize this technology, not one identified more than one market opportunity for the new technology because of their limited prior knowledge of customer needs in other markets. For instance, the entrepreneur who was familiar with orthopedics identified an opportunity in custom-fitted orthopedic devices for the medical market, whereas another entrepreneur with a background in architecture identified

¹⁰ Gans and Stern (2017) provide a more complete model of control versus execution, and provide conditions under which strategic substitutability arises between these paths.

an opportunity in creating models for architects. More recently, Gruber et. al. (Gruber, MacMillan, & Thompson, 2013) finds that across a sample of 496 technology ventures, founding teams vary greatly in the identification of market opportunities. Moreover, the extent to which these opportunities are identified depends on the founders' technological expertise, and those founders who consider a wider range of options are also able to realize higher performance. A key implication of these studies is not simply that entrepreneurs face uncertainty, but that entrepreneurs inherently face a choice about which of many paths to pursue. As such, the choice of how to commercialize the innovation – the appropriability regime – is *endogenous* to the choices and strategy of the entrepreneur.¹¹

Choosing an Appropriability Regime

To shed light on the potential trade-offs entrepreneurs face in their choice of appropriability, we develop a simple framework that explicitly considers the entrepreneur's choices of strategy (control vs execution) in executing on entrepreneurial opportunities. At the core of the notion of endogenous appropriability is that there is no single path to appropriation. Relative to most discussions of appropriability where the focus is on achieving the maximal level of protection from imitation, our focus here is on highlighting the potential for a strategic tradeoff between control-based appropriability and a more open execution-oriented approach.

In other words, we argue that entrepreneurs face a key strategic choice in choosing how to compete. The path of *control* involves taking pre-emptive actions to ensure that would be imitators face barriers in competing with the entrepreneur in the future. The most familiar means by which this takes place is patent protection that explicitly ensures that should an innovation prove out to be successful, others are prevented from competing with that innovation without the permission of the entrepreneur. However, one could also imagine control coming through secrecy that prevented

¹¹ We distinguish between the endogenous choice of appropriability regime, and how appropriability regimes may be endogenously influenced and determined by firms. As discussed in Pisano (2006), appropriability regimes may be endogenously influenced by the behaviors and strategies of firms themselves, such that firms may take their complementary asset positions as given, and then attempt to shape the appropriability regime to optimize the value of those assets. For example, embracing open source may allow firms to deliberately weaken the general appropriability environment faced by the rest of the industry, such that firms with greater strengths in downstream assets may benefit more by shifting the locus of value capture. This has been taken up in recent work on open innovation, developing both theory to suggest when firms should open (versus closed) forms of innovation to shape the appropriability regime they are facing (Felin & Zenger, 2014), and documenting evidence of managerial choice in relation to altering the level of legal appropriability in the face of industry level patterns (Laursen & Salter, 2014)

key knowledge from being exploited by competitors, employing non-compete and non-disclosure clauses, securing regulatory barriers that limited future entry into market and the leveraging of network effects that, in a closed platform, can create entry barriers. Control can also be achieved by embedding activities in complicated or complex organizations, such that organizational design can also be a choice that affects appropriability conditions.

Control is a strategy not without its costs. First, protection is rarely perfect. Even intellectual property protection faces uncertainty in the ability of the entrepreneur to navigate legal systems (Lemley and Shapiro, 2005). Second, to secure the elements of control often takes time and, as a result, market entry is likely to be delayed. Finally, investing in control can take explicit capital and human resources up front which may be particularly costly for liquidity constrained start-ups.

What is the alternative to control? Many start-up companies, excited by their idea and desirous of figuring out how to make their idea “better” through contact with real customers and the marketplace, prioritize the ability to popularize and test their ideas with others in the marketplace. In other words, rather than engage in overly complicated negotiations with anyone over issues of control, the founding team simply works with customers, suppliers, and investors who can contribute to the venture’s success, with issues of intellectual property or ultimate control over the “idea” put off for future discussion. This we refer to as an *Execution* orientation.

In many cases, this free form approach works. The entrepreneur will be actively searching for new information and flexibly adjusting activities and targets to this new information, testing and refining her idea in the marketplace. Scholars have documented that this behavior may be common in startup companies (Loch, Solt, & Bailey, 2008). This type of flexible adjustment to unforeseen changes has characterized the development of many breakthrough technologies such as for example, Corning’s fiber optics (Lynn, Morone, & Paulson, 1996), Apple and HP’s personal digital assistants (Leonard-Barton, 1995), and integrated circuit design (Thomke & Reinertsen, 1998).

Having economized on early flexibility, how can a start-up appropriate value from an *execution* approach, especially, as the approach opens up the market for future entrants? In many circumstances, a firm can earn significant quasi-rents in competition with other firms so long as

they have capabilities (e.g., cost or quality) that provide them a competitive advantage. Moreover, a firm can develop such capabilities through nurtured experience (Gans, 2017) allowing them to leverage those advantages over time. Such experience is gained by fast market entry and iterative experimentation that is that hall-mark of entrepreneurs focused on execution.

For example, Mark Benioff, the founder of Salesforce.com, has been a longtime evangelist of “The End of Software” and both he and his company have been relatively transparent about how they were going to deliver on the underlying value proposition of Software as a Service (SaaS). Salesforce.com scaled quickly and aimed to improve on their idea over time through experimentation, learning, and feedback from their core customers (which, importantly, were not in the earliest days the same customers as those of more traditional CRM software vendors). At the same time, it is useful to note that for certain startups, prioritizing “control” over the idea (either through an emphasis on trade secrecy or even through aggressive acquisition of intellectual property) would have significantly hampered their ability to engage a wide variety of early customers, and draw on that experience in refining their service offering and technology platform over time.

This strategic trade-off has been explored in other fields of strategy related literature. Scholars have examined mechanisms that underlie firms’ attempts to deter new entrants. Speed and Exclusion are two mechanisms that have been examined in some detail to explain why (see for example Lieberman and Montgomery 1988; Lee et. al. 2000). Speed deters through indicating lead-time in the development of resources, such that firms may be too late to follow suit even if they may be capable to. Exclusion deters through indicating exclusivity of resources such that firms may not be develop similar resources even if they are inclined to. In more recent work, Clarkson and Toh (2010) empirically examined the deterrence effects of these two mechanisms, explaining how resource heterogeneity among firms may be created through deterrence from technological spaces. We build on these literatures in advocating an analogous strategic choice tension for entrepreneurs.

