Strategic Entrepreneurship Journal
Strat. Entrepreneurship J., **11**: 287–305 (2017)
Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/sej.1259

Athena's Birth: Triggers, Actors, and Actions Preceding Industry Inception

Rajshree Agarwal,[1]* Mahka Moeen,[2] and Sonali K. Shah[3]
[1]Management and Organization, University of Maryland, College Park, Maryland
[2]Strategy & Entrepreneurship, University of North Carolina, Chapel Hill, North Carolina
[3]Strategy & Entrepreneurship Group, Department of Business Administration, University of Illinois, Champaign, Illinois

Research summary: *Industry evolution scholars define industry inception as the first instance of product commercialization, focusing on subsequent time periods of growth and maturity. Left understudied are the triggers, actors, and actions preceding industry inception. We integrate recent research in a preliminary framework, conceptualizing the incubation stage as activated by a "trigger" event—a scientific discovery, unmet user need, or mission-oriented grand challenges—and continuing through the first instances of product commercialization. We focus on illuminating actions of multiple and heterogeneous actors that help reduce high technological and demand uncertainty, thereby shaping industry structure and strategic action post-commercialization. To point, although the actors may be different, their actions follow a similar theme. We hope this framework spurs future research investigating the understudied incubation stage of new industries.*

Managerial summary: *Numerous visionaries—inventors, entrepreneurs, scientists, users, managers, policy makers, and others—spend decades laying the groundwork that leads to the creation of new industries. Their contributions are critical, yet have received little systematic attention. Here, we illuminate their actions during the understudied "incubation" stage sparked by a trigger event and culminating in the first instance of product commercialization. We begin by documenting three triggers: scientific and technological discoveries, unmet user needs, and mission-oriented grand challenges. We show that following a trigger event, visionaries solve the technological problems required to transform an innovative idea into a viable commercial product and engage potential adopters and stakeholders; they do this by both applying their existing knowledge base and engaging in experimentation. Their efforts set the stage for subsequent commercialization efforts.* Copyright © 2017 Strategic Management Society.

A rich literature spanning economics, strategy, marketing, sociology, and science and technology studies has examined industry evolution, focusing on how entrepreneurial activity following the first instance of commercialization reduces technological and demand uncertainty, shapes industry structure, and impacts firm strategy and performance (Abernathy & Utterback, 1978; Agarwal & Bayus, 2002; Bijker, Hughes, & Pinch, 1987; Gort & Klepper, 1982; Hannan & Freeman, 1977). In contrast to the extensive study of the takeoff and growth stages, less systematic attention has been paid to the time period *preceding* the first product commercialization, although scholars note industries incubate over an average duration lasting from

Keywords: entrepreneurship; industry evolution; nascent industries; innovation; knowledge
*Correspondence to: Rajshree Agarwal, University of Maryland, 4512 Van Munching Hall, College Park, MD 20742.
E-mail: rajshree@rhsmith.umd.edu
Authors contributed equally, and last names are listed in alphabetical order.

Copyright © 2017 Strategic Management Society

26 to 28 years (Agarwal & Bayus, 2002; Golder, Shacham, & Mitra, 2009). Recent work has started to examine the "incubation stage" (Moeen & Agarwal, 2017; Shah & Mody, 2014), defined here as the period between an initial *trigger* event and the first instance of product commercialization. Building on our review of this work, we ask: "What are the triggers of, and what types of actors and actions lead to, industry inception?"

Our integrative review of empirical work provides several insights into the incubation stage. First, we elaborate on the nature of the initial event activating the emergence of an industry, showing that industries can be initiated by several triggers, including scientific and technological discoveries (Moeen & Agarwal, 2017), unmet user needs (Shah & Tripsas, 2007), and mission-oriented grand challenges (Mowery, 2010). Second, we show each trigger systematically results in myriad actors engaging in innovative and entrepreneurial actions, bringing to bear diverse knowledge bases and experimental pathways to incubate the industry. Third, their actions relate to sensemaking and proactive investment in the presence of technological and demand uncertainty. It appears that although the triggers and actors may be different, the actions are similar: these efforts typically center around solving many technological problems to transform an innovative idea into a viable commercial product, as well as engaging potential adopters and stakeholders to gauge demand potential.

These insights set the stage for fruitful avenues for future research on the entrepreneurial actions that characterize the incubation stage of industries. We highlight several questions pertaining to a deeper study of this stage, the answers to which should help us understand how the "pre-life" of an industry may determine the structure, strategy, and performance consequences during its more traditional life cycle stages post-commercialization.

Research Gap

The Emergence and Growth Stages of the Industries: A Brief Review

In Greek mythology, Athena, the goddess of intelligence and reason, sprang out of Zeus' forehead fully grown and in a full set of armor. She soon evolved to become the patron of city and civilization, promoting the arts and agriculture and defending the city from outside enemies. Similarly, the literature on industry evolution marks the inception of the new industries at the time of first commercialization and studies subsequent growth and evolution due to innovation and entrepreneurship. The generic industry life cycle model documented across numerous industries illustrates an early quasi-monopoly period, followed by accelerated market entry of firms during the emergence or growth stage, sharp decline in the number of firms during the shakeout stage, and an eventual mature stage with low levels of firm entry and exit (Abernathy & Utterback, 1978; Gort & Klepper, 1982; Hannan & Freeman, 1977).

