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Moving from an Exception to a Rule: Analyzing Mechanisms in Emergence-Based Institutionalization

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We analyze the conditions under which a practice moves from rare and unacceptable to preponderant and legitimate through bottom-up, relational processes. To better understand the mechanisms and contingencies of such “emergence-based institutionalization,” we combine computational agent-based modeling with insights from a setting where a seemingly deviant local practice became institutionalized: the case of the emergence of proprietary disclosure in the academic life sciences. Our approach results in both theoretical and methodological contributions. From a theoretical perspective, we develop propositions related to microlevel processes that lead to the institutionalization of new rules or those that leave existing arrangements unchanged. Our analysis suggests that traditional social explanations, such as organizational reproduction and copying successful peers, are less likely to drive emergence-based institutionalization than cognitive factors that direct individuals to anticipate and preempt the actions of others. From a methodological perspective, we provide an example of how case analysis and computational modeling can be combined to study the varying and contingent roles that normative, social, and cognitive factors play in persistence and change in institutionalization.

Keywords: institutional theory; technology transfer; organizational evolution and change; computer simulations; entrepreneurship; organizational learning

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1. Introduction

How do practices move from an exception to a rule? This question is fundamental to the organizational sciences, since rules are important building blocks of institutions (March et al. 2000, Heimer 2010). When defined as the principles that govern action (Scott 2001), rules can take many forms, ranging from formal regulations to taken-for-granted cognitive scripts to faithfully observed social norms. In this capacity, they direct individuals and organizations to follow a logic of appropriateness by matching situations to identities in an ongoing process of sensemaking (March and Simon 1958, March and Olsen 1984, Weick 1995). Rules also serve as the “genes” of organizations, by encoding routines that reproduce organizational arrangements (Nelson and Winter 1982, Winter 1990) and by producing interaction patterns that delineate communities of members and skills (Becker 2004). Understanding how new practices become field-level rules opens a window into the cognitive, normative, and social bases of institutional persistence and change (Clemens and Cook 1999).

Contemporary studies, notably in the tradition of institutional theory, have treated this exception-to-a-rule process as one of institutionalization—that is, the integration of a new and not widely accepted practice into a self-reproducing social system that is made up of modes of organizing, norms, controls, and beliefs that

together constitute regular behavior (Scott 2001, Greif 2006). In this literature, scholarship has demonstrated the many ways individual actors transpose new practices into established places by facilitating connections from one domain into others settings (Hwang and Powell 2005, Padgett and Powell 2012), such as the development of rules for the allocation of the radio spectrum (Leblebici et al. 1991) or change in principles for the delivery of medical care (Scott et al. 2000). Similarly, other work has shown how relational factors, such as a change in social referent, facilitate the importation of new practices, thereby contributing to broader institutional changes (Dunn and Jones 2010, Jones et al. 2012). Despite such contributions, however, institutional theory lacks an account of institutionalization that fully articulates the contingencies for which local actions that begin as exceptions become self-reproducing, field-level structures themselves—a case we call emergence-based institutionalization. For example, under what conditions are such local and relational processes more or less likely to bring about institutional change? Would a mechanism have equal leverage across fields with different organizing principles, reward conditions, or competitive pressures? Some scholarship even suggests that there are certain conditions under which change efforts on the ground may even support, instead of alter, a higher-level status quo (Jepperson 1999, Powell and Colyvas 2008, Lok and

de Rond 2013). Indeed, without a better understanding of the processes that underlie emergence-based institutionalization, it is difficult to predict when a practice that is new and not widely accepted should be expected to bring about higher-order institutional change or when it might maintain what is already in place (Schneiberg and Lounsbury 2008, Lawrence et al. 2011).

We address this challenge with a novel methodological strategy. We combine computational agent-based modeling with insights from a setting where a local practice that was initially an exception became self-reproducing—the case of the emergence of proprietary disclosure in the academic life sciences—to further develop theory that articulates the contingencies involved in emergence-based institutionalization. Drawing on prior empirical and theoretical research, we focus especially on the role of social interactions and cognitive search mechanisms in decision making. Our approach results in both theoretical and methodological contributions. From a theoretical perspective, we develop and refine propositions related to microlevel processes that lead to the institutionalization of new rules or those that leave existing arrangements unchanged. In particular, our analysis suggests that traditional social explanations, such as organizational reproduction and copying successful peers, are less likely to drive emergence-based institutionalization than cognitive factors that direct individuals to anticipate and preempt the action of others. Moreover, our refined propositions also articulate the conditions under which these differences in microlevel processes are more or less salient. From a methodological perspective, we provide an example of how case analysis and computational modeling can be combined to study the varying and contingent roles that social and cognitive mechanisms can play in institutionalization.

1.1. Explaining Emergence-Based Institutionalization

An enduring critique in institutional theory is that too much scholarship overemphasizes field-level incentives and constraints that define the range of what is legitimate for individuals and organizations to do. In particular, institutional scholarship has been criticized for overlooking the multiple ways that higher-order structures provide opportunities to construct different practices (Hallett and Ventresca 2006, Weber and Glynn 2006, Hallett 2010). Individuals or organizations need not be prisoners of the monolithic constraints of institutions such as reward systems or norms that dictate what behavior is appropriate (Weick et al. 2005). Instead, they can alter or maintain institutions by working within existing environments to construct new practices, import alternatives from other domains, or edit existing ones (Lawrence et al. 2009).

This critique is especially relevant when trying to understand how actions that begin as exceptions at the

individual level can become field-level rules—a case we refer to as emergence-based institutionalization. More specifically, we define *emergence-based institutionalization* as the shift of a new practice or structure from rare and unacceptable to preponderant and legitimate through microlevel interactions that do not depend on top-down, field-level coordination or control. It entails two components: the legitimacy status of the originating practice and the processes that integrate the new practice into a self-reproducing social system. This distinction is in contrast to cases of institutionalization that do not entail an initial legitimacy threat or are driven by top-down field-level mandates, incentives, or changes.

Our focus on emergence-based institutionalization does not imply that existing scholarship has ignored the microfoundations of higher-level institutionalization. Institutional scholarship that addresses the relationship between local action and higher-level change provides important guideposts to investigating emergence-based institutionalization (Powell and Colyvas 2008, Loewenstein et al. 2012, Thornton et al. 2012). Studies ranging from the founding of the Paris Opera to changes in the library sciences to the creation of active money management practices in U.S. mutual funds point out how microlevel factors interact with field-level circumstances to contribute to the institutionalization of new rules (Lounsbury and Crumley 2007, Jonsson 2008, Nelson and Irwin 2014). A substantial literature also emphasizes the role of individuals in championing the design and implementation of new rules and therefore transforming institutions (Lawrence and Suddaby 2006, Battilana et al. 2009). By focusing on the ability of entrepreneurs to exert effort and utilize their skills, this literature has done much to integrate the multiple means by which individuals and organizations enact meaningful institutional change (DiMaggio 1988, Fligstein 2001, Hwang and Powell 2005, Battilana 2011). Indeed, much scholarship calls for the need to theoretically connect institutional change to action situated in discrete social contexts (Hallett and Ventresca 2006, Loewenstein et al. 2012).

Considered together, this scholarship suggests that understanding the contingencies for which actions that are initially exceptions can lead to field-level change requires a clear articulation of how local practices interact and coalesce to produce sustainable, patterned action (March et al. 2000, Heimer 2010, Padgett and Powell 2012). For these purposes, three premises are particularly salient. First, capturing this relationship requires theorizing the broader social system that defines actors and their repertoires of actions, interests, and aspirations in specific social contexts (Clemens and Cook 1999; Fligstein 2001; Drori et al. 2006, 2009; Hwang and Colyvas 2011). Doing so sheds light not only on the range of permissible behavior available to an actor but also on the established routines, currencies, rewards,

and consequences that can arise through fidelity or infidelity in a given setting (Scott 2001). Without this clarity, mechanisms that give rise to an institution can be mistaken with those that support them once in place (Stinchcombe 1968, 2005).

Second, analyzing the exception-to-a-rule process requires acknowledging that institutionalization can take place at both lower and higher social orders (Jepperson 1991, Colyvas and Jonsson 2011). In other words, a new practice can settle into a routine solely within an organizational boundary, or it can settle into a field-level rule that directs individual action regardless of an actor's organizational affiliation. Moreover, the rules of higher and lower social orders can interact, generating contradictions between opportunities on the ground and field-level constraints of what kinds of actions are legitimate (Clemens and Cook 1999, Smith-Doerr 2005). Without greater theoretical clarity on the relationship between lower and higher social orders, what looks like a case of an exception becoming a rule in a lower social order may in fact only be reinforcing the status quo (Colyvas and Powell 2007).