3.1 A Framework

Consider an entrepreneur with a commercializable idea. The idea has potential value of v per period. An entrepreneur is interested in the share, $\alpha \in [0,1]$, of value they can capture. One path to appropriability is control. Control takes time to establish that delays market entry by t periods and involves upfront costs of c . The other path is execution that allows immediate entry but involves on-going costs of e ($< v$) in each period to reinvest and maintain capabilities. Thus, if the share, α_i where i is C (Control) or E (Execution) is known, the expected payoff (V_i) from each appropriation strategy would be:

$$V_C = \frac{\delta^t}{1 - \delta} \alpha_C v - c$$

$$V_E = \frac{1}{1 - \delta} (\alpha_E v - e)$$

where δ is the (common) discount factor. Given this, we can see that control will be chosen over execution if and only if:

$$V_C > V_E \implies (\delta^t \alpha_C - \alpha_E) v > (1 - \delta) c - e$$

Interestingly, this demonstrates that absent significant differences in costs (i.e., the right-hand side of the inequality), that the value captured from control needs to be significantly higher than that from execution to be the preferred strategy (i.e., $\alpha_C > \alpha_E / \delta^t$). This arises because the ability to earn rents at all is delayed by the investment in control.

3.2 Impact of Uncertainty

Thus far, we have treated key parameters as known. What happens if there is uncertainty regarding some of them? For instance, suppose that v is unknown; perhaps taking on a value of \bar{v} with probability p and otherwise having a value of \underline{v} where (a) $\delta^t \alpha_C (p \bar{v} + (1 - p) \underline{v}) > (1 - \delta) c$; and (b) $\alpha_E (p \bar{v} + (1 - p) \underline{v}) > e$. Suppose also that $\underline{v} < e / \alpha_E$ meaning that if the innovation has low value, the execution approach becomes unviable. Finally, suppose that uncertainty is resolved in the first period after market entry.

In this case, the expected payoffs become:

$$V_C = \frac{\delta^t}{1-\delta} \alpha_C (p\bar{v} + (1-p)\underline{v}) - c$$

$$V_E = \alpha_E (p\bar{v} + (1-p)\underline{v}) - e + p \frac{1}{1-\delta} (\alpha_E \bar{v} - e)$$

Thus,

$$V_C > V_E \Rightarrow (\delta^t \alpha_C - \alpha_E) (p\bar{v} + (1-p)\underline{v}) - p\alpha_E \bar{v} > (1-\delta)c - (1+p)e \quad (*)$$

This uncovers an additional cost associated with a control approach relative to execution: because the costs of control are upfront, founders cannot gain from learning the value of the innovation whereas under execution, learning the value of execution allows the entrepreneur to forestall additional costs (e) should that value turn out to be low. Thus, while uncertainty makes both approaches risky, the costs of uncertainty are relatively higher for the control approach precisely because costs are incurred regardless of its resolution.¹²

3.3 *Rosenbergian Uncertainty*

Rosenberg (1994) argues for appreciation of more fundamental uncertainty even after traditional technological uncertainty has been resolved. In particular, even after something has been shown to be feasible, there is deep uncertainty about both the value of the innovation per se as well as the shares that can be appropriated under control versus execution. In addition, it will make it difficult to even assign probabilities to different outcomes. Contingent, however, on the commercialization of innovation being viable even in the presence of such uncertainty, what interests us here is the impact on the choice between control and execution. To see this more clearly, consider the following formal definition of Rosenbergian uncertainty.

Definition. Rosenbergian uncertainty arises when it is not possible to rank the future profits from alternative strategic choices.

To be sure, it is often the case that there is enough information present that some strategic choices can be discarded. However, even after this process, some cannot be so easily dismissed. Formally, this means that the expected future payoffs from those choices are equivalent at the time a choice is being made. Importantly, this does not imply that the immediate implications of those

¹² Other extensions of this model can be found in Gans and Stern (2017).

choices (e.g., the costs associated with implementing them) are similarly unknown. Indeed, they may be very clear and hence, decisive in choosing between alternative options.

With respect to the choice between control and execution, if Rosenbergian uncertainty is present, then the future profits from each path cannot be ranked. Hence, those future profits cannot be decisive in the decision between them. Instead, what matters is the immediate implications of these decisions. In particular, the choice between control and execution will be driven disproportionately by the right-hand side of (*) where p is reinterpreted to mean the probability that the project remains viable upon the resolution of fundamental uncertainty. *In other words, the decision will be driven by the relative costs of each appropriation path, the impact of delay under control and the beliefs that learning can be utilized under execution.*

3.4 Entrepreneurial Strategy and Entrepreneurial Identity

Under Rosenbergian uncertainty, traditional environmental determinants of strategic choice – for example, the likely strength of formal intellectual property protection in the face of litigation – are likely to be relatively less important than more idiosyncratic near-term factors such as the capabilities, resources and personal objectives of the entrepreneur.

Consider, for example, the age of the entrepreneur. On the one hand, from a classical environmental perspective, the identity or personal characteristics of innovators should not be a predominant factor in explaining whether or not an innovation receives intellectual property or the speed of market introduction. However, in the model above, we can interpret the costs of execution (e), in terms of the opportunity cost of time of the entrepreneur. These costs will be lower for individuals who have the time and temperament to engage in hustle and quick responsiveness. As such, for a given invention, a younger entrepreneur might seek the execution-oriented path (placing less value on her time and putting a premium on the value of learning from actual market experience), a more established, older innovator might choose to pursue the more control-oriented path and seek to establish formal intellectual property protection for the idea (at the expense of speed).

Similarly, it is possible that the commercialization path pursued might reflect near-term institutional constraints rather than reflecting a decision as to which path maximizes long-term

economic value. For example, as we develop in our empirical setting, innovations that are first developed in a university setting place differential levels of constraint on the commercialization path for student versus faculty entrepreneurs. While faculty entrepreneurs are steered towards control-oriented strategies (e.g., through the policies of their technology licensing office), student entrepreneurs have more discretion about the degree to which a start-up leveraging academic research engages in formal university technology disclosure and intellectual property rights procedures. Put another way, faculty entrepreneurs supported by their universities to pursue control-oriented strategies face a relatively lower short-term cost of control (c).