The early quasi-monopoly and growth stages are particularly relevant for understanding industry emergence processes. The early quasi-monopoly stage occurs immediately after the first product commercialization. This stage is often characterized by the narrative of lone inventors such as Edison or the Wright Brothers toiling away in isolation as they transform their ideas into reality. Accordingly, most industry evolution models assume industries emerge from a monopoly on the innovation process (Gort & Klepper, 1982; Jovanovic & Macdonald, 1994) or take the innovation to be a given/exogenous (Rao, 1994; Sine, Haveman, & Tolbert, 2005).

During the emergence or growth stage of industry evolution, there is a steep rise in the number of firms. Scholars of economics, organizations, and technology have extensively examined factors leading to firm entry during this stage (Agarwal & Tripsas, 2008). Evolutionary economics scholars note information sources, accumulated stock of knowledge, and rates of interfirm knowledge diffusion as key factors influencing firm entry (Agarwal & Gort, 2001; Gort & Klepper, 1982), and they link takeoff in firms to takeoff in industry sales (Agarwal & Bayus, 2002). Science and technology studies scholars have examined evolution of technologies through technological design improvements by social groups (Bijker, 1997; Bijker et al., 1987; Oudshoorn & Pinch, 2003), and creation/prototyping of innovative new features by individual users (Franz, 2000; Kline & Pinch, 1996). Organizational theorists highlight how firm density is shaped by forces of legitimization and competition (Aldrich & Fiol, 1994; Hannan & Freeman, 1977) and note the role of social

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

movements (Hiatt, Sine, & Tolbert, 2009; Pacheco, York, & Hargrave, 2014; Rao, 1994; Sine et al., 2005; Weber, Heinze, & DeSoucey, 2008) and socio-cognitive categories (Santos & Eisenhardt, 2009; Wry, Lounsbury, & Glynn, 2011) in influencing entrepreneurial entry and legitimizing industries. Technology management scholars attribute the rise in the number of firms to the need for experimentation prior to dominant design (Abernathy & Utterback, 1978; Tushman & Anderson, 1986), and they link experimentation paths to heterogeneity in firms' prior knowledge (Kapoor & Furr, 2015) or cognitive frames (Anthony, Nelson, & Tripsas, 2016; Benner & Tripsas, 2012; Garud & Rappa, 1994).

The Understudied Incubation Stage

Lesser-known features about Athena's birth are the events occurring *prior* to her springing forth from Zeus' head. Zeus, the god of war, and Metis, the goddess of thought, procreated. Zeus later swallowed the unborn child and her mother, providing the time and opportunity for Athena to gain knowledge and warrior skills before emerging to the public eye as a fully armed and grown goddess of intelligence and reason.

Similarly, understudied features of new industries relate to the set of actors and actions prior to an industry's inception. Two implicit assumptions may have limited our understanding of these precursors of industry inception. First, most of the industry evolution literature has characterized the starting point of an industry as the first instance of product commercialization, thereby leading to a lack of attention to the incubation stage that precedes the first product commercialization (Moeen & Agarwal, 2017). In part, because the available data sources often lacked richness of information on actors and their actions during industry incubation stage, studies have been limited to a few historical narratives (Cortada, 1993; Greenstein, 2015; Mody, 2006; Rosenbloom & Cusumano, 1987) or comparison between invention and commercialization times of new products (Agarwal & Bayus, 2002; Enos, 1962; Golder et al., 2009). However, recent research points to the need to question this implicit assumption. During the incubation stage, with an average duration of 28 years across numerous industries (Agarwal & Bayus, 2002), heterogeneous actors seem to shape industry architecture and underlying knowledge bases through investments that transform opportunities into commercial products (Moeen, 2017; Moeen & Agarwal, 2017; Shah & Mody, 2014). Concurrently, actors seem to benefit from the formative incubation stage to construct the socio-cognitive category and collective identity of an industry (Bingham & Kahl, 2013; Navis & Glynn, 2010).

Second, most industry evolution scholars have focused on high-technology industries as empirical contexts, leading to a disproportionate attention on scientific discoveries as triggers that initiate the industry incubation stage (Dosi, 1988). This is an appropriate characterization of biotechnology, nanotechnology, and information technology discoveries, each of which led to the emergence of multiple industries (Rothaermel & Thursby, 2007). However, recent research highlights unmet needs of users (Shah & Mody, 2014; Shah & Tripsas, 2007) and mission-oriented grand challenges (Klepper, 2016; Mowery, 2010) as other important triggers leading to industry emergence. For example, user needs initiated the investments preceding probe microscopy (Mody, 2006) and the windsurfing, skateboarding, and snowboarding equipment industries (Shah, 2003). Similarly, mission-oriented grand challenges to address national security or public health needs were critical to the emergence of the penicillin industry (Klepper, 2016).

Relaxing these two assumptions provides valuable research opportunities for extending the industry emergence literature by not only inquiring about the variety of actors and actions during the industry incubation stage, but also understanding different triggers that initiate the incubation stage. Figure 1 visually depicts the incubation stage in the context of the industry life cycle.