Finally, addressing the conditions under which local actions aggregate into field-level change also requires foregrounding the ways in which microlevel social and cognitive influences shape action (Ocasio 1999, Weber and Glynn 2006, Gavetti et al. 2007). Organizational learning research, for example, underscores the distinction between action that is based solely on one's own experience and action that results from searching a broader environment for legitimate alternatives (Zald and Denton 1963, Cyert and March 1963, March et al. 1991, Gavetti and Levinthal 2000, Kim and Miner 2007). The wisdom of experience can narrow the perceived range of options organizations might pursue or even discount efficacious ones that lead to longer term rewards or organizational survival as a result of past failures (Gavetti and Levinthal 2000). Scanning a broader environment directs attention to a more extensive range of possibilities and raises questions about what actions would be most appropriate for a given situation (March 1999, Weick 2005). As with institutionalization at lower and higher social orders, undertheorizing both the social and cognitive influences on decision making makes it difficult to distinguish between microlevel actions that prompt profound institutional change and those that might break from local norms but actually reproduce broader social arrangements (Schneiberg and Lounsbury 2008, Lawrence et al. 2009, Aldrich 2010).

1.2. A Mechanism-Focused Approach to the Institutionalization of New Rules

To distinguish between conditions where initially unaccepted behavior supports existing arrangements and those that generate field-level change, we need a theoretical account of institutionalization that not only links

lower-order action to higher-order structures but also captures the normative, social, and cognitive conditions that influence local practice, as well as the conditions that maintain rules that are already in place. It must do so in the institutional context that defines actors, aspirations, and actions, but it must also incorporate the perceptible and imperceptible consequences of fidelity to such action (Powell and Colyvas 2008, Thornton et al. 2012).

We address this challenge by taking a mechanism-based approach to understanding how a new behavioral pattern emerges and becomes institutionalized (Aldrich and Ruef 2006). Mechanisms reflect social processes that bring about persistence or change. The focus of numerous calls for theory building in the organization sciences, social mechanisms are not simply an aggregation of individual preferences or actions (Davis and Marquis 2005, Anderson et al. 2006, Weber 2006, Gross 2009). Rather, they represent diachronic processes that are identified through their causal relationship to an outcome (Stinchcombe 1991, Hedstrom and Ylikoski 2010). Their effects, however, are often beyond the level and cognitive understanding of those who participate in them (Barley and Tolbert 1997, Hedstrom and Swedberg 1998). Our mechanism-based perspective shifts an institutionalization-of-rules focus away from top-down constraints or bottom-up purposive change toward the sequences of actions that take place at local levels of social relations and bring about an effect in broader structures (Abrahamson and Rosenkopf 1993, 1997; Powell and Colyvas 2008). In doing so, we demonstrate an approach to modeling and analyzing the conditions under which microlevel processes reinforce existing rules or lead to the emergence of new ones.

1.3. Methodological Strategy

Social processes, especially those related to mechanisms and institutionalization, are difficult to disentangle in the real world (McAdam et al. 2008, Colyvas and Jonsson 2011). By allowing careful and controlled examination of the relationship between underlying social processes and consequences, computational modeling has been put forth as a way to gain traction on this problem in organizational scholarship (Harrison et al. 2007, Burton and Obel 2011). At the same time, abstract theory and models can be intractably detached from empirical application (Stinchcombe 2005). We seek a balance: we use an empirical context to protect against the pitfalls of abstract modeling while still leveraging the strengths of simulation as a tool to refine theory (Maroulis and Wilensky 2014). Our approach can be thought of as an instance of using simulation to produce computational characterizations of what Merton (1968) referred to as "middle-range theories" (p. 39). Such computational models do not attempt to faithfully reproduce the particulars of an empirical context (Gilbert 2008,

pp. 42–43), but rather go beyond purely abstract models by incorporating lower-order characteristics (which we refer to below as “system features”) and qualitatively matching those characteristics to higher-order outcomes of the system (which we refer to later as a “reference pattern”).¹

The basic steps are as follows: First, we choose an empirical context that allows us to investigate the institutionalization of an exception to a rule. We turn to the emergence of proprietary science in the academic life sciences, specifically as a set of rules that define how university research findings should be disclosed and thus commercialized (Owen-Smith 2003). Second, we ask a specific question about an emergent outcome in our focal context that can be explained by several potential microlevel mechanisms. In particular, we ask, how did the academic system change from a state where the proprietary disclosure of scientific research findings was rare and unacceptable into a system where patenting of scientific products was widespread and appropriate? Third, we identify two types of insights about our question through a critique and synthesis of existing literature. One type of insight is a *system feature*—a characteristic of the underlying social system that can be used to guide our modeling decisions. The other type of insight is a proposition—a theoretical statement that relates a factor in the social system to the outcome of interest. Fourth, we operationalize the identified system features into a computational, agent-based model (ABM). The ABM is a form of simulation that emphasizes understanding the emergent system-level behavior of adaptive actors that interact with and influence each other in a social system (Epstein and Axtell 1996, Wilensky 1999, Miller and Page 2007, Hedstrom and Ylikoski 2010). It also provides the benefit of forcing concrete specification of ambiguous constructs and processes, because they must be translated into specific interaction rules and formalized as code. This feature requires a “theoretical grasp of underlying microlevel processes” and provides a foundation for analysis and refinement (Harrison et al. 2007, p. 1231). Fifth, we use the ABM to better understand the simultaneously occurring mechanisms operating within this particular case of institutional change. The primary end product of this analysis is a set of refinements to the initial propositions about emergence-based institutionalization described in our critique and synthesis of the literature.

We proceed in §2 by framing our empirical setting of the emergence of proprietary science using a critique and synthesis of historical, theoretical, and empirical research to motivate our system features and propositions. In §3 we describe our agent-based model and make the connection between the system features and modeling decisions. In §4 we report our analysis and refine our propositions based on our results. We conclude in §5 with a discussion of specific implications for the focal case of

this paper, as well as general implications for institutional theory and mechanism-focused approaches to organizational analysis.

2. System Features and Propositions: Proprietary Science as a Case of Emergence-Based Institutionalization

Although institutions shape the range of available options one can pursue, cases of emergence-based institutionalization entail the introduction of new practices that conflict with established rules (Clemens and Cook 1999, Aldrich and Ruef 2006). Therefore, explaining the emergence of proprietary science in the academic life sciences requires delineating the strong social and organizational differences between two contradictory realms of public (academic) and proprietary (industry) science—specifically, “[i]t is the nature of the goals accepted as legitimate within the two communities of researchers, the norms of behavior especially in regard to the disclosure of knowledge, and the features of the reward systems that constitute the fundamental structural differences . . .” (Dasgupta and David 1994, p. 494). In this view, science is understood in terms of the highly competitive social system in which it is produced, rather than its material character or academic-versus-industry location (Rosenberg 1990). In academia, adherence to rules of appropriate action is socially sanctioned, with strong consequences for the survival of labs where science is conducted (Merton 1973).

Viewed this way, the emergence of proprietary science represents an apt case of emergence-based institutionalization, since patenting in the academy challenges the social system of science. After World War II (WWII), science was prefaced on the cumulative production of knowledge, whereby scientists built on one another’s work and relied on disparate skills distributed across laboratories (Cole and Cole 1973, Merton 1973, Allison et al. 1982, Owen-Smith 2003). Academic knowledge production rested on the normative foundations of open disclosure, was monitored through peer review, and was rewarded through publication and citation (Rhoten and Powell 2007). Success in this system reinforced researchers’ ability to obtain awards or external funds and thus supported the survival of research labs. The rise of academic intellectual property (IP), beginning in the early 1970s and surging in the 1990s, represented a competing norm of disclosure. First, it bestowed on academic scientists the legal ability to exclude others from using a finding, and second, it conferred on them the opportunity for profits through licensing revenues. The proliferation of academic patenting reflects the intermingling of two, once separate, domains of public and proprietary science (Owen-Smith 2003, Powell and Sandholtz 2012).

In addition to the initial legitimacy threat of patenting in the academy, its shift from a rare exception to a preponderant and legitimate practice occurred in large part through microlevel interactions of the individuals and organizations in the system (Colyvas and Powell 2007). Whereas the diffusion of academic patenting is often explained as a consequence of national policies and financial incentives that encouraged commercialization (Shane 2004)—particularly in relation to the passage of the Bayh–Dole Act in 1980—the institutionalization of this practice cannot solely be explained as a consequence of such top-down forces. First, historical scholarship argues that the early post-WWII realms of academic science and industrial firms were much more proximate and interactive than generally acknowledged (Geiger 1993, Shapin 2008). Numerous successful universities already had commercial practices on the books and under way, more than a decade before the biotechnology industry’s birth and the establishment of national policies such as the Bayh–Dole Act, that encouraged technology transfer through patents (Mowery et al. 2004). In the late 1960s and early 1970s, faculty contact with companies through consulting and professional conferences was not uncommon, particularly in chemistry, engineering, and biomedical fields. Second, the policies “on the books” at early university entrants were often different from the practices occurring within laboratories and among administrators (Colyvas and Powell 2006). Scientists with the option of taking personal profits from their licensed research often declined to do so, stating that making money from their research was inappropriate (Colyvas 2007a, Colyvas 2007b; Berman 2012). Indeed, the most consequential role of local entrepreneurs was not strategic design of top-down policies or incentives but the acknowledgement that scientists were more likely to engage in technology transfer if they could do so on their own terms, within the norms and routines of academic science, so that they could maintain their professional legitimacy.