To be clear, the proposed differences between, for example, younger or older researchers, or faculty versus students, may result from behavioural rather than objectively different costs and benefits. Younger innovators may simply “believe” that the costs of control are higher (or that the benefits are lower), and faculty may simply be unaware of how to go about the process of implementing an execution-oriented strategy. An interesting direction for research in this area will be to consider the interplay between objective versus more behavioural explanations for choice.

Putting these ideas together, the key implication of our analysis is to suggest that, in the face of Rosenbergian uncertainty, near-term idiosyncratic costs and benefits will loom large in the choice of how to commercialize, and that such costs are not entirely random but result in intuitive predictions about how the choice of commercialization path will be impacted by founder characteristics. In particular, our analysis suggests that, relative to faculty entrepreneurs, student entrepreneurs, with lower opportunity costs of time and with less prioritized access to university intellectual property institutions, are more likely to choose an execution-oriented strategy and faculty are more likely to pursue control-oriented approaches.

4 Paper-Startup Pairs: An Empirical Exploration

In the remainder of this paper, we explore these ideas empirically by considering the relationship between more control-oriented versus execution-oriented strategies in an exploratory way. While preliminary in nature, we argue that clarifying the nature of the empirical challenge and presenting preliminary empirical evidence is a useful first step for considering the endogeneity of appropriability more generally.

In particular, in an ideal setting, we would be able to observe a population of entrepreneurial “ideas” and then randomly allocate start-up firms to execute or control strategies for each of these ideas. We would then track related measures of entrepreneurial strategy and measure their impact on short-term and long-term performance. While this ideal set-up does not exist, we nonetheless leverage its key insights by focusing on a population of start-ups in which we are able to observe “ideas” independent of strategy, and for which there are natural sources of variation that might lead to the endogenous choice of execution versus control, even after accounting for the inherent nature of the underlying idea. In particular, we propose an empirical strategy based on a population of *paper-startup pairs*. A paper-startup pair describes an instance of an academic paper involving collaboration between faculty and student, and that ultimately serves as the anchor for a startup company (with involvement by the student, the faculty member, or both).¹³

Consider Ginger.io, a start-up from the MIT Media Lab. PhD student Anmol Madan was a researcher in big data analytics, and developed novel algorithms that measure exposure and adoption of opinions in social networks. In a paper published in 2010, he and his co-authors (including his PhD supervisor) proposed using mobile phone based co-location and communication sensing to measure characteristic behavior changes in symptomatic individuals. Using these extracted mobile features, they demonstrated that it is possible to predict the health status of an individual, without having actual health measurements from the subject. In January 2011, Anmol founded Ginger.io around the insights from his paper. His advisor was not part of the founding team and does not participate on the Scientific Advisory Board. Ginger.io rapidly garnered media attention as a high impact startup, as their technology allows pervasive yet non-invasive monitoring in patients.

¹³ Most research on academic entrepreneurship focus on inventions that result from the formal technology licensing process (Rothaermel, Agung, and Jiang 2007), and the role of faculty in that process (Dechenaux et al. 2008; Perkmann, et al, 2013). A more recent stream of work has turned attention towards the role of students in the commercialization of university innovations (Hsu, Roberts, and Eesley 2007; Eesley, Roberts, and Yang 2009), including the insight that start-ups by recent university graduates significantly not only outnumber those by faculty and staff (Astebro, Bazzazian, and Braguinsky 2012), but also achieve more impactful outcomes (e.g., in terms of equity growth or entrepreneurial earnings). For the purposes of the present study, we simply leverage the fact that, whereas faculty are both supported by and face incentives to engage with their TLO, students may neither have adequate access nor incentives to engage in the formal TLO process (Astebro et al. 2012).

In terms of our approach, the scientific discovery of Anmol Madan and his co-authors, has been instantiated as both a publication emphasizing its scientific contribution and as a firm emphasizing its utility. Even more critically, because the paper was co-written by the student and the faculty, the disclosed idea in the paper is at risk from being commercialized by the student and/or the faculty.

Two key complementary differences arise between a student-led versus faculty-led instantiation of this venture. On the one hand, whereas a faculty member has significant current job responsibilities (and a high opportunity cost of time) that limit the total level of marginal effort able to be devoted to the start-up, the relative costs of the execution strategy are higher for a faculty member than a student or recent graduate (who might indeed need some activity to keep them employed).

At the same time, universities governed under the Bayh-Dole Act have developed significant institutional structures that provide support for and incentives for researchers to disclose any inventions that will be commercialized to the university technology and licensing office (Mowery, Sampat, and Ziedonis, 2002; Thursby and Thursby, 2007; Astebro, et al 2012). By and large, the constraints for faculty researchers are binding: as an ongoing employee, a faculty member is subject to the administrative procedures of their university without recourse to costly external litigation or arbitration. Conversely, while students have the option of seeking the support and engaging with university TLOs, this constraint is far less binding: by and large, student entrepreneurs that do not seek formal intellectual property protection over their ideas are likely able to simply start a business without too much near-term scrutiny by the university.¹⁴ Put another way, our identification assumption is that, the passage of the Bayh-Dole Act has placed a much lower relative cost on Control for a faculty-led venture, while allowing significant discretion for student-led start-ups (even those that initially involved faculty involvement but for which the faculty member chooses to not be directly involved in follow-on commercialization activities).

¹⁴ A significant literature examines both the structure, incentives, and impact of technology transfer offices, and the role of the Bayh-Dole Act in encouraging their formation and growth. For an overview, see Grimaldi et al. 2011.