Conceptual Framework

We begin with a review of the studies of industry incubation stage in the current literature. We bring together empirical documentation of triggers, actors, and actions preceding industry inception, and we then identify themes characterizing the incubation stage following individual triggers. Based on our integrative literature review, we identify and discuss three *trigger* events that initiate the incubation stage of industries—scientific discoveries, unmet user

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

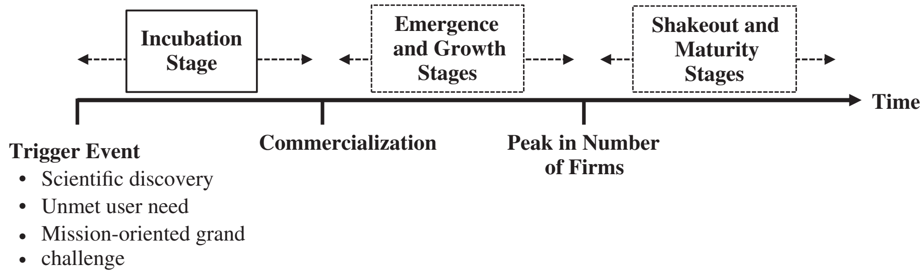

Figure 1. Incubation stage in the industry timeline.

needs, and mission-oriented grand challenges. Each type of trigger engages a relatively distinct set of heterogeneous *actors* who explore the new opportunity. The actors engage in a wide-variety of *actions*, which collectively help identify and build the potential for industry inception by resolving critical technological and demand uncertainties associated with transforming the opportunity to a commercialized innovation.

Industries Triggered by Scientific Discoveries

In 1908, George Shull at the Cold Spring Harbor Laboratory and Edward East at the Connecticut State College detected lack of deterioration in yield and vigor of inbred corn, a scientific discovery that would underpin the emergence of the hybrid corn industry (Griliches, 1957). Similarly, scientific discoveries are an initial trigger event of the incubation stage of many industries, including flat panel displays (Eggers, 2014), biopharmaceuticals (Zucker, Darby, & Brewer, 1998), nano-technology based (Rothaermel & Thursby, 2007), service robotics (Lechevalier, Nishimura, & Storz, 2014), solid-state lighting (Min & Sarkar, 2015; Sanderson & Simons, 2014), synthetic diamonds (Phaal, O'Sullivan, Routley, Ford, & Probert, 2011), CCD image sensors (Roy & Sarkar, 2017), and agricultural biotechnology (Moeen & Agarwal, 2017).

Such scientific discoveries overwhelmingly occur in universities or corporate research units, and these knowledge contexts privilege academic and industry scientists as actors who explore transformation of the scientific or technological opportunity into a commercial product. Much of the early stage work occurring in these contexts constitutes a noncommercial period emphasizing scientific advancement, motivated in part by the quest for new knowledge and incentivized by the norms of science (Merton, 1973). However, at some transition point, Agarwal, Audretsch, and Sarkar (2007) note that individuals face the choice of whether to pursue entrepreneurial action within existing organizations or to form a new venture. Depending on the route taken, the actors engage in university technology transfer, technology or academic entrepreneurship, or intrapreneurship within existing firms. In the case of hybrid corn, scientists in land-grant universities and agricultural experiment stations were at the forefront of early scientific exploration and basic research. However, starting in 1920, entrepreneurial founding of Pioneer Hi-Bred, Funk Seeds, Pfister Hybrids, and DeKalb marked a shift toward harvesting the commercial value. In biopharmaceuticals, 3 years after he discovered recombinant DNA discovery in 1973, Herbert Boyer bonded with venture capitalist Robert Swanson over their love of science and desire to apply biotechnology for human health benefits to found Genentech as the first university biotechnology spinoff (Weintraub, 2004). This set forth a stream of academic entrepreneurship, ultimately comprising 50% of biotechnology IPO activity (Audretsch & Stephan, 1996). In agricultural biotechnology, heterogeneity of actors is exemplified by the different pathways pursued by the three sets of scientists involved in the 1977 scientific discovery of Agrobacterium-mediated plant gene transfer. Jeff Schell and Marc van Montagu at the University of Ghent founded a university spinoff named Advanced Genetic Sciences in 1979. Monsanto scientists, Erin Jaworski, Rob Horsch, and Steve Rogers established a dedicated biotechnology unit within Monsanto in 1980. Mary-Dell Chilton from Washington University joined a diversifying entrant named Ciba-Geigy in 1983 (Charles, 2001). The heterogeneity of actors responding to the initial agricultural biotechnology trigger holds more generally, as Moeen and Agarwal (2017) show that

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

entrepreneurial start-ups, incumbents from the obsolescing seed breeding industry, and diversifying entrants each represented 26, 48, and 26% respectively, of firms making technological investments.

What did these actors focus on during the incubation stage, given there was no production of goods and services? The actions undertaken focused on addressing the substantial technological and demand uncertainty surrounding the idea. Importantly, both the nature of the uncertainty and the actions undertaken seem to be qualitatively different from what scholars have highlighted in the post-commercialization stages of the industry. In terms of technological uncertainty, the actions involved transforming basic scientific discoveries into usable applications. Further, there was a concomitant need to scout for advancements in complementary domains and integrate across diverse knowledge bases for viable prototypes. For example, the initial scientific discovery about the attributes of inbred corn was not by itself commercially useful. Even the follow-on procedure for corn breeding outlined by George Shull in 1909 yielded very small quantities of seed to create commercial value. Subsequent research programs at multiple universities motivated by knowledge-seeking aspirations or commercial opportunities helped resolve the technological challenges. After a decade of research, Donald Jones at Harvard University finally solved the problem by introducing four-way or double-cross hybrids in 1918, and this technical feasibility of producing abundant seeds spurred the development of several strains of hybrid corn by the early 1920s (Crow, 1998; Nelson, 1993). Likewise, in the flat panel display industry, an initial technical design became possible due to concurrent experimentation with liquid crystal and gas plasma displays within research units of IBM, Sony, Canon, Siemens, and Seiko-Epson, while benefiting from university advances related to amorphous silicon (Eggers, 2014). A similar case holds for the CCD image sensor and solid-state lighting industries, in which both firms and universities contributed to the gradual evolution of science in multiple competing paths (Roy & Sarkar, 2017; Sanderson & Simons, 2014).