Acknowledging the important role of individuals, analyses of the spread of patenting underscore the relational aspects of producing science through exposure to coworkers—particularly advisors or mentors with commercial orientations (Nanda and Sørensen 2010). Scientists who trained at patenting-intensive research institutions, with coauthors who have commercialized their research findings or colleagues who have patented, are more likely to seek IP protection (Stuart and Ding 2006, Bercovitz and Feldman 2008). Laboratory exposure is also important, as students adopt patenting behavior from their advisers by engaging in technology transfer efforts (Colyvas and Powell 2007, 2008; Azoulay et al. 2009). Labs also exhibit different orientations toward proprietary science, based on the experience and commercial orientation of the principal investigator (PI) (Owen-Smith and Powell 2001a). These factors shape

the model that graduates replicate in their careers as they leave their place of training and establish labs of their own. This process is an important form of reproduction for the social system of science, in terms of passing on skills and ways of disclosing science and also in terms of reproducing the organizational form of academic laboratories. This process can also play a role in emergence. Therefore,

SYSTEM FEATURE A. *A model of the emergence of proprietary science needs to capture the reproduction of scientific labs as organizational forms.*

Furthermore, we might expect the following.

PROPOSITION 1. *Emergence-based institutionalization will occur through the reproduction of organizational forms, as parent organizations with varying orientations toward a new practice pass their proclivities on to offspring organizations, such as academic labs that pass their skills to students who go on to establish labs of their own.*

It is important to note that diffusion analyses treat patenting as a discrete attribute of individuals, contingent on the propensity of scientists to patent and their legal ability to obtain IP rights to a finding (Azoulay et al. 2009). From this perspective, proprietary disclosure is modeled conceptually as an individual characteristic that a scientist adopts, rather than a decision that a scientist makes each time she produces a research finding. These approaches also emphasize the legal criteria for patentability in making these decisions, rather than the perceived threat to a scientist’s research program should she chose to patent. In contrast, Colyvas (2007a) found that in the early years of formal technology transfer, the decision to patent was episodic and contingent on each case of inventing, even among faculty with prior patenting experience. For example, one lab in her early 1970s sample decided to commercialize a device that became very successful. Later, when faced with the opportunity to patent a biological target, the lab PI declined, stating that it was inappropriate to patent scientific findings that were materials or processes. Another scientist argued that intellectual property was legitimate for his or her prior invention because it was a commercial application. However, the scientists expressed that patenting was not appropriate for a later invention because it was basic science and fundamental contributions should be disseminated openly. Scientists were concerned about both the ability of other scientists to use their patented research findings and the effects that patenting would have on their research programs and ultimately the survival of their labs should they chose to patent (Hughes 2001). More recent work validates this concern about the threat that IP poses in bestowing the ability to exclude others from using research results: patenting hinders the longer-term development of some life science research (Huang

and Murray 2009) and can impinge on scientists' autonomy to set research agendas and promote the use of their work (Gans et al. 2008, Aghion et al. 2010). Thus,

SYSTEM FEATURE B. *A model of the emergence of proprietary science requires capturing the character of discrete inventions (e.g., how fundamental to science) and the heterogeneity of perceptions about patenting such inventions (e.g., what findings are appropriate to patent) in the context of professional norms and values of science.*

A number of analyses of proprietary science also place special emphasis on the social influences that shape individual decision making. These studies highlight that scientists who personally experience patenting come to view their labs as entrepreneurial and their science as commercially valuable, and they come to believe that they can be legitimately rewarded through revenues from their inventions (Owen-Smith and Powell 2001a, b). This perceptual change reflects the dimensions by which academics evaluate their research from exclusively valuable to science to a broader conception that includes its value to industry.

This transformation takes place through different sets of social relations that are often independent of the advisor–trainee relationship (Ding and Stuart 2006, Bercovitz and Feldman 2008). Direct contact with scientists represents a social cohesion whereby socialization and tacit learning can occur. Indirect contact, notably through peer groups or common social position, represents shared advantages, such as access to information and a greater sense of similarity and expectations (Coleman et al. 1966; Burt 1987, 1992; Strang and Meyer 1993; Jonsson et al. 2009). Scientists who interact directly learn in the literal sense through the process of developing their research, gain access to opportunities to commercialize, and can also witness more direct threats to their research when a peer tries to patent their own or closely related findings (Levitt and March 1988, Schulz 2002, Ding and Stuart 2006). Colyvas (2007b, p. 472) illustrated this “learning-by-doing” through disputes among scientists who were not listed as inventors of research that was patented by their collaborators. As a result, one lab reported the decision to “patent everything imaginable” in order to protect its research program from the ability of others to exclude access to it. Others may just conform to their peers by observing the proclivities and actions of others at a similar career stage, within their department, or in the profession more broadly (Burt 1987). Owen-Smith and Powell (2001a, b) aptly demonstrated this more general threat that scientists experienced in observing colleagues who would patent anything imaginable because others were undermining academic freedom and their own research programs. Still other scientists made reference to highly

successful patents as a means of justifying their decisions and reasoned that the exception of patenting had a greater benefit to society because of the revenues it would bring back to the university and therefore academic research (Colyvas 2007b, Owen-Smith and Powell 2001a). Some scientists took less noble paths in their justifications and simply expressed the observation that their neighboring colleagues were making money and even had nicer cars (Owen-Smith and Powell 2001a). Thus labs can alter their own aspirations about patenting without having direct contact with commercial rewards but by observing the success of other scientists in commercializing their research (Schulz 2002, Bercovitz and Feldman 2008). Therefore,

SYSTEM FEATURE C. *A model of the emergence of proprietary science requires disentangling sets of social relations that can influence action.*

Furthermore, we can expect the following.

PROPOSITION 2. *Emergence-based institutionalization will occur through interaction with different sets of social relations, such as when labs learn by engagement with others in producing science and also conform by observing a broader set of peers.*

Although backgrounded in most discussions of the role of social relations, patenting's spread also raises the question of whether organizations change their behavior as the result of prior consequences or through the anticipation of others' actions (March 1994, Weick 1995, Gavetti and Levinthal 2000, Weber and Glynn 2006). Scientists may experience “the short end of the stick” by witnessing their published research patented later by others, or they may anticipate lesser rewards by not patenting when they are about to disclose new findings (Owen-Smith and Powell 2001a, Colyvas 2007b). The diffusion of proprietary science literature emphasizes change through reactions to prior consequences. The studies inside of laboratories described above suggest evidence of both.

The reasons for problematizing this temporal distinction are both empirical and theoretical. Empirically, scholars of diffusion and institutionalization stress the sequencing of contact and diachronic aspects of gaining access to information or responding to stimuli (Barley and Tolbert 1997, Moody 2002). One catches a disease only after having contact in a romantic network, and one takes action over a technology only after it is introduced to the subjects who may adopt it (Barley 1986, Bearman et al. 2004). Yet the social structure of science suggests that scientists also react preemptively owing to the strong values of autonomy and control of one's own research direction (Colyvas 2007b, Aghion et al. 2010, Gans et al. 2008). Across literatures, numerous scientists reported patenting their research out of anticipation of what others might do with their work (Owen-Smith and Powell 2001a, b; Colyvas 2007a). From a

theoretical perspective, this distinction ties to organizational learning research that emphasizes its cognitive effects—namely, the difference between backward-looking and forward-looking search in shaping the range of options perceived to be available to an organization (Gavetti and Levinthal 2000). Backward-looking search directs attention to an organization’s own experience of a situation and the perceived consequences of prior actions. As a result, organizations pay attention to a more narrow range of options perceived as legitimately available. For academic scientists, observing the results of patenting certain types of science can prompt oneself and proximate others to do the same. Alternatively, forward-looking search in decision making directs attention to a broader environment of peers, expanding the range of options an organization perceives as available (Gavetti and Levinthal 2000). In proprietary science, an expansion in the perceived opportunities to disseminate research findings can induce a shift in a scientist’s focus on the citation value of a research finding (informing the choice to publish) to its commercial value (informing the choice to patent). It can also expand the perception of what characteristics of findings are appropriate to patent in the first place. Thus,

SYSTEM FEATURE D. *Modeling the emergence of proprietary science requires disambiguating different forms of decision making, whether looking backward to what has occurred in the past or looking forward to perceptions of what others might do.*

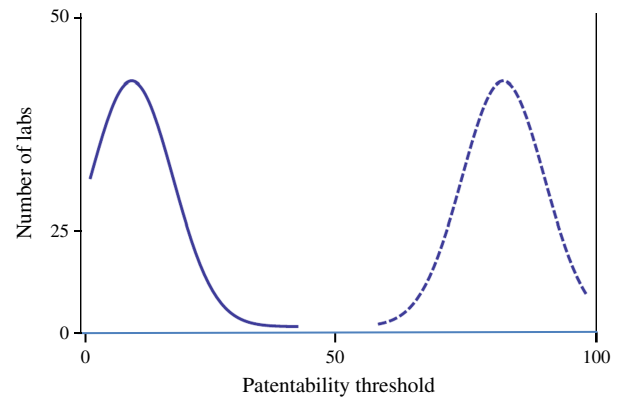
Furthermore, we would expect the following.