4.1 Implementing the Paper-Startup-Pairs Framework

The first step in our approach is to collect a sample of research papers with high potential for commercialization. We focus specifically on publications in the broad area of electrical engineering, gathering potential paper-startup pairs in two complementary ways. First, we scan the corpus of Institute of Electrical and Electronics Engineers (IEEE) journals and gather data regarding authors, affiliations and bibliometric information from *Scopus*. As well, we collect papers in the areas of electrical engineering, computer and statistical science from a set of high quality general interdisciplinary scientific journals including Nature, Science, Physical Review Letters and Proceedings of the National Academy of Sciences to supplement our core IEEE dataset.¹⁵

We focus on this area to capture emerging trends towards the commercialization of academic research in fields such as data analytics, mobile technologies, and software. Three key aspects of these fields are particularly appealing. First, relative to broad technology platform areas such as biotechnology or clean energy, many startups in these fields are organized around the discoveries embedded in a discrete (i.e., unique) academic paper, such as those that describe a new algorithm or statistical technique. For instance, Google was founded and anchored around the page rank algorithm, which was itself the subject of a core academic paper in the area of search (Brin and Page, 1998). As well, capital requirements in this area tend to be modest, and so these discrete discoveries often result in the development of a startup firm, and there are instances of both faculty-led and student-led entrepreneurial activity. Finally, formal intellectual property protection in the form of patenting is relatively common but not universal (i.e., some startups in this area rely on formal IPR and some do not). As a reference point, nearly 17000 patent applications in 2015 mention “algorithm” in their title or description (Laney, 2016).

Second, we identify startup firms formed off scientific disclosures in our universe of technical papers. To do this, we leverage Crunchbase, as this provides a convenience sample of early-stage startups which receive a round of early-stage funding and for which we can

¹⁵ IEEE produces over 30% of the world’s literature in the electrical and electronics engineering and computer science fields, publishing well over 100 peer-reviewed journals. In addition, IEEE also publishes an extensive set of conference proceedings in various fields and sub-fields. This is important as would-be inventors and entrepreneurs may choose not to disclose their inventions in full research papers, given the relatively longer publishing time.

systematically examine key founding information and also the nature of their underlying technology (i.e., we can see specific information about the overall technology base and strategy of the firm).^{16,17} We use the CrunchBase dataset to match names of paper authors with names of listed founders. The name matching procedures thus allows us to develop a dataset of potential startups, which may be instantiated off technical disclosures in papers and publications. We then refine this list by manual inspection, focusing on the specificity of the startup's technologies. Each startup-paper pair must satisfy two conditions. First, each company must reflect a narrow "idea" published in an academic paper. As such we do not consider companies that are too broad in scope where identification of the underlying technologies are not specific. Second and most critically, each paper must be a faculty-student collaborative paper. In other words, each paper must include at least one full-time faculty and one student at the time of publication. We also incorporate keyword matching, whereby keywords in the papers are cross-matched with description texts in the corporate websites.

We then trace the history of each startup and their founders. We collect key information, including their reliance on underlying technologies, year and month of founding, and funding histories. Using the Internet Wayback Machine, we then collect information about each firm's timing of the availability of their first product.¹⁸ When possible, we cross-reference the information using public incorporation data, SEC filings, public reports, LinkedIn public profiles and the corporate websites of the firms themselves. We then collect educational history about each founder, and other key staff members including the Chief Scientific Officer (or equivalent).

¹⁶ *CrunchBase* is an open-source database of technology companies and start-ups, which comprises around 500,000 data points profiling companies, people, funds, fundings and events. The website claims to have more than 50,000 active contributors. Members of the public, subject to registration, can make submissions to the database; however, all changes are subject to review by a moderator before being accepted. A significant limitation of these data are that they are self-reported and do not provide a comprehensive sample of all founded companies (i.e., Crunchbase only includes those companies for which information is recorded). Andrews, et al (2017) offer a useful contrast in the form of a comprehensive dataset of all registered firms, combined with data analytics to identify growth potential at the time of founding.

¹⁷ By construction, our sample is highly selective, both as we condition on the receipt of an initial round of venture capital financing and also focus only on startups formed between 2007 and 2014. We focus on this sample in order to identify a sample of firms connected to the academic literature where we are able to observe both detailed information about their founding team, their reliance on underlying technology, as well as intellectual property and commercialization milestones.

¹⁸ The Internet Wayback Machine is an Internet archival project, hosted at the University of California-Berkeley, that collects and stores the historical cached webpages of Internet websites. It can be accessed at www.archive.org

Specifically, we pay careful attention as to whether founders were faculty, students (or just graduated) at the time of founding. Finally, we supplement our data with patenting information from USPTO, as well as full publication histories for all founders using Google Scholar and Web of Science. Appendix Figure 1 summarizes this procedure for our construction of these paper-startup-pairs.

4.2 *Empirical Analysis*

The final sample consists of 103 firm-paper pairs, drawn across a narrow range of industry sub-sectors in the electrical engineering and computer science space (see Appendix Figure 2). Using (when possible) the self-reported industry classifications to Crunchbase, our sample is composed of firm primarily in analytics (60% of the sample) hardware (20%), as well as a smaller number of startups in semiconductors and mobile applications. Tables 1 reports variable definitions and summary statistics (Appendix Table 1 reports the pairwise correlation table).

The main goal of our empirical exercise is to relate faculty and/or student involvement to variables proxying for the theorized characteristics of firms practicing either Control or Execution oriented strategies. Our key independent variable is *STUDENT*, which describes if the founder of the firm is an active student at the University, at the time of company founding. It is a dummy variable equal to 1 if there exist founders in the companies that fit the description. As can be seen in Panel A of Table 2 about 45% of all companies had no faculty involvement at all.

We then examined the relationship between *STUDENT* and 4 different measures of firm behavior. First, we examine their patenting behavior using the collected data on the firms' patents. We define *PATENT* as a dummy variable equal to 1 if the firm had filed for a patent *after* the paper is published. Second, we examine their time to key milestones. We measured the *TIME FROM PAPER TO FOUNDING* which describes the length of time it took from paper publication to incorporation of the company; the *TIME FROM PAPER TO FIRST FUNDING* which describes the length of time it took from paper publication to their first funding even; and the *TIME FROM PAPER TO FIRST PRODUCT*, which describes the length of time it took from paper publication to unveiling their first commercial product. These variables are measured in months.