In addition to the competing internal research experimentations, the extent of interaction with multiple external stakeholders for resolving technological uncertainty is remarkable, as firms typically engage in joint problem solving and collaborations to advance technical trajectories toward a commercial product. For example, the incubation stages of the biopharmaceutical and solid-state lighting industries were characterized by numerous alliances (Rothaermel & Thursby, 2007; Sanderson & Simons, 2014). Similarly, internal firm research in agricultural biotechnology was complemented by informal interfirm or university-firm information exchange processes, as well as by leveraging formal markets for technology and corporate control. In this context, the frequency of alliances and acquisitions in the 10 years preceding industry inception was 75 and 45% of the 10-year period following industry inception, respectively (Moeen & Agarwal, 2017). Further, firms' interactions with a broader set of stakeholders may help develop a better understanding of the emerging socio-cognitive categories and labels, which can prompt and inspire new technological variations (Grodal, Gotsopoulos, & Suarez, 2015).

To resolve demand uncertainty, the lack of even a viable prototype implied an investment in actions to proactively create or verify demand conditions through either shaping social and economic perceptions of future customers or securing lead users who may *ex ante* commit to product sales. For hybrid corn, while the general desired features of corn seed were known, firms sought to assess demand and understand what factors underpinned reluctance by farmers in future adoption of hybrid corn. To enhance public knowledge and alleviate farmers' concerns, not only did entrepreneurs organize several demonstration plantings and field observations, but the founder of Pioneer Hi-Bred became the editor of an agricultural magazine named *Wallaces' Farmer* and wrote frequent and persuasive editorials about hybrid corn (Brown, 1983). A similar focus on shaping customers' perceptions is observed in firms and other stakeholders' efforts to build legitimacy and carve out socio-cognitive categories echoing specifications of future products (Grodal et al., 2015). For example, during the incubation stage, investing radio satellite firms used consistent linguistic framing and storytelling to shape the collective industry identity (Navis & Glynn, 2010), whereas stakeholders in the business computer industry relied on familiar analogies for new product descriptions (Bingham & Kahl, 2013). In the wind energy industry, entrepreneurs joined efforts with

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

environmental movements such as the Sierra Club to promote demand for the industry (Sine & Lee, 2009). An alternative path in alleviating demand uncertainty focused on securing sales contracts with institutional buyers such as the military in the semiconductor and radar industries (Mowery, 2010). As these examples indicate, besides technological investments, actions undertaken during the incubation stage were strategically targeted to gauge and reduce demand uncertainty.

As the first bushels of hybrid corn were sold by Pioneer Hi-Bred in 1926, the birth of the hybrid corn industry rested on internal development and information exchange between actors stemming from heterogeneous knowledge bases and cognitive frames. More generally, and across science-triggered industries, although the starting point of the incubation stage is a scientific discovery, the eventual industry inception entails actions focused on both technical advancements and demand conditions. In turn, significant experimentation, competition, and collaboration by actors in the incubation stage critically shape the ensuing industry structure.

Industries Triggered by Unmet User Needs

In the 1870s, Josephine Cochrane grew tired of servants chipping her heirloom china and began designing a machine that could clean dirty dishes, thereby identifying an unmet user need that would underpin the emergence of the dishwashing machine industry (Fenster, 1999). Similarly, users' drive to find a solution to their unmet needs triggered the incubation stage of industries such as sports equipment (Baldwin, Hienerth, & Von Hippel, 2006; Shah, 2003), probe microscopy (Mody, 2006; Shah & Mody, 2014), and photo typesetters (Tripsas, 2008).

Unique understanding of needs unfulfilled by existing products or services often provides the knowledge context for end-users or professional users as actors who invent to fulfill that need (Von Hippel, 1988). User-inventors typically design an initial prototype for their private use and may share it with other users, either individually or within a community (Franke & Shah, 2003). Some users, due to their own experiences with the invention and/or positive community feedback, subsequently perceive a commercial opportunity and found firms to commercialize the invention (Shah & Tripsas, 2007). In dishwashing machines, for example, after several years of personal use and display to neighbors in her kitchen, Josephine Cochrane received her first patent in 1886 and set about founding Cochran's Crescent Washing Machine Company. Similarly, in the rodeo kayaking industry, although Walt Blackader, an enthusiast kayaker, introduced rodeo kayaking techniques and specialized sport equipment in 1968, it was only in the early 1970s that users in the rodeo kayaking community founded new firms to address unsolicited requests from others wishing to own equipment similar to theirs (Baldwin et al., 2006). In the photo typesetter industry, while in charge of publishing a French patent gazette for International Telephone & Telegraph, professional users Louis Moyroud and Rene Higonnet invented the first mechanical photo typesetter in 1944, and they later commercialized it with a firm named Lithomat in 1949 (Tripsas, 2008).

Similar to industries triggered by scientific discoveries, actors focused their efforts on resolving technological and demand uncertainties during the incubation stage. The resolution of technological uncertainty often entailed designing a prototype that could address the unmet need. Therefore, key actions consisted of identifying and integrating relevant knowledge and technology bases, which were often redeployed from other industry contexts or cocreated for the focal industry. For example, in order to build the first dishwashing machine, Josephine Cochrane hired a mechanic named George Butters as a collaborator. While they were able to draw on the available mechanical technologies, the first few attempts showed poor results. However, several design revisions resulted in an operational prototype, which was later improved with a motor pumping the water and movable dish rack. In designing the photo typesetter prototype, Rene Higonnet relied on available photography technologies of the time (Tripsas, 2008). Similarly, user entrepreneurs in the rodeo kayaking industry designed the first prototypes by leveraging the existing manufacturing technique of hand lay-up molding of fiberglass (Baldwin et al., 2006).