PROPOSITION 3. *Emergence-based institutionalization will occur through both backward-looking and forward-looking decision making, such as when labs alter their disclosure behavior retrospectively through prior experience in commercializing science or prospectively through the anticipation of what others might do with their science.*

3. Modeling the Emergence of Proprietary Science

We converted our system features into a computational, agent-based model in three phases. First, we characterized our research question as an emergent macrolevel change in the distribution of labs’ patentability thresholds. Figure 1 depicts this “reference pattern” (Stermann 2000) for our model. The solid line represents the distribution of patentability thresholds across labs in the initial time period, when labs were only willing to patent scientific products of low scientific importance. The dashed line represents the shift in the distribution that we are trying to understand—a shift to a state of academic science where labs were willing to patent scientific products of almost any level of scientific value. Second, we operationalized the system features from our

Figure 1 (Color online) Distribution of Labs’ Patentability Thresholds



theoretical and empirical critique as mechanisms in an ABM that can give rise to the reference pattern of interest (and its opposite).² Third, we experimented with the model to examine which mechanisms provide the most leverage in shifting the threshold of the science that labs are willing to patent.³

Below, we elaborate on the model details and computational experiments. In Table 1, we also summarize our conceptual and computational model, research question, social system, and change mechanisms in the context of our system features, assumptions, and computational representations.

3.1. Characterizing the Social System of Science and Change Mechanisms

Our model characterizes the social system of science—specifically, the processes by which science and scientific labs are produced, the form that scientific disclosure takes, and the ways in which labs change.

3.1.1. The Scientific Production Process. We assumed that scientific advance is highly competitive for survival yet prefaced on cumulative knowledge production (Merton 1973). Scientists build on each other’s work, often in self-reinforcing ways (Cole and Cole 1973, Allison et al. 1982, Owen-Smith 2003). From this perspective, scientific advance relies on a combination of skills and tools distributed across scientists, which creates material networks of the accumulative science that is produced and the social networks of scientists engaged in producing that science. Survival therefore depends on others using the knowledge that one has produced. Labs reproduce their skills and practices as graduates and postdocs take jobs elsewhere and establish labs of their own (Stephan 2008, Vallas and Kleinman 2008). Labs that cannot use their skills and reproduce do not survive. We thus included self-reinforcing mechanisms that produce both science and scientific labs (System Features A and B in §2).

Table 1 Conceptual Framework: Insights, Constructs, and Computational Representations

Critical insights	Constructs and assumptions	Computational representation
<ul style="list-style-type: none"> Objective: To gain a better understanding of the conditions under which a local practice moves from rare and unacceptable to preponderant and legitimate through bottom-up, relational processes 	<p>Research problem and outcome of interest</p> <ul style="list-style-type: none"> Institutionalization can be understood as emergence, i.e., how a social pattern arises temporally through some means of reproduction and reinforcement, shifting the analytic focus to the sequences of actions and abstract relations that take place at local levels of social relation and bring about an effect in broader social structures. We examine the emergence of proprietary science in the academic life sciences as a set of rules that came to define how university research findings should be commercialized. Our outcome of interest is the institutionalization of disclosing science as intellectual property in the life sciences. <p>Features of the social system of science</p> <ul style="list-style-type: none"> The social system of science is prefaced on the cumulative production of knowledge, whereby scientists build on each other's work, often in self-reinforcing ways. Scientific advance is complex because it relies on the combination of skills distributed across scientists. Features of the reward system rely on peer review, publication, and citation. Academic success depends on others using the knowledge scientists produce. Although publication is critical, an important form of knowledge transfer occurs by training and mobility of Ph.D.'s. Successful labs can reproduce their practices by training scientists. 	<ul style="list-style-type: none"> We operationalize emergence as a reference pattern, reflecting a macrolevel change in a key outcome of interest. Our reference pattern reflects a shift in the distribution of scientists' willingness to patent a broader range of findings (from few scientists patenting only certain types of findings to a much more widespread deployment of patenting of more fundamental scientific output).
<p>Scientific production</p> <ul style="list-style-type: none"> A model of the emergence of proprietary science needs to capture the production of science. A model of the emergence of proprietary science needs to capture the reproduction of academic labs. 	<ul style="list-style-type: none"> Each lab is given a <i>lab reproduction routine</i>, whereby new labs are "hatched" from <i>successful</i> parents with some amount of random mutation. 	<ul style="list-style-type: none"> We build on existing autocatalytic models of economic production where scientific labs are made up of skills that transform scientific products into other products in the form of a knowledge advancement routine. Lab survival depends on having skills that are replicated when knowledge is successfully transformed and advanced to another lab. Each lab is given a <i>lab reproduction routine</i>, whereby new labs are "hatched" from <i>successful</i> parents with some amount of random mutation.
<p>Knowledge disclosure</p> <ul style="list-style-type: none"> Modeling emergence of proprietary science requires capturing the character of discrete inventions and the heterogeneity of perceptions about patenting such inventions in the context of professional norms and values of science. 	<ul style="list-style-type: none"> Opportunities to change disclosure practices and opportunities to produce science are strongly linked. Patenting was a contingent choice that varied across scientists, depended on characteristics of particular findings, and was subject to change at each disclosure opportunity. The decision of whether to patent involved both one's own perceptions of patenting and one's own perception of the importance to science of the idea produced. 	<ul style="list-style-type: none"> Each lab is given a <i>knowledge disclosure routine</i> that is activated by the knowledge production process. Each lab agent in the model has a different <i>patenting threshold</i>, and each scientific product has a different <i>science value</i> on a scale of 1–100. During the disclosure routine, the lab compares its patenting threshold to the <i>science value</i> of the finding.

Table 1 (cont'd)

Critical insights	Constructs and assumptions	Computational representation
	Learning and adaptation of labs	
<ul style="list-style-type: none"> Modeling the emergence of proprietary science requires disentangling different sets of social relations. Modeling the emergence of proprietary science requires disambiguating different forms of decision making. 	<ul style="list-style-type: none"> Scientists were influenced by the practices of transaction partners and learned from those who were successful in patenting the downstream developments of their work. Scientists were concerned about the consequences on their own research programs and flow of rewards incurred by proprietary uses of their science. Labs reacted to others having patented the further development of their work by adapting their own proclivity to patent. Scientists were cognizant of the ability of others to build on their research and commercialize it. They preempted transaction partners' ability to patent their own research by adapting their own practices in advance. Scientists were cognizant of the commercial opportunities of their work. Labs adapted to the patenting taking place among their peers over the same kind of science by choosing to patent themselves. 	<ul style="list-style-type: none"> Each lab is given a <i>learning-by-doing routine</i>: labs retrospectively update their individual thresholds when a transaction partner gets the reward in a knowledge advancement transaction. Each lab is given a <i>conformity routine</i>: labs retrospectively update their threshold when they observe a more liberal threshold among colleagues. Each lab is given a <i>preemption routine</i>: labs prospectively update their individual thresholds based on the existence of more liberal transaction partners. Each lab is given an <i>anticipation routine</i>: labs prospectively update their individual thresholds based on the existence of more liberal thresholds among colleagues.

3.1.2. Forms of Knowledge Disclosure. Scholarship demonstrates that opportunities to change disclosure practices and opportunities to produce science are strongly linked (System Feature B). At its origins, patenting was a contingent choice that varied across scientists, depended on characteristics of particular research findings, and was subject to change at each disclosure opportunity. Therefore the decision to patent in our model depends on (1) a scientist's orientation toward patenting's legitimate use within the norms of academic science and (2) the perceived significance of a particular finding to advancing science. Our rationale links to academic rewards, because basic findings that are more important to the progression of science are also more vulnerable to exclusion by property rights. Furthermore, exclusion through IP would negatively affect citations of the inventor's work, which is an important mode of reputation and career advance. Our approach makes knowledge disclosure an endogenous decision, whereby patenting is an episodic attribute of each incidence of a research finding, rather than of an individual, and can change at each decision opportunity that arises with a research finding. Therefore we distinguished between publishing and patenting as forms of knowledge disclosure, and we also related the character of a finding to a scientist's orientation toward IP.

3.1.3. Lab Learning and Adaptation. Acknowledging social and cognitive influences in the adoption of new practices (System Features C and D), we distinguish between sets of social relations and forms of decision

making (see Figure 2). The sets of social relations, represented by the rows, reflect how change occurs from one's own and others' experiences. We distinguish between two sets of social relations—those that arise through the production of knowledge (production partners) and those that arise through social proximity (network neighbors). In the former, knowledge accumulates through the experience of joint production of knowledge; in the latter, labs use socially proximate others, with whom they do not necessarily engage in production, as a frame of reference to guide one's own interpretation of what is socially acceptable.

Forms of decision making (represented by columns) distinguish between prospective decision making, which directs attention to what others might do, and retrospective decision making, which directs attention to the results of prior experience. In practice and within the

Figure 2 Learning and Adaptation of Labs

		Decision making	
		Retrospective	Prospective
Social relations	Production partners	Quadrant a: Learning-by-doing	Quadrant c: Preemption
	Network neighbors	Quadrant b: Conformity	Quadrant d: Anticipation

social system of science, retrospective decision making shapes a lab's perspective in two important ways: it not only narrows attention to what has only occurred in the past but also mobilizes the consequences of the past to direct future disclosure decisions. In contrast, prospective decision making shapes a lab's perspective by expanding attention to what others hypothetically could do in the future and also by deploying those perceptions to direct an immediate, rather than future, disclosure decision.