Insert Table 1 about here

There is substantial heterogeneity among the companies along these measures across the founder types. Table 2 shows the means of each measure as segmented by the founder types. We see that on average, student-founded companies are less likely to apply for patents after paper publication, take less time to incorporate the company after publishing the initial innovation, and take less time to achieve first funding. Student founded companies are also more likely to have their first product ready, and take less time to develop and offer their first products. Each of these patterns is consistent with the hypothesis that student-linked ventures are implementing a more execution-oriented strategy relative to their faculty counterparts.¹⁹

Insert Table 2 about here

While these descriptive results are suggestive, they do not systematically control for a variety of factors. Therefore, the remaining empirical analyses examine correlates of founder type and firm behavior in a more systematic way through multivariate regressions. We include several firm-level and industry-level variables into our analysis. To control for differences across industries, we included industry fixed effects. We further incorporated controls based on the underlying paper of the firm. For the journal quality, we broadly categorize the journals into three tiers for parsimony (JOURNAL GROUP). Top tier journals (based on impact factor) are classified in tier one, other journals are classified in tier 2, and conference proceedings and published theses are classified in tier 3. For the paper itself, we control for the average number of citations (AVERAGE PAPER CITATIONS) the paper has received annually as of December 2013 since its publication. While neither measure is perfect, they will help us to capture the underlying quality of the innovation, thereby lending greater robustness to our results. Finally, we control for the publication year of the paper (PAPER YEAR).

¹⁹ ¹⁹ Additional means comparisons exploring ex-ante differences between the companies are provided in Table 2 in the Appendix.

Table 3 reports our core empirical results. We use a linear probability model with errors clustered at the industry level.²⁰ The results are striking. Panel A documents that, relative to faculty-founded ventures, student-founded companies are less likely to patent after paper publication. To give a sense of magnitude, even after controlling for the full suite of fixed effects and control variables (Column 3), companies founded by students are nearly 40 percentage points less likely to file for formal intellectual property protection (statistically significant at the 1% level).

 Insert Table 3 about here

We now turn to the timing of key commercialization milestones. We had predicted that student-oriented firms will be faster to reach key milestones. To assess this, we first repeat our regressions with the TIME FROM PAPER TO FOUNDING, and TIME FROM PAPER TO FIRST FUNDING as the dependent variables. Panel B and Panel C in Table 3 shows the results for the effect of founder type on the time from paper publication to actual incorporation of the company. Incorporating the same controls as we did earlier, our results suggest that on average student founded companies take less than half as much time from paper submission to actual incorporation of the startup, relative to faculty founded startups. The result is significant at the 1% level. We repeat the analysis for the time from paper to first funding. The direction is consistent with our earlier priors, with student founded companies taking on average 75% less time to get funded. Finally, for those firms for which we can observe data, we examine the dynamics for product release. In Panel D, we examined the TIME FROM PAPER TO PRODUCT off the sample of startups, which have produced at least one commercial product. Consistent with our earlier results, student founded companies take significantly less time to produce their first products. Our regression results suggest that student founded startups take around half as much time to produce their first products.

Overall, these findings are consistent with our broad hypothesis that student-led firms face a lower relative cost of execution versus control, and so pursue a more rapid but less control-oriented commercialization path. However, we want to once again emphasize the exploratory

²⁰ Results from non-linear models are broadly consistent. Results are available on request.

nature of our results. Faculty and students are of selecting into particular ventures, and so the assignment of students or faculty into venture involvement is endogenous. However, the most likely source of bias would be that the most “important” innovations would likely attract the involvement (in some capacity) of faculty, and so we might simply see that faculty-led ventures were more intensively commercialized on all dimensions (i.e., more patents, quicker to incorporation and funding, and even potentially product launch). It is useful to note two points in this regard. First, as documented in Appendix Table 2, faculty-led ventures have a somewhat higher academic impact (more citations per year), but are statistically indistinguishable from student-led ventures in terms of initial journal quality or overall level of venture financing. In other words, faculty-led ventures seem to have a noisy but somewhat higher level of quality that we account for directly in our regressions (with no change in the underlying results). Second, and more importantly, if there a strong bias that faculty-led ventures were simply intrinsically of higher quality, we would anticipate that faculty-led ventures would be commercialized more intensively on all dimensions. However, Table 3 documents that whereas faculty-led ventures are more closely associated with formal intellectual property protection, student-led ventures are associated with more timely commercialization milestones.

With that said, the empirical tests so far are closer to a test of our conceptual framework, rather than tests of its predictions. Specifically, the prior empirical results show an association of the lack of institutional constraints – which we theoretically motivate as associated with an Execution strategic orientation -- with lack of formal intellectual protection. The final piece of our empirical analysis is a test that relates the strategic choice of intellectual property protection to the expected impact of product developmental delay. We now use PATENT as an explanatory variable and examine the interaction between PATENT and STUDENT. We argue that if our framework holds true, student founded ventures, facing a higher level of resource constraint, experience a more salient tradeoff between *Control* and *Execution*. Hence conditional on application for intellectual property protection or choosing a *Control* strategic orientation, student led ventures should incur further developmental delays than their professor founded counterparts. In other words, we should expect that the coefficient for the interaction between STUDENT and PATENT to be positive.

Insert Table 4 about here

Table 4 reports this exploratory analysis. In Panel A, we see the regression results for TIME FROM PAPER TO FOUNDING, with the coefficient of the interaction variable (STUDENT X PATENT) as our main variable of interest. In Column (2), we see that the coefficient on STUDENT X PATENT is positive and statistically significant. With the inclusion of indicators corresponding to the founding year in Column (3), we lose some statistical significance but the direction remains consistent. We see similar results in Panel B and C, using TIME FROM PAPER TO FUNDING and TIME FROM PAPER TO PRODUCT as the respective dependent variables. Again, we see that the coefficient on the interaction variable is positive across the different models. In Column (3) for Panel C, with the full inclusion of controls and indicator variables, our estimations suggest that student managed startups which had applied for intellectual property protection incur an additional delay of 27 months later relative to those which had not (significant at the 10% level).

By construction, these are descriptive results even within the assumptions of our framework – patenting is a choice variable of the entrepreneur. Indeed, the result in Table 4 that, overall, patenting is associated with faster commercialization is consistent with the hypothesis that intrinsically higher-quality innovations are associated with more intensive commercialization on multiple dimensions. With that said, the fact that, relative to faculty-led ventures, student-led ventures display a meaningful tradeoff in terms of timing and intellectual property protection is instructive, and consistent with the idea that the interplay between uncertainty and resource constraints leads entrepreneurs to pursue commercialization on the basis of near-term idiosyncratic factors rather than long-term environmental conditions.