When prototype design entailed access and integration of novel areas of expertise not easily redeployable from other contexts, collective design and knowledge development by engaging the user community became pertinent. Participants within these communities exchanged information freely through discussions and presentation of artifacts and

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

invested time and effort to address others' needs, thereby facilitating improvements and new feature development (Franke & Shah, 2003). In the probe microscopy industry, academics who wanted to use the probe microscope for their research formed user communities to share knowledge on how to build copies of the probe microscope, extend its functionality, share tips and component parts, and provide data in support of the image's scientific value. They also worked jointly in labs through visits, sabbaticals, and graduate student and postdoc exchanges (Mody, 2006). These efforts led to the gradual development of explicit knowledge for the microscope to be reliably replicated. Within windsurfing, skateboarding, and snowboarding equipment industries, higher novelty was achieved as users freely exchanged information on their designs and received feedback from the user community (Shah, 2003).

In terms of demand uncertainty, even though the commercial opportunity for user entrepreneurship is based on realization of a personal unmet need, the extent to which a set of potential consumers faces a similar need and is willing to adopt the product is unknown. Therefore, there is a need for proactive assessment and shaping of demand conditions by engaging other users through direct product experience and community feedback. For dishwashing machines, while the need for dishwashers as a replacement for handwashing was well understood by Cochrane, that a machine could do the task had yet to be established for wider customer groups. Indeed, in contrast to her own experiences, housewives were initially not interested. Instead, Cochrane had to personally visit restaurants and hotels to not only display the machine to a wide audience, but also provide the direct product experience for users, which enabled resolution of demand uncertainty. The role of community feedback was salient within industry contexts such as sport equipment and probe microscopy, as wider adoption required incorporation of the voices of multiple actors into the technological artifact (Baldwin et al., 2006; Mody, 2006; Shah, 2003). In these contexts, word of mouth diffusion of prototype attributes as well as obtaining input from the user community about desired features and applications turned critical (Shah & Tripsas, 2007).

As Josephine Cochrane sold the first dishwashing machine to Palmer House hotel in Chicago in the late 1880s, the birth of the dishwashing machine industry rested on her entrepreneurial drive to satisfy her own unmet need and the needs her invention satisfied for others. More broadly, when industries are initiated from unmet user needs, users engage in rich information exchanges with broader communities, and their development of prototypes that address their own needs fuels new industry emergence. Despite differences in triggers and actors between science- and user-triggered industries, they nonetheless follow similar patterns in that actions are focused on reducing technological and demand uncertainties, thereby helping shape an industry's future structure.

Industries Triggered by Mission-Oriented Grand Challenges

In 1941, the U.S. government appointed a committee at the Office of Scientific Research and Development (OSRD) to overcome the excessive needs of the military to treat infection during World War II, a mission-oriented grand challenge that would underpin the emergence of the penicillin industry (Klepper, 2016). Mission-oriented grand challenges in response to national security, public health, or social issues have initiated public-private partnerships, which have led to the emergence of industries such as bionic prosthetics (Kim, 2016) and mobile money platforms (Shah et al., 2017).

Challenges related to national security or public health drive government agencies or not-for-profit foundations to define and support specific missions and coordinated actions for achieving a solution with immense social and global impact (Foray, Mowery, & Nelson, 2012; George, Howard-Grenville, Joshi, & Tihanyi, 2016). These missions typically involve extensive partnerships between private sector (e.g., firms) and public sector (e.g., universities, government labs) actors and are coordinated by the original government agency or foundation defining the mission (these actors may or may not be local to the area where the industry develops. See, for example, Shah et al., 2017). The immediate beneficiaries of the missions may not necessarily be the general public, particularly in the case of military and defense-related challenges. However, some technological achievements spill over to the public/civilian domain and provide the basis for private entrepreneurial activity (Mowery, 2010). In the case of penicillin, OSRD served as the

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

coordinator of research efforts between pharmaceutical firms such as Merck, Squibb, and Pfizer, government labs, and multiple universities. In parallel, the War Production Board funded relevant research of more than 175 firms and several hundred university scientists. Although the primary objective was to provide the military with antibiotics, penicillin later became available for commercial sales (Klepper, 2016). Within several Central American countries, the Swiss Agency for Development and Cooperation (SDC) facilitated the creation of metal silos markets to reduce post-harvest loss by engaging stakeholders in both public and private sectors (Shah, Agarwal, & Sonka, 2017; Sonka, Cheng, & Kenney, 2014). These cases note heterogeneous roles of university scientists and firms as key actors, with government agencies and foundations serving as coordinators.