The intersection of these two dimensions yields four change mechanisms that can lead to emergence (see Figure 2), to which we refer as learning-by-doing, conformity, preemption, and anticipation. *Learning-by-doing* (Quadrant a: Retrospective decisions × Production partners) denotes the process through which labs change their behavior after observing the consequences of their actions in the production of their own science—for example, when labs learn that they got the short end of the stick in a collaboration. *Conformity* (Quadrant b: Retrospective decisions × Network neighbors) denotes the process through which labs change their behavior after observing the consequences of others' actions—for example, when they conform to what peers do after they see the rewards gained when colleagues patented. *Preemption* (Quadrant c: Prospective decisions × Production partners) denotes the process through which labs preemptively change their behavior prior to disclosing their findings by observing what their production partner might potentially do—for example, when labs patent their findings to maintain the autonomy and control of their own research results. Finally, *anticipation* (Quadrant d: Prospective decisions × Network neighbors) denotes the process through which labs change their behavior prior to disclosing their finding by anticipating what their broader set of peers might do—for example, when labs use their perceptions that peers would patent as a justification that they can legitimately patent their own research finding.

3.2. Computational Operationalization

For the underlying evolutionary engine of the model, we borrow from and build on a well-tested ABM of economic production developed by Padgett (1997) and Padgett et al. (2003, 2012), which has subsequently been adapted for the context of knowledge production (Colyvas and Maroulis 2012).⁴ We further modify this model here to account for the mechanisms of emergence-based institutionalization implied by our critique and synthesis of the literature in the previous section. The primary elements of our model are (1) scientific products, (2) laboratories whose actions and decision making are governed by routines, and (3) collegial ties that connect those laboratories. The basic idea of the model is that laboratories contain skills (what we

Table 2 Model Elements

Model element	Attributes
Primary elements	
Scientific products	<i>Scientific importance, product type, patented</i>
Laboratories	Defined by skills and routines they own
Collegial ties	<i>Usage</i>
Lab-owned elements	
Knowledge transformation skill	<i>Input product type, output product type</i>
Disclosure routine	<i>Patentability threshold</i>
Laboratory reproduction routine	<i>Mutation</i>
Learning-by-doing routine	α
Conformity routine	α
Preemption routine	N/A
Anticipation routine	N/A

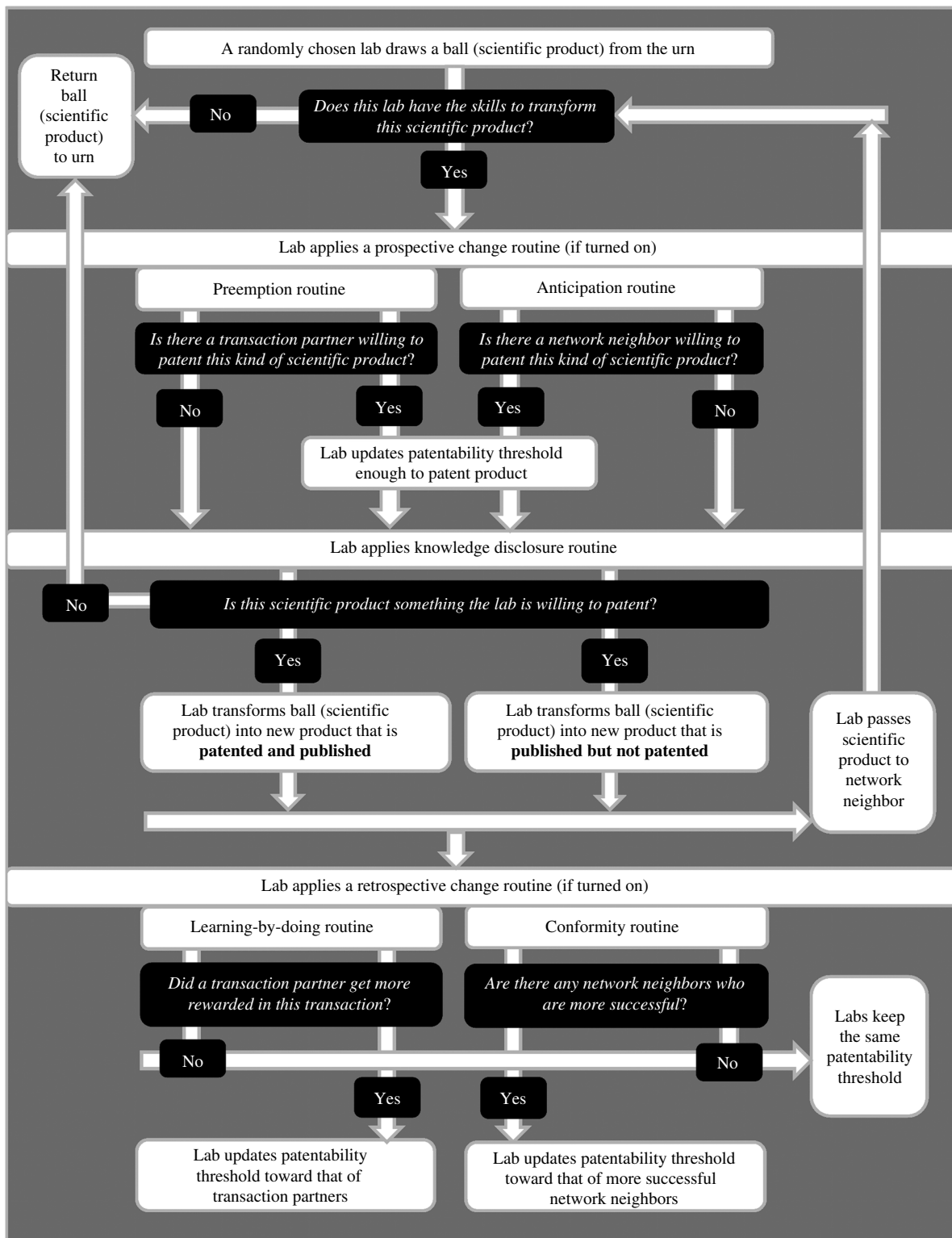
will call “knowledge transformation skills”) that transform one type of scientific product into another type of scientific product that can potentially be used by other labs. The knowledge transformation skills used often by labs are strengthened relative to those that are not, and the stronger skills (and hence labs that possess them) are more likely to survive over time. Laboratories also contain a set of routines that govern knowledge disclosure and allow labs to change. Consequently, we are able to experiment with an evolutionary process with routines that capture the interactive mechanisms that lead to emergence-based institutionalization enumerated in our critique. We can also experiment with a process that reflects the idea that organizational rules in a field (the patenting practices in scientific labs) did not evolve independently from the actual work of the field (the production of knowledge). We describe the model in greater detail below by delineating its primary elements (see Table 2), routines, and the sequence in which they occur (see Figure 3).⁵

3.2.1. Primary Elements of the Model. The model has three primary elements: scientific products, laboratories, and collegial ties.

Scientific products reflect research findings in their many tangible and intangible forms—from materials to tools to ideas—and are modeled as balls waiting in an urn for use by a lab. Scientific products have three attributes: product type, scientific importance, and disclosure type. *Product type* is modeled as a number from 1 to n to represent qualitatively different scientific products. *Scientific importance*, modeled as a number from 1 to 100, reflects the degree of scientific value a given product has to the progression of the field of science. *Disclosure type* simply captures whether a product was published only or patented as well. The model was initialized with 4 product types and 50 unpatented products (initially comprising approximately equal amounts of each product type).

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Figure 3 Flowchart of Modeled Social System of Scientific Production



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Laboratories in the model are bundles of skills and routines. Each lab has a *patentability threshold*, which is represented as a numerical value that corresponds to the scientific importance of products. This value sets the upper limit for which each lab will patent a particular scientific product. The disclosure routines of labs can change, depending on the experimental variation of the model. The model contains 100 labs initially arrayed spatially on individual sites of a 10×10 grid with wraparound borders.

Collegial ties represent the ways in which labs can interact (i.e., pass transformed scientific products). Each lab has a set of *network neighbors* that identify those labs with which the focal lab shares a collegial tie and are therefore understood as socially proximate to the focal lab. A subset of those network neighbors are *production partners*, which refer to those labs that have successfully transformed a scientific product with the focal lab. We utilize the terms “collegial ties” and “network neighbors” interchangeably. A lab’s initial collegial ties are its spatial neighbors (Moore neighborhood), but this can change over time. The *usage* of a collegial tie keeps track of the number of successful transactions between the labs it connects. As the simulation progresses, low-usage collegial ties are replaced with new ties to the progeny of the lab.