In summary, our results suggest that student management of startups is associated with less patenting, and a faster pace for commercialization. While the results are exploratory, the fact that faculty-led ventures take longer to even incorporate or raise an initial round of funding is consistent with the idea that the identity of the entrepreneur shapes the strategic path being followed.

5 Discussion and Conclusion

Motivated by the substantial differences observed in start-up commercialization strategies despite facing the same exogenous conditions, this paper considers the role of Rosenbergian uncertainty (i.e., economic uncertainties that arise after successful invention) in shaping appropriability for entrepreneurs. We then developed and tested a simple conceptual model highlighting appropriability as an endogenous strategic investment. We focused and examined the key entrepreneurial strategic choice between a *Control* orientation versus an *Execution* orientation. We explore these ideas empirically by considering the choice of appropriability regime among a sample of academic entrepreneurs: within a sample of ventures that could have been developed by either faculty or students (or both), we find that faculty-led ventures are much more closely associated with formal intellectual property, but are less agile in terms of start-up and commercialization activities. In line with recent work (such as Ceccagnoli 2009), we suggest that the reformulation of appropriability as an endogenous consideration offers new insight into the nature and implications of the entrepreneurial choice process.

We want to emphasize again that our empirical results are exploratory and descriptive rather than causal. Most notably, the choice by students or faculty to found a venture is clearly endogenous. While our results are consistent with the hypothesis that the identity of founders matter for entrepreneurial strategy choice, we do not test directly whether Rosenbergian uncertainty per se is the driver of our observed patterns (e.g., short-term considerations of course play a role even if long-term factors are also accounted for). With that said, the large magnitude of difference in the patterns between student-led and faculty-led ventures suggest the potential value of further exploration of the interplay between the choice process governing firm founding, the uncertainty surrounding that process, and the implications for strategy and performance.

Our analysis suggest that it may be instructive to clearly delineate the roles of the environment from the choice among uncertain alternatives in future research. Consistent with the idea that the entrepreneurs' choices matter and that there are strong complementarities between distinct elements of entrepreneurial strategy (Gans, Stern, and Wu, 2018), our analysis suggests that a distinct and powerful approach to the study of entrepreneurial strategy is to confront and return to the inherent tension between learning and commitment. What should an entrepreneur do

when resolution of inherent Rosenbergian uncertainty in commercialization of an innovation can only be obtained through learning from venturing down a particular path? We posit that unpacking this process lies at the heart of entrepreneurial choice process.

As we emphasize in related work (Gans and Stern, 2017; Gans, Stern, and Wu, 2018; Gans, Scott and Stern, 2018), one potential direction for attack is to consider how the choice between control and execution impacts upon other entrepreneurial strategic choices. Consider first the choice of consumer an entrepreneur initially targets. For instance, they can target a mass market or alternatively a niche segment. However, while the costs associated with control will likely not vary much with this choice, for execution oriented entrepreneurs, the costs of execution are far higher when pursuing a mass market rather than a niche approach. Hence, we expect that execution choice to be associated with the targeting of a narrower class of consumer initially. Similarly, there may be implications for innovation itself. Whereas student-led ventures with faster commercialization may be more focused on launching a near-term product, a more control-oriented approach might be complementary with a more exploratory innovation process (perhaps yielding more breakthroughs over time). Complementarities between entrepreneurial strategy choices are a rich domain for investigation.

From the perspective of open innovation, a key extension is to consider how the choices of the firm and its effect on the effect on its competitors. It is plausible to hypothesize that firms can leverage the potential endogeneity of the appropriability regime to gain competitive advantage. For example, if a firm has stronger downstream asset positions, it may consider weakening control on the upstream portion of the value chain where the typical battle for intellectual property resides. As the upstream portion of the value becomes commoditized, the locus of value capture in the innovation chain shifts downwards. Here we can clearly see that the choice of a weaker appropriability regime can be economically beneficial to some firms. It may well be in the interest of firms with strong downstream complementary asset positions to proactively weaken the upstream appropriability regime. Scholars have already begun to hypothesize that indeed such a scenario may take place in industries such as the Open Source movement in software (see for example Pisano 2006).

Simply put, our analysis highlights the need for further research into the process of entrepreneurial choice. This may involve inquiries into the backgrounds of entrepreneurs and their interactions with the strategic paths undertaken. This choice-based approach also opens avenues into incorporation of dynamic considerations in entrepreneurial strategy. For instance, Marx, Gans and Hsu (2015) identified how the initial choice of a start-up to compete against incumbent firms can potentially extend put the firm in a better position to co-operate with incumbents later. A choice-based approach to entrepreneurial strategy research offers foundations that allow us to clearly separate the roles of the environment and the uncertainty of the innovation process, emphasizes the entrepreneur's central role in the entrepreneurial process, and offers insight into the role that strategy plays for start-up firms.

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TABLE 1
VARIABLES & DEFINITIONS

VARIABLE	DEFINITION	SOURCE	OBS	MEAN	STD
<i>Dependent Variables</i>					
PATENT	Dummy variable equal to 1 if the firm had filed for a patent	USPTO	103	0.524	0.502
TIME FROM PAPER TO FOUNDDING	Length of time firm took from paper publication to incorporation of the company in months	CrunchBase ; Incorporation data	103	30.874	33.003
TIME FROM PAPER TO FUNDING	Length of time firm took from paper publication to first investment by VC in months	CrunchBase ; Incorporation data	103	50.408	37.547
TIME FROM PAPER TO PRODUCT	Length of time firm took from paper publication to offering first product in months	Internet Wayback Machine	82	55.061	39.684
<i>Independent Variable</i>					
STUDENT	Dummy variable, set=1 if firm is founded by at least one student with no faculty involvement	CrunchBase ; Company website; Linkedin;	103	0.456	0.501
<i>Control Variables</i>					
JOURNAL GROUP	Categorical variable. Top tier journals (based on impact factor) are classified in tier one (2), other journals are classified in tier two (1), and conference proceedings and published theses are classified in tier three (0)	Google Scholar	103	0.612	0.783
AVERAGE PAPER CITATIONS	Average number of citations received by paper each year	Google Scholar	103	2.288	1.442
PAPER YEAR	Year in which paper is published	Google Scholar	103	2007.7	3.525