Resolution of technological and demand uncertainty is also the focus of actions during the incubation stage. For technological uncertainty, while some missions need to extend available knowledge and technology bases, others require development of entire knowledge bases from scratch. These efforts typically involve coordinated research by firms and universities and extensive information exchange. For the case of penicillin, Fleming's original discovery of penicillin in 1928 and the subsequent research by Howard Florey at the University of Oxford with the financial support of the Rockefeller Foundation provided an initial scientific base (Kingston, 2000). However, the treatment efficacy needed to be scientifically confirmed, and there were no production processes available for mass production. Collectively and through interactive experimentation, government agencies, universities, and firm collaborators found a solution. An important feature was that the firms involved received regular progress reports and agreed to freely exchange information about their findings (Klepper, 2016). In metal silos, with easily sourced technology from the developed countries, the creation of a well-functioning ecosystem within the Central American countries required attention to local needs. The SDC coordinated technology experimentation by tinsmiths and farmers during the incubation stage to address problems in the development of a viable supply chain and in optimal storage features that reduced harvest spoilage and pest control (Shah et al., 2017; Sonka et al., 2014). Within Sub-Saharan Africa, mission-driven coordination between nonprofit agencies such as the U.K. Department for International Development, diversifying entrants such as Vodafone, and entrepreneurial start-ups such as Safaricom and various independent agents addressed the technological and supply chain challenges for successful launch of M-Pesa as a mobile money platform. In contrast, within the same context, the inability to create win-win outcomes around the NFC (near field communication) chip standard for secure financial transactions between banks, credit card companies, and other intermediaries stifled inception of this industry (Ozcan & Santos, 2015). Similarly, in the absence of coordinated and collective efforts in the context of drugs for neglected diseases in poor countries, despite scattered basic scientific progress, a translation to clinical and commercial knowledge was largely unfruitful (Vakili & McGahan, 2016).

While it may seem demand uncertainties are typically less salient in these industries given their mission-oriented nature, the assessment of potential commercial value and its actualization are far from a certain undertaking. The initial sustenance of mission-oriented efforts are often assured by procurement and purchasing agreements. For example, the military committed to purchase penicillin (Kingston, 2000; Klepper, 2016), and the SDC program helped support the initial purchases of metal silos in Central America (Shah et al., 2017; Sonka et al., 2014). However, in other cases, reaching commercialization involved convincing other actors of the merits of the technology, often through information provision. For penicillin, despite promising clinical trial evidence, additional medical demonstrations and direct advocacy of Howard Florey in battlefields became essential for assessing and shaping its adoption, even by military doctors (Kingston, 2000). Further, to gauge general commercial demand, there was ongoing publicity about the prospective miracle drug for human infection and animal farming (Achilladelis, 1993). For metal silos, extensive information exchange—ranging from posters and street boards to radio programs to agricultural exhibitions as well as partnerships with governments and locally respected stakeholders such as NGOs, religious institutions, and women leaders—helped engender trust and overcome demand resistance. Even when rural farmers were convinced of benefits, the prohibitively expensive costs of metal silos required public-private partnerships to create financial solutions for sustainable demand (Shah et al., 2017; Sonka et al., 2014).

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

As Merck and Pfizer addressed military penicillin needs and subsequently commercialized penicillin in 1945, the birth of the antibiotics industry rested on complex yet coordinated responses by multiple private and public actors to a mission challenge. Today, commercial space travel may be an industry in the incubation stage initially triggered by a mission-oriented grand challenge. More broadly, industries triggered by mission-oriented grand challenges depict concerted channeling of efforts across diverse communities and organizations, with rich information exchange to create new institutional and industry structures and facilitate solving thorny technical and demand problems.

Integrative Themes from the Conceptual Framework

We now synthesize overarching themes based on the aforementioned empirical observations of the incubation stage. Table 1 provides a summary.

Theme 1: The incubation stage can have one of several triggers and is motivated by different incentives. We begin by underscoring the premise of the work reviewed earlier. Prior to industry inception, there is an incubation stage activated by a trigger event (Table 1, Column 1). Although trigger events differ, the subsequent incubation stage is a dynamic time period lasting several years and even decades. In science-triggered industries, the incubation stage leverages university and industry inventors. A focus on basic science, within academic norms and reward structures, privileges non-pecuniary motives spanning the joy of discovery, publications, and the resulting reputational awards due to recognition of merit (Feynman & Leighton, 2010; Merton, 1973). The commercial potential of scientific discoveries thereafter motivates for-profit application, often through the creation of new firms in the process. In industries triggered by unmet user needs, the incubation stage leverages lead or niche users solving problems for their own purposes and, in the process, they discover the potential for commercialization. Mission-oriented grand challenges initiated by the government or not-for-profit foundations also represent a distinct trigger, for which the incubation stage involves individual and organizational efforts rising to the challenge of social needs left underaddressed by existing markets. Perhaps more than any other stage, the actors and actions undertaken during incubation are most characteristic of "creative destruction" (Schumpeter, 1942). However, given high and endogenous uncertainty, the motivations for the fundamental breakthroughs occurring during this stage represent expected, rather than actual, monetary returns. Though economic models (Aghion & Howitt, 1992) emphasize "prizes offered by capitalist society to the successful innovator" (Schumpeter, 1942, p. 102), the incubation stage points to additional non-pecuniary motives, such as solving problems of individual or societal import and "the joy of creating, of getting things done, or simply of exercising one's energy and ingenuity" (Schumpeter, 1934, pp. 93–94).

Theme 2: The incubation stage is characterized by heterogeneous actors drawing from diverse knowledge bases, even within each type of trigger. While Theme 1 highlighted differences in actors across different triggers for industry incubation, a second theme relates to within-industry numerosity and heterogeneity of actors and the diversity of knowledge bases that ultimately need to be integrated for industry emergence (Table 1, Column 2). Contrary to the images invoked by lone inventors in scientific labs or garages, each trigger event unleashes the creative energies of multiple actors who engage in problem solving and development of the industry's knowledge base. These actors represent diversity in experiments and pathways undertaken to sensemake of the opportunities presented by the triggers and diversity in knowledge bases drawn upon. Also, and in contradiction to received transactions costs predictions that high uncertainty and asset specificity may preclude operational markets for technology, the incubation stage seems to be characterized by rich interaction of the actors in formal and informal exchange of ideas, knowledge bases, and assets—all designed to integrate relevant information to further enhance viability of the industry.