3.2.2. Lab-Owned Elements. *Knowledge transformation skills* represent each lab’s capabilities to transform a scientific product of one type to a product of another type. For example, when a lab has a skill of $2 \rightarrow 4$, it can transform a scientific product of type 2 to one of type 4. The model is designed to permit any combination of n types except for self-transformations (e.g., $2 \rightarrow 2$). Since our model contains $n = 4$ product types, 12 different knowledge transformation skills are possible. The model was initialized with 200 instances of transformation skills, where each instantiation was a random draw from the set of 12 possible skills. The 200 instances of skills were distributed randomly across the labs with uniform probability.

The *disclosure routine* provides the means by which a lab evaluates the patentability of a scientific product. When a lab evaluates a scientific product, it compares its own patentability threshold to the scientific importance of the product. If the scientific importance of the product is greater than the patentability threshold, then the lab will not patent. Unless otherwise noted, the patentability threshold of each lab’s disclosure routine was randomly determined by a draw from a normal distribution with a mean of 15 and a standard deviation of 2. The learning and adaptation routines (described below) delineate the ways in which a lab can change its patentability threshold over time.

The *laboratory reproduction routine* permits a parent lab (when chosen) to produce offspring and initializes

the patentability threshold of that offspring. More specifically, the patentability threshold of the child is a random draw from a normal distribution with the mean equal to the parent lab’s patentability threshold and the standard deviation equal to an exogenously determined parameter, *mutation*. When born, the child inherits a collegial tie to the parent, as well as the parent’s network neighbors.⁶

The *learning-by-doing routine* provides a means by which a lab can update its patentability threshold after every transaction where its production partner was rewarded more than it was. The learning-by-doing routine recalculates the patentability threshold of the focal lab as the weighted average of its current threshold and that of the production partner who was more successful. The partner’s weight is determined by the exogenous parameter, α , and the focal lab’s weight is determined by $1 - \alpha$. Unless otherwise noted, α was set to 0.2 in all runs of the model.

The *conformity routine* is identical to learning-by-doing, except that the lab that influences the change is not a previous transaction partner. Instead, it is a randomly selected lab from a comparison group composed of “more successful” network neighbors—i.e., neighbors that have accumulated a larger number of production rules than the focal lab.

The *anticipation routine* permits a lab to patent a product in anticipation of what others might do with a scientific product, regardless of whether a focal lab’s disclosure routine views that product as patentable. Specifically, when a focal lab has a network neighbor whose disclosure routine deems a product patentable, the focal lab updates its patentability threshold to the minimum level that allows the product to be patented.

The *preemption routine* is identical to the anticipation routine, but with an additional condition: the network neighbor not only has a disclosure routine that would lead to the patenting of the product but also is a potential production partner; that is, the network neighbor must have the skills required to advance the knowledge it will receive.

3.3. Knowledge Production and Disclosure Process

The following steps occur within each time step of the model:

1. A lab with at least one knowledge transformation skill is chosen at random to draw a ball (scientific product) from the urn to evaluate.⁷
2. The lab reviews its knowledge transformation skills to decide whether the scientific product is something it can transform. If so, it then initiates its disclosure routine to evaluate whether the drawn product is something appropriate to patent.
3. If “anticipation” or “preemption” is on, the lab initiates its anticipation or preemption routine.
4. Evaluation of the drawn scientific product can result in one of three potential outcomes: If the scientific product under evaluation is not something the lab

has the skill to transform, then the lab returns it to the urn. If the scientific product is something the lab can transform, but is not something it is willing to patent, then the lab transforms and advances it to one of its randomly selected network neighbors. This outcome represents a scientific product that is only published and is not patented. If the scientific product is something the lab can transform and is willing to patent, then the lab not only transforms the scientific product but also patents it. The ball is subsequently advanced to one of its randomly selected network neighbors.⁸

5. The receiving network neighbor evaluates the scientific product just as though it had been drawn from the urn. If the scientific product is not something that the receiving network neighbor can transform (i.e., does not have a corresponding skill), then the network neighbor puts the ball back into the urn. If the scientific product is something that the receiver can transform, it does so and then passes it on to one of its own network neighbors. The model then codes this result as one of four possible “successful” transactions between the initial sending and receiving labs: publication–patent transaction, whereby the sender patents but the receiver does not; publication–publication transaction, whereby neither the sender nor the receiver patents; patent–patent transaction, whereby both the sender and the receiver patents; and patent–publication transaction, whereby the sender patents but the receiver does not. The passing of the scientific product continues until the product encounters a lab that cannot transform it, at which point it is passed back to the urn.

6. Labs receive rewards for successful transactions through a duplication of the knowledge transformation skills involved in the transaction. For each duplicated skill, a randomly chosen one elsewhere in the system is destroyed. Consequently, the more copies of transformation skills, the higher a lab’s relative chances of survival. Which labs and skills are rewarded depend on the transaction type. Publication–publication transactions duplicate the sender’s knowledge transformation skills, but not the receiver’s, reflecting the sender’s benefit from citations from another lab. Publication–patent transactions duplicate the receiver’s knowledge transformation skills, reflecting the receiver’s benefit from obtaining a patent, and that the sender captures neither benefit from participating in the patent nor from gaining citations. Patent–publication transactions also duplicate the receiver’s knowledge transformation skills. The receiver gains from publishing, but the sender does not gain from the right to exclude others from using a scientific product. Finally, patent–patent transactions duplicate both the sender’s and the receiver’s knowledge transformation skills, since both benefit from obtaining a patent.

7. If “learning-by-doing” or “conformity” is turned on, labs initiate their learning-by-doing or conformity routine.

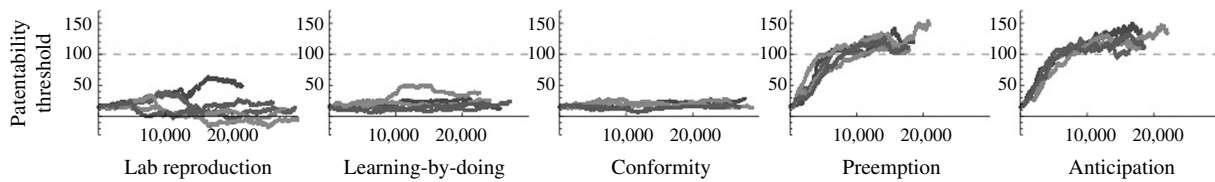
8. Labs with no remaining knowledge transformation skills are destroyed and are replaced by offspring of another randomly chosen lab. The probability of a lab being chosen to reproduce is proportional to its quantity of knowledge transformation skills.

4. Experimental Results and Refined Propositions

Our computational experiment compared five distinctive mechanisms, represented as routines in our model, that can lead to the emergence of proprietary science: (1) the baseline case of laboratory reproduction only, (2) reproduction plus learning-by-doing, (3) reproduction plus conformity, (4) reproduction plus preemption, and (5) reproduction plus anticipation (see Figure 2). In practice, all can operate simultaneously. A great advantage of ABM is that we investigate what happens if one or more of those mechanisms are “turned off.” We experiment to see whether any of those mechanisms has more leverage than the others in the emergence of proprietary science, our primary outcome of interest, represented as a shift in the mean of the patentability thresholds across labs at the final time period of a run.

Figure 4 depicts sample results under the baseline case and each experimental condition. The *y* axis of each graph is the mean patentability threshold across all labs, and the *x* axis is *time* measured by the number of successful transactions that have occurred between labs. Each plotted line on a single graph comes from a separate run of the model under that particular experimental condition. The dashed horizontal line represents a patentability threshold of 100, above which all products are patented. In all runs under all conditions, the initial mean patentability threshold of the labs was equal to 15. First, note the slight variability within each condition. This variability reflects the fact that each run of the model is a single realization of a process that has multiple stochastic elements. In the baseline “lab reproduction” condition, for example, random mutation sometimes leads to an upward drift in thresholds but at other times drifts to below 0. Second, note that under both the preemption and anticipation conditions, the mean patentability threshold climbs to over 100 for all five runs. This suggests that moving from a very low to very high mean patentability threshold in a population of labs is more likely to occur when reproduction is coupled with prospective forms of decision making than it is when reproduction coincides with retrospective forms of decision making, regardless of the kind of social relations (i.e., whether they are ties through production partners or network neighbors).

To more systematically investigate this finding, every run was repeated 50 times for each experimental condition to create a distribution of outcomes for analysis. Figure 5 presents the results for the 50 runs within

Figure 4 Model Dynamics for Each Separate Run Mean Patentability Threshold Over Time (Five Sample Runs per Condition)

each experimental condition. The x axis plots the mean patentability threshold across the labs at the end of a run, along with its corresponding 95% confidence interval. The y axis indicates the mechanism (in addition to the baseline reproduction process) that was turned on for that experimental condition. Figure 5 confirms the findings from the analysis of the dynamics of the individual runs. For the baseline case of only reproduction, as well as for both retrospective mechanisms (learning-by-doing and conformity), the mean patentability threshold remains essentially unchanged from its initial mean of 15. Instead, the prospective forms of decision making (preemption and anticipation) produce results that resemble our reference pattern—a large, left-to-right shift in the distribution of patentability thresholds.