TABLE 2
PANEL A: T-TESTS OF KEY MILESTONES SEGMENTED BY FOUNDER-
TYPE

(N=103 observations)

	PATENT	TIME FROM PAPER TO FOUNDING	TIME FROM PAPER TO FUNDING	TIME FROM PAPER TO PRODUCT
STUDENT	0.319	13.787	29.277	31.023
PROFESSOR	0.696	45.214	68.143	81.564
DIFFERENCE	0.377	30.873	50.408	55.061
T-STAT	4.082	5.449	6.088	7.449

TABLE 3
BASELINE OLS REGRESSIONS

	(1)	(2)	(3)
<u>Panel A: Dependent Variable PATENT</u>			
<u>N=103 observations</u>			
STUDENT	-0.377 (0.0783)	-0.354 (0.101)	-0.425 (0.0795)
PAPER YEAR		-0.001 (0.003)	-0.001 (0.002)
AVERAGE PAPER CITATIONS (log)		0.0210 (0.0306)	-0.000 (0.0273)
<u>Panel B: Dependent Variable TIME FROM PAPER TO FUNDING</u>			
<u>N=103 observations</u>			
STUDENT	-31.427 (2.248)	-29.155 (3.661)	-28.274 (3.680)
PAPER YEAR		-0.002 (0.003)	-0.002 (0.004)
AVERAGE PAPER CITATIONS (log)		1.981 (1.601)	2.205 (2.031)
<u>Panel C: Dependent Variable TIME FROM PAPER TO FUNDING</u>			
<u>N=103 observations</u>			
STUDENT	-38.866 (3.764)	-33.876 (7.611)	-35.623 (7.089)
PAPER YEAR		-0.002 (0.005)	-0.003 (0.006)
AVERAGE PAPER CITATIONS (log)		4.635 (3.416)	3.771 (3.209)
<u>Panel D: Dependent Variable TIME FROM PAPER TO PRODUCT</u>			
<u>N=82 observations</u>			
STUDENT	-50.541 (5.481)	-45.175 (6.319)	-45.607 (6.579)
PAPER YEAR		-0.026 (0.003)	-0.027 (0.004)
AVERAGE PAPER CITATIONS (log)		3.686* (1.732)	3.462 (2.576)
Industry Fixed Effects			YES
Journal Quality Categories			YES

Robust standard errors clustered at the industry level, are reported in parentheses.

TABLE 4
OLS REGRESSIONS WITH INTERACTION VARIABLES

	(1)	(2)	(3)
<u>Panel A: Dependent Variable TIME FROM PAPER TO FOUNDING</u>			
<u>N=103 observations</u>			
STUDENT	-44.278 (6.701)	-41.865 (8.251)	-41.319 (7.721)
PATENT	-19.879 (9.076)	-20.211 (8.336)	-20.572 (8.159)
STUDENT X PATENT	16.765 (10.372)	16.721 (9.923)	15.606 (7.767)
PAPER YEAR		-0.002 (0.003)	-0.003 (0.004)
AVERAGE PAPER CITATIONS (log)		2.226 (1.900)	2.255 (2.338)
<u>Panel B: Dependent Variable TIME FROM PAPER TO FUNDING</u>			
<u>N=103 observations</u>			
STUDENT	-51.934 (10.268)	-47.068 (13.405)	-50.766 (11.573)
PATENT	-17.110 (12.062)	-17.869 (10.319)	-21.739 (9.778)
STUDENT X PATENT	20.718 (14.428)	20.672 (13.380)	21.427 (8.902)
PAPER YEAR		-0.002 (0.005)	-0.003 (0.006)
AVERAGE PAPER CITATIONS (log)		4.789 (3.674)	3.839 (3.487)
<u>Panel B: Dependent Variable TIME FROM PAPER TO PRODUCT</u>			
<u>N=82 observations</u>			
STUDENT	-68.003 (9.137)	-63.451 (10.782)	-64.780 (8.0431)
PATENT	-22.462 (10.339)	-24.053 (11.010)	-26.293 (7.951)
STUDENT X PATENT	29.592 (10.276)	30.343 (11.011)	31.0959 (5.674)
PAPER YEAR		-0.029 (0.002)	-0.031 (0.002)
AVERAGE PAPER CITATIONS (log)		3.456 (1.917)	3.296 (2.534)
Industry Fixed Effects			YES
Journal Quality Categories			YES

Robust standard errors clustered at the industry level, are reported in parentheses.