Theme 3: The incubation stage represents simultaneous and recursive (rather than linear) actions intended to reduce technological and demand uncertainty. Linear pathways for science-push emphasize scientific discovery resulting in invention, manufacturing, and marketing, and for demand-pull, emphasize customer suggestions resulting in invention and manufacturing (Schilling,

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

Table 1
Triggers, Actors, and Actions in the Incubation Stage

Trigger event	Key actors	Actions reducing technological uncertainty in the incubation stage	Actions reducing demand uncertainty in the incubation stage
Scientific Discovery	• University and industry scientists • Technology and academic entrepreneurs • Established and diversifying firms	• *Concurrent experimentation and development* undertaken by university scientists and firms • *Knowledge exchange* through formal and informal scientific collaborations • *Leveraging and development* of both core and enabling technologies	• *Identification of potential uses and users* through experimental search across consumer groups • *Development of a communicable identity* for the technology's use and function • *Interest in the technology assessed, shaped, and built* through trade associations, foundations, newspapers, social movements, and exhibitions
Unmet User Needs	• User inventors • User entrepreneurs • User communities	• *Concurrent experimentation and development* undertaken by individual users; users working within user communities (as well as firms and labs); firms; and/or university scientists • *Open information exchange* through participation in user communities makes knowledge widely available • *Diverse knowledge accessed* and integrated through participation in user communities or hires	• *Identification of additional uses* through encouragement of diverse users to build and/or use the technology and exhibitions/ demonstrations • *Interest in the technology assessed and built* through word-of-mouth, participation in user communities, and technical demonstrations
Mission-Oriented Grand Challenges	• Government agencies • Foundations • University and industry scientists • For-profit firms	• *Concurrent experimentation and development* undertaken by scientists and administrators in universities, government and nonprofit agencies • *Knowledge exchange* through formal and open collaborations between government scientists, university scientists, and foundations (made possible by extensive funding provided by institutionalized actors (e.g., governments, foundations) • *Rules/standards development* to support complex system development	• *Identification of commercial uses* by encouragement of involved individuals' usage of technology • *Interest in the technology assessed and built* through exhibits, demonstrations, and support from key stakeholders • *Demand initiated* through government procurement and purchasing agreements

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

2016). In contrast, a third theme emerging from the above observations is that regardless of the type of trigger, the actions undertaken during the incubation stage represent simultaneous and recursive attention to *both* technological and demand uncertainty (Table 1, Columns 3 & 4). Rather than linear pathways, "the Marshallian scissors cuts with both blades" (Cohen, 2010, p. 169) when viewing actions undertaken to reduce uncertainty.

Further, the nature of technological/demand uncertainty during the incubation stage seems qualitatively different than for later stages. Subsequent to product commercialization and within the context of an operating market, scholars have conceptualized technological uncertainty as either partial knowledge about cost, features, and performance of a nontrivial set of product designs (Abernathy & Utterback, 1978; Clark, 1985; Tushman & Anderson, 1986) or partial knowledge about the timing and extent of obsolescence of technology-specific investments in assets and capabilities (Balakrishnan & Wernerfelt, 1986). However, prior to first product commercialization, technological uncertainties include additional dimensions, characteristic of the large differences between the amount of information required to develop the innovation and the amount of information already possessed (Galbraith, 1977). Qualitatively then, technological uncertainty during the incubation stage arises due to partial knowledge about whether and how adequate advancements in core and complementary knowledge domains can be integrated into introducing a viable product.

Similarly, demand uncertainty subsequent to commercialization takes the forms of partial knowledge about customers understanding of a product, their evaluation of various design features (Abernathy & Utterback, 1978; Clark, 1985; Tushman & Anderson, 1986), and unanticipated volatility in demand size (Walker & Weber, 1984). During the incubation stage, however, demand uncertainty is qualitatively different, resulting from partial knowledge about customers' preferences about a product concept that may or may not even be available as a prototype for them to experience. Even in user- and mission-triggered contexts, the needs experienced by lead users serve as a guidepost around which further actions are undertaken to assess the technology's commercial potential and resolve demand uncertainties through outreach and development.

Theme 4: The incubation stage is characterized by experimentation directed at resolving technological and demand uncertainty. Experimentation is a consistent and recurring feature of the incubation stage. Actors start out with limited information on the technology and its potential, as well as its intended or unintended applications. Building off the preceding two themes, the incubation stage is well characterized by the notion of "human agents [who] differ in their skills, capabilities, and orientations…enlisted into the realm of potentially useful experimentation" (Rosenberg, 1992, pp. 188–189). Only through experimentation is information uncovered to reduce the technological and demand uncertainties described earlier. The results of experimentation appear to manifold: the characteristics of the technology (e.g., its design, features, and functionality) and the market the technology serves evolve and often proliferate. That is, a trigger event sets in motion panoply of experiments by myriad actors drawing on heterogeneous sets of resources (Table 1, Column 3). In science-triggered industries, university and industry inventors engage in sequential efforts and trial and error to transform basic research into commercial applications. In industries propelled by unmet user needs, the incubation stage depends upon similar efforts by users who bricolage relevant knowledge from various sources. Mission-oriented grand challenges initiated by the government or not-for-profit foundations coalesce individual and organizational efforts, also engaging in trial and error process. Simultaneously, across all three triggers, experimental search and discovery about potential use and users during the incubation stage relate to sensemaking about desirable features, incorporating knowledge from lead users into the prototype products and services and experimental teaching and learning loops with potential consumers about desirability of design features (Table 1, Column 4).