The intuition follows: the reproduction, learning-by-doing, and conformity mechanisms share the characteristic of reinforcing the existing norm in the system. Given the simulation's initial state, this characteristic results in the maintenance of low patentability thresholds. In other words, the retrospective mechanisms (learning-by-doing and conformity) require the a priori existence of a successful high patentability threshold to emulate. On the other hand, all that is required with the prospective mechanisms (preemption and anticipation) is that someone close by has a slightly higher threshold than the “threatened” lab, whether it is a scientific transaction partner or merely a network neighbor. Once the threatened lab changes its patentability threshold, then that change makes it more likely that it will become a “threatener” to other labs, which in turn may choose to

take prospective action. Stated differently, the retrospective mechanisms need a “seed” to diffuse in the population, whereas the prospective mechanisms do not—they require only small threshold variations across labs. Interestingly, the difference between the retrospective and prospective mechanisms is not terribly sensitive to the number of initial outliers in the population of labs. Although not shown here, we experimented with a bimodal distribution of initial thresholds whereby labs were centered around a “low” (15) and a “high” (85) mean, varying the fraction in the high group from 0 to 0.5. Although the population's mean threshold increases, increasing the proportion of “highs” did not produce a large shift in the threshold distributions.⁹

More generally, we experimented extensively to understand (a) other model conditions that might bring about a shift in patentability thresholds and (b) when prospective mechanisms would *not* lead to such a large shift.¹⁰ Figure 6 answers the first part of that question: all mechanisms can increase the patentability threshold if the survival/reward environment strongly favors the new practice (patenting). We implemented this change by replicating skills involved in successful patented transactions 10 times instead of 2 as in the baseline case (leaving the nonpatenting rewards the same). In this case, all mechanisms lead to mean patentability thresholds of over 100. Consequently, the prospective mechanisms (preemption and anticipation) appear to play a secondary role in explaining a shift to higher thresholds in this case.

On the other hand, modifying the survival/reward environment to favor the status quo shows that the result

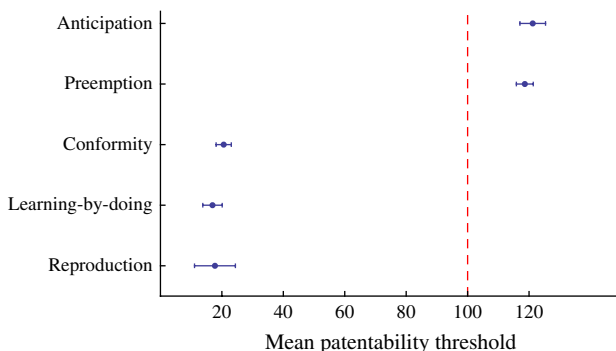
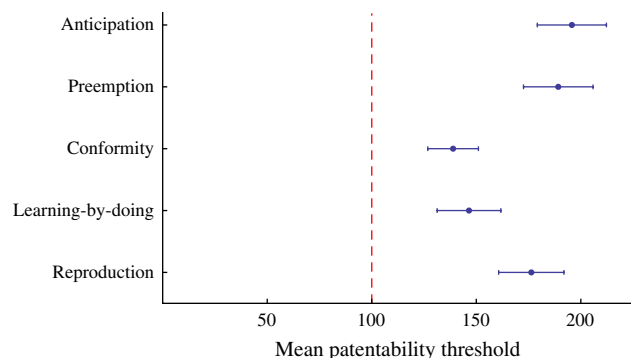
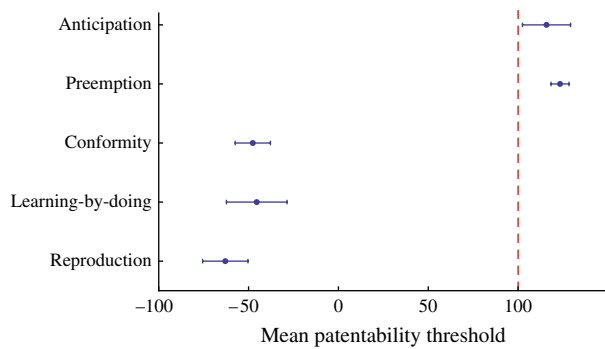
Figure 5 (Color online) Mean Patentability Thresholds by Condition: Neutral Environment**Figure 6 (Color online) Mean Patentability Thresholds by Condition: Environment Favors New Practice**

Figure 7 (Color online) Mean Patentability Thresholds by Condition: Environment Favors Status Quo



is rather robust (see Figure 7). Running an experiment that inverts the reward environment—whereby skills are replicated for *not patenting* 10 times after successful transactions—still does not prevent the prospective mechanisms from driving a large shift in thresholds.¹¹

The results from our computational experiments underscore the varying and contingent roles of mechanisms thought to be responsible for the institutionalization of new practices. We operationalize that understanding in the form of revised propositions about the likelihood that emergence-based institutionalization will occur.

Proposition 1 encapsulates a claim in the literature related to the often-discussed “imprinting” or “reproduction” mechanism.

PROPOSITION 1. *Emergence-based institutionalization will occur through the reproduction of organizational forms, as parent organizations with varying orientations toward a new practice pass their proclivities on to offspring organizations, such as academic labs that pass their skills to students who go on to establish labs of their own.*

Our analysis of our baseline lab reproduction only case, however, illustrates that without help from an additional mechanism or a favorable environment, Proposition 1 does not necessarily hold. We therefore refine Proposition 1 into the following two parts.

PROPOSITION 1A. *The reproduction of organizational forms will have a stronger role in reinforcing existing rules in place than driving the emergence of new ones.*

PROPOSITION 1B. *The reproduction of organizational forms will more likely contribute to emergence-based institutionalization when the survival/reward environment strongly favors the new practice over the existing one.*

Proposition 2 articulates an idea prominent in social perspectives in the emergence of proprietary science—namely, that change takes place through interaction with others.

PROPOSITION 2. *Emergence-based institutionalization will occur through interaction with different sets of social relations, such as when labs learn by engagement with others in producing science and also conform by observing a broader set of peers.*

Our model assumes that social interaction plays an integral role in change, but distinguishes between interactions with production partners and interactions with a broader set of peers. If this distinction mattered to the likelihood of emergence-based institutionalization, one would expect to see differences between the learning-by-doing and conformity conditions or differences between the preemption and anticipation conditions in our experiments in Figures 5–7. We did not find such differences, suggesting the following refinement.

PROPOSITION 2A. *Differences in the sets of social relations alone will not impact the likelihood of emergence-based institutionalization.*

Proposition 3 captures a key idea from organizational learning and decision-making literature that emphasizes the importance of cognitive processes in learning and adaptation.

PROPOSITION 3. *Emergence-based institutionalization will occur through both backward-looking and forward-looking decision making, such as when labs alter their disclosure behavior retrospectively through prior experience in commercializing science or prospectively through the anticipation of what others might do with their science.*

Our analysis and results speak most clearly with respect to this distinction. Figure 5 shows that the prospective mechanisms (preemption and anticipation) lead to a large shift in the threshold distributions, whereas the retrospective mechanisms (learning-by-doing and conformity) do not. Figure 6 shows that this difference is even more pronounced even in cases where the incumbent practices were strongly favored by the environment. Therefore, we can refine Proposition 3 to reflect these contingencies and differences.

PROPOSITION 3A. *Emergence-based institutionalization will more likely occur when decision-making processes are prospective.*

PROPOSITION 3B. *Differences in the forms of decision making will more greatly impact the likelihood of emergence-based institutionalization when the survival/reward environment strongly favors the old practice over the new one.*

5. Discussion and Conclusion

Taken together, the propositions resulting from our computational case study approach represent the primary contribution of this work: a refined understanding of the

contingent roles of social and cognitive mechanisms in emergence-based institutionalization. More specifically, our results suggest that unless strongly aided by selection forces, reproduction mechanisms and the retrospective mechanisms of learning-by-doing and conformity are unlikely to lead to an exception becoming a rule. The opposite is true of the prospective mechanisms of preemption and anticipation, however, which can lead to institutionalization even when selection forces strongly favor the status quo. These findings have implications for our focal case of the emergence of proprietary science. They also contribute more generally to the analysis of mechanisms in institutional persistence and change.

With respect to our focal case, most studies treat the emergence of proprietary science as a top-down, induced effort or as the result of social contagion and individual propensities, overlooking disclosure practices when patenting was first introduced (Colyvas 2007b, Shapin 2008). Other studies emphasize the imprinting effect of training in entrepreneurial labs as a primary means of institutionalizing commercial practices in the academy yet, without distinguishing when this mechanism drives change, merely supports it or actually slows change down (Powell and Colyvas 2008). Our analysis speaks to this existing work on the spread of patenting in several ways. First, we demonstrate the difficulty of attaining a self-reinforcing system of proprietary disclosure through mechanisms that prevail in contemporary analyses of scientific production. In particular, many studies emphasize the importance of the entrepreneurial imprint that takes place through exposure in the training process (e.g., when doctoral students gain experience in more commercially oriented labs). All other things being equal, our analysis suggests that this imprinting-through-training mechanism is more likely to reinforce disclosure practices that are already in place than to kick-start profound change. Second, diffusion is often used as an indicator of institutionalization, but it can reflect a host of processes, including fads, which never take on the self-reproducing character of institutionalization (Scott 2001, Schneiberg and Clemens 2006, Colyvas and Jonsson 2011). We have turned this problem on its head: rather than focus on the spread of a structure and multiple means of contagion, we deconstruct the cognitive, social, and normative processes behind different forms of influence. By making the distinction between influences from different sets of social relations and different forms of decision making, we found that the likelihood of seeing an extreme shift in the distribution of lab patentability thresholds was much more sensitive to changes in the latter than the former. Moreover, the differences were most pronounced in cases when the survival/reward conditions greatly favored incumbent disclosure practices.