**APPENDIX
FIGURE 1
SUMMARY OF DATASET ASSEMBLY**

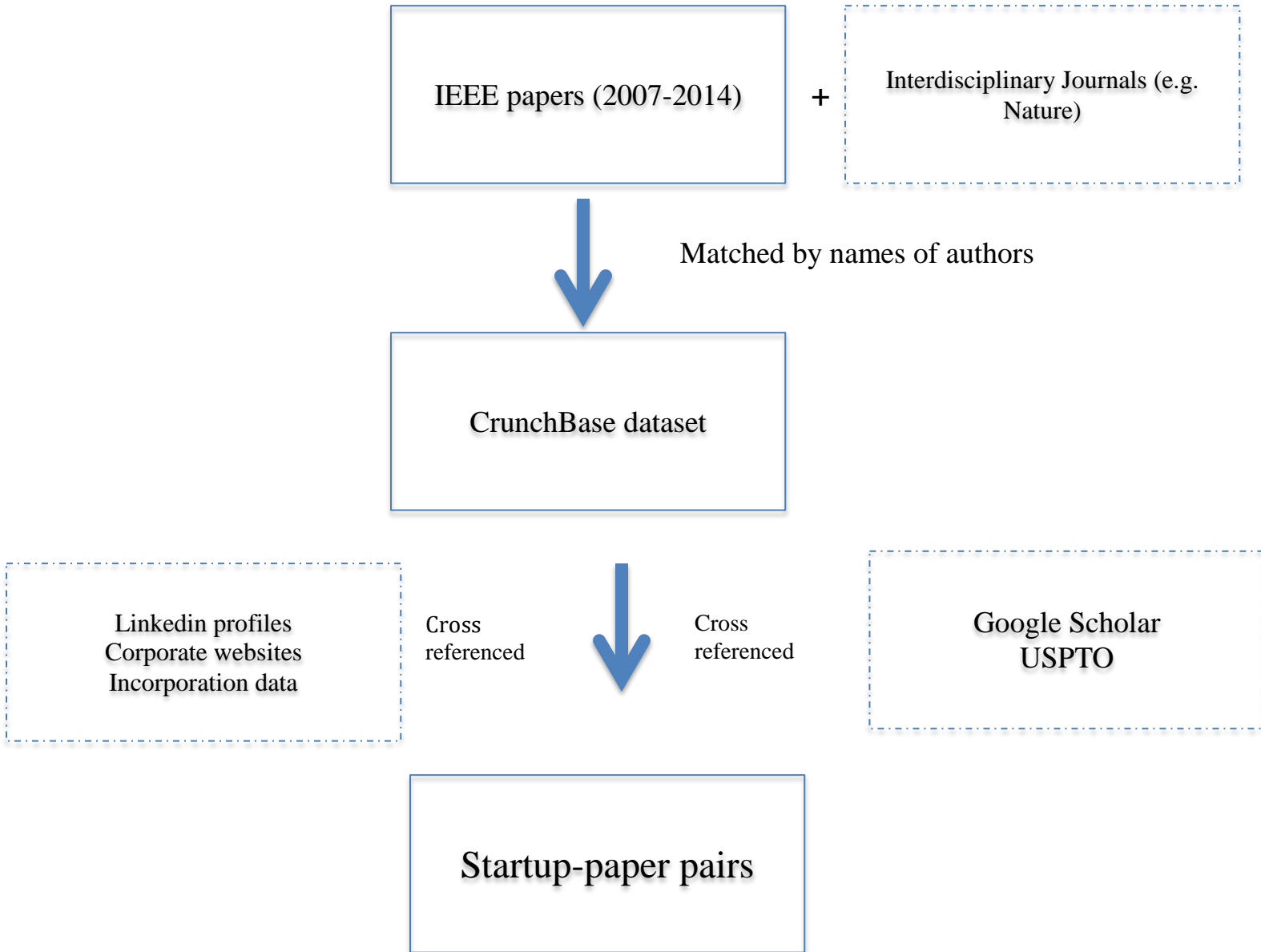


FIGURE 2
FREQUENCY DISTRIBUTION OF STARTUPS BY INDUSTRY
(N=103 observations)

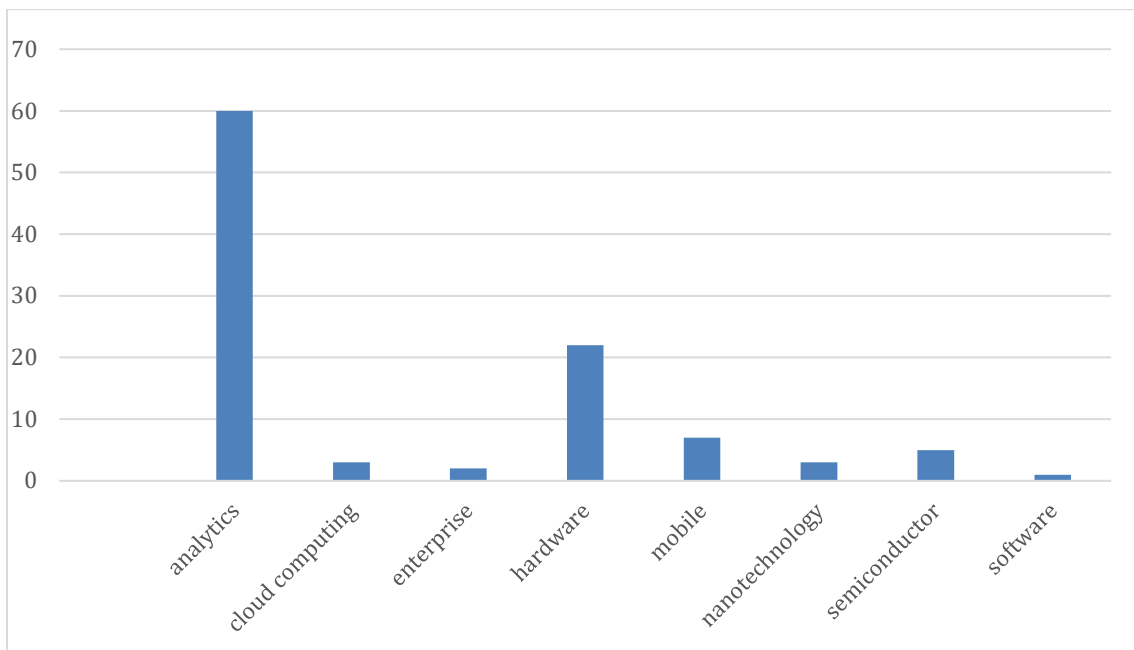


TABLE 1
CORRELATION TABLE

	PATENT	TIME FROM PAPER TO FOUNGING	TIME FROM PAPER TO FUNDING	TIME FROM PAPER TO PRODUCT	STUDENT	JOURNAL GROUP	AVERAGE PAPER CITATIONS (log)	PAPER YEAR
PATENT	1							
TIME FROM PAPER TO FOUNGING	0.02	1						
TIME FROM PAPER TO FUNDING	0.11	0.89	1					
TIME FROM PAPER TO PRODUCT	0.13	0.87	0.93	1				
STUDENT	-0.38	-0.48	-0.52	-0.64	1			
JOURNAL GROUP	0.12	0.07	0.13	0.02	-0.07	1		
AVERAGE PAPER CITATIONS (log)	0.18	0.24	0.33	0.33	-0.36	0.22	1	
PAPER YEAR	-0.05	-0.07	-0.04	-0.19	0.16	0.06	0.27	1

TABLE 2
T-TESTS EXPLORING EX-ANTE DIFFERENCES SEGMENTED BY FOUNDER-TYPE
(N=103 observations)

	JOURNAL GROUP	AVERAGE PAPER CITATIONS	VENTURE CAPITAL FUNDING (000s)
STUDENT	0.556	1.729	7690
PROFESSOR	0.661	2.757	12600
DIFFERENCE	-0.107	1.029	-4909
T-STAT	0.692	3.842	1.482