Theme 5: The incubation stage is characterized by significant sharing of knowledge through formal and informal channels. A second hallmark of the actions designed to resolve "partial knowledge" is the iteration between internal development experiments and integration of external knowledge and resources. The incubation stage is characterized by rich information exchanges within relevant communities to address uncertainties (Table 1, Columns 3 and 4). For industries triggered by

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

scientific discoveries or mission-oriented challenges, these communities are within universities and firms and for unmet user needs, the actors engage with user communities—individuals who unite together based on similarities in use. Further, the motivations discussed in Theme 1 imply that knowledge exchange occurs not only through formal channels (alliances and/or acquisitions for resource reconfiguration) governed by monetary incentives, but also through informal (open) and social channels. Nonmonetary motivations for use of informal channels relate to norms of science in science-based and mission-driven triggers and the desire of users to share ideas with like-minded others for the purpose of enjoyment and creativity in unmet user need triggers.

Together, experimentation and knowledge sharing imply that multiple actors, possessing a wide-variety of knowledge, apply their insights and expertise to guide efforts in problem search and discovery of solutions. As knowledge is shared through various mechanisms and for various reasons, deliberate and vicarious learning across actors informs and guides future experiments, potentially reducing duplication of effort, but surely building the knowledge base for the industry during the incubation stage.

Theme 6: The incubation stage shapes industry structure and firm strategy in the stages post-commercialization. The earlier themes underscore an important overarching theme regarding the incubation stage: notwithstanding that some industries stem from lone inventors toiling in isolation of others resulting in a monopoly, the work reviewed here points to an alternative pathway wherein the incubation stage is characterized by vibrant actions undertaken by numerous and heterogeneous actors. Importantly, most of the industries we have featured depict a quasi-monopoly period after the first commercialization, but the one or, at most, few firms that initially commercialize a product belie the significant number of actors who invest in incubating the industry. The strategies undertaken by investing firms, in the form of both competitive and collaborative decision making, determine who takes on the commercialization role and who takes on supplementary roles in the developing ecosystem. Thus, whether industries evolve to become oligopolies or monopolistically competitive may well be traced to seeds sown during the incubation stage.

A Research Agenda

Our brief review and preliminary conceptual framework underscoring our understanding of the incubation stage of new industries are themselves in an incubation stage and deserving of effort from numerous and heterogeneous scholars with diverse disciplinary lenses and research expertise. We next provide a few potential pathways for experimentation, knowledge sharing, and exploration.

Theoretical Areas of Inquiry

Initial triggers. The review of the current industry incubation literature revealed three sets of initial triggers that activate the emergence trajectory of nascent industries. While informed by the current state of the literature, these three sets of triggers may not fully cover the variety of incubation paths experienced in different industries. Future research drawing on novel and heterogeneous industry contexts may uncover other important triggers. For example, scholars have noted how social movements shape industry demand and channel resources to industry producers after industry inception (Lounsbury, Ventresca, & Hirsch, 2003; Pacheco et al., 2014; Wry et al., 2011), and new empirical evidence may identify industries with social movements as the initial trigger of the incubation stage. Further, although we focused on the role of government in triggering new industries via mission-oriented grand challenges, other triggers may be regulatory or public policy.

Our conceptual framework incorporated a sharp distinction between the three sets of triggers. However, we acknowledge the presence of hybrid triggers. Particularly in high-technology industries, scientific discoveries may result from both core expertise and from unmet needs encountered through use. The same holds for scientific discoveries that are in response to mission-driven research. The internet is a salient example of such a hybrid trigger (Greenstein, 2015). It was partly triggered by a mission-oriented grand challenge by DARPA,[1] which not only funded but also coordinated efforts

[1] DARPA refers to the Defense Advanced Research Projects Agency, an agency responsible for developing emerging technologies for use in the military. The internet project was initially funded and coordinated by the agency under its first name, Advanced Research Projects Agency (ARPA).

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

of several university scientists and firms to develop packet switching data network. Concurrently, though, it was also built on the discoveries shifting the scientific frontier such as routing algorithms as well as private firms' need for communication (Greenstein, 2015). Research examining pure and hybrid trigger industries will provide useful insights regarding similarities and differences.

Finally, while the conceptualization of a distinct, recognizable trigger event may be an appropriate characterization for many industries, future research needs to explore the incubation paths of industry contexts with no evident trigger. In particular, new industries and organizational forms emerging due to convergence or disintegration in existing industry architectures (David, Sine, & Haveman, 2013; Jacobides & Winter, 2005) may prove insightful.

Characteristics of the incubation stage. Additional research may focus on documenting and providing theoretical explanations about the attributes of the incubation stage. Our review alluded to the presence of a noncommercial period, starting with an initial trigger event until actors engage in for-profit commercial investigation of the opportunity. Future studies may identify other subperiods within which actors undertake actions targeted at resolution of technological or demand uncertainties. The duration of these subperiods, their temporal sequence, their potential overlap, and their structural differences in number and types of firms may not only enable a more systematic analysis of the incubation stage, but also reveal important contingency factors.

By inquiring about the patterns and underlying reasons for entry, exit, and investments made by heterogeneous actors during the incubation stage, future research may provide a more complete picture of investing firm demography, the knowledge bases they draw on, and the performance consequences of their strategy. Our review shows industries triggered by a scientific discovery may initially comprise academic entrepreneurs, employee spinouts from related industries, or diversifying firms, whereas industries triggered by unmet user needs may initially comprise user entrepreneurs. A fruitful avenue of research lies in examining the extent to which this initial firm demography persists over time and what type of new entrants at what time junctures may change this demography.

Further, examining contributions and motives of non-firm actors such as regulators, analysts