By design, the characteristics of the system we modeled in this paper were motivated by observations, mechanisms, and theoretical insights from our focal case of

patenting in the academy. They were operationalized, however, with the application to other contexts in mind. For example, with respect to our strongest finding about the leverage of prospective decision making, the inclusion of a prospective mechanism was motivated by the observation in the focal case of scientists desiring to keep control of their intellectual property. Our actual model, however, is agnostic to the underlying motivation of the lab. All that is technically required is a response based on an evaluation of the extent to which another organization can capitalize on a lab's actions in the future. Consequently, our finding with respect to prospective decision making and emergence is likely to apply in any competitive environment where a reason for taking preemptive or anticipatory action toward another organization exists.

Although the findings in this study are not solely limited to the case of patenting in the academy, at least two broad assumptions in our approach should be kept in mind. First, our definition of emergence-based institutionalization refers to cases where practices shift from rare and unacceptable to widespread and legitimate through bottom-up relational processes. To the extent that field-level change is driven in a more top-down or centralized manner, statements such as Proposition 3 that emphasize the importance of prospective decision-making mechanisms in institutionalization have less applicability. Moreover, it is important to note that in our case, although patenting was a widely unaccepted practice, it was not entirely foreign to the actors in the system. Our findings may not apply as well in contexts where the actors in the system know so little about the practice that they are unable to develop initial decision criteria for their adoptions. Second, the model in this study is predicated on the idea that institutionalization takes place in a highly competitive environment. To the extent that organizations do not need to compete to survive, our propositions also have less applicability. Indeed, in additional sensitivity analyses not reported here, we tested the extreme case of no competition by making the selection process randomly reward rules (as opposed to rewarding success). Without meaningful selection processes, the distinctions we observe among mechanisms disappear, with none leading to emergence.

With respect to broader theoretical and methodological contributions to institutional theory, we emphasize that explanations of emergence-based institutionalization must include the social and normative system that constrains practical action. It must also acknowledge institutions' constitutive role in defining actors, aspirations, and rules of appropriate action (Clemens and Cook 1999; Fligstein 2001; Drori et al. 2006, 2009; Hwang and Colyvas 2011). In many respects these features are built into our analysis—methodologically speaking, a computational model defines underlying units, their interactions, and core processes, thereby representing the

theory itself (Cohen and Cyert 1965, Carley and Gasser 1999, Harrison et al. 2007). In our case, we incorporated abstract aspects of our social system—namely, a competitive, self-reproducing, and relational system of skills, products, and organizations based on rules of knowledge disclosure and survival that together constitute a regularity of behavior, reflecting standard definitions of institutions (Scott 2001, Greif 2006).

The analysis of social mechanisms has provided a fertile basis for recent theory-building scholarship, particularly in the middle range (Anderson et al. 2006, Gross 2009, Hedstrom and Ylikoski 2010). We contribute to this work by operationalizing one case of institutionalization as a “middle range [computational] model” (Gilbert 2008, §3.3.2). In particular, our approach allows us to tackle two persisting puzzles in the application of mechanisms to institutional theory and organizational scholarship more generally. First, a growing literature underscores the challenges of studying mechanisms as systems unfold through time. As the “cogs and wheels” rather than the “nuts and bolts” of social science analysis, mechanisms are conceptually meant to induce a consideration of the entire system and the operation of constituent parts that produce effects (Hedstrom and Swedberg 1998, Hernes 1998, Davis and Marquis 2005). Yet their causal applications can artificially force “the theorist to freeze the process in question at a certain point in time...[and] induce a kind of reductionism that causes scholars to lose sight of the whole” (Anderson et al. 2006, pp. 108–109). Our analysis makes an important conceptual and theoretical contribution. In this paper, we demonstrate an approach for identifying the varying, dynamic, and contingent roles that mechanisms take in institutional persistence and change as social systems unfold over time; that is, we demonstrate how one can independently test the role of parts without losing sight of the whole. This distinction allows for the possibility that the role of an identified process, such as organizational reproduction, can change over time and vary under different conditions. We can thus demonstrate how certain mechanisms can reinforce existing arrangements, contribute to their transformation, and lead to emergence-based institutionalization.

Second, mechanisms may explain but do not necessarily predict which direction actors will take in responding to particular pressures and thereby affecting outcomes (Elster 1998, Davis and Marquis 2005). An individual’s response to a parent’s drinking by either embracing or eschewing alcoholism is an often-cited example (Elster 1998). Davis and Marquis (2005, p. 336) aptly described this puzzle in capitalist economies: “The quest for novelty... suggests that we will often be in this situation: confident that actors will respond to particular pressures, but uncertain in what direction. Thus, we may be able to explain afterward but not predict prospectively.” One approach to rectifying this issue is to examine microprocesses involved in the system as a whole

that explain the direction of effects on an outcome of interest. By examining multiple mechanisms and their effects, our approach permitted us to analyze the conditions under which a mechanism currently serving one role in a system, such as organizational reproduction, can play another role in that system, such as the emergence of a new practice.

Indeed, the problem of understanding the mechanisms that transform practices from an exception to a rule pervades the organization sciences as much as organizations themselves. From risky innovations to avant-garde fashions to more equitable hiring practices, understanding how the normative, social, and cognitive elements of institutions unfold over time is fundamental to understanding institutional change (Dobbin 2009, Ansari et al. 2010). Yet studying the dynamics and contingencies of institutional change poses the methodological challenges of distinguishing among competing mechanisms, as well as operationalizing the connection between lower-order action and higher-order structures (Vaughan 2002, Stinchcombe 2005). In this study, we have taken a step toward addressing such challenges and in doing so have contributed new theoretical insight into the contingent roles of different mechanisms in emergence-based institutionalization.

Supplemental Material

Supplemental material to this paper is available at <http://dx.doi.org/10.1287/orsc.2014.0948>.

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Endnotes

¹One can also think of this distinction as the difference between micro- and macro-face validation of a model (Rand and Rust 2011). We are using our empirical context as the basis for both.

²Note, however, that we are not using the reference pattern to directly conduct a best-fit calibration of the model, where the microlevel parameter values are selected in a manner that minimizes error with respect to the macrolevel pattern. Instead, we are simply ensuring that our model can qualitatively reproduce the case where the exception becomes the rule and the case where it does not—an approach closer to what Railsback and Grimm (2012, p. 259) called “categorical calibration.”

³The model was developed using the NetLogo multiagent programmable modeling environment (Wilensky 1999), a widely used and powerful environment used to model a large range of natural and social systems. See the online appendix (available as supplemental material at <http://dx.doi.org/10.1287/orsc.2014.0948>) for all codes.

⁴A primary reason for building on this particular evolutionary engine is that economic production is modeled as a set of self-reinforcing chains of skills, the strength of which determines firm survival—a characterization entirely consistent with the feature we desire for the production of scientific knowledge. For more detail, see Padgett (1997) and Padgett et al. (2003).

⁵The NetLogo code for the model is available in the online appendix.

⁶The total number of network neighbors is not allowed to exceed the initial maximum number of 8. In cases where the reproduction process leads to some labs having more than eight network neighbors, the lab destroys a link by selecting one at random from the set of links with which it has had the fewest successful transactions. Note that this does not imply that the link to the new child is the one that will be destroyed, as the lab typically will have one of several other links with zero transactions from which to choose.

⁷This “scheduling” decision—i.e., whether one or more labs picked at the same time—does not change differences observed across conditions described later in this paper.

⁸The product eventually makes it back to the urn for use by other labs, so it is effectively “published” as well.

⁹Results were similarly robust to our specification of the weight given α .

¹⁰We also tried to find ways to change the details of the evolutionary engine—such as the specification of the length of the production chains, the number of products, and the number of rules—in a manner that would invalidate the differences we see between the prospective and retrospective mechanisms. Our findings are robust with two exceptions, both of which lead to the process getting “stuck.” One is that at least one production chain must be self-reinforcing (e.g., include $1 \rightarrow 3$ and $3 \rightarrow 1$), or else the urn fills up with products that cannot be used as inputs, and the production process effectively comes to a halt. The second is that if mutation is exactly zero, all of an agent’s network neighbors converge to the same threshold value. As a result, there is nothing for that agent to “preempt,” and no threshold can increase past the highest initial value in the population.

¹¹In addition to experimenting with the relative magnitude of the patenting rewards, we also experimented with which member of a successful transaction (recipient or sender) was rewarded. In all cases, changing which member received the reward did not affect the primary result that prospective mechanisms more likely lead to emergence. The only way we could prevent such emergence was by entirely disassociating rewards and performance—i.e., when we forced the rewards to be distributed at random to any rule in the system and not on the basis of having participated in a successful transaction.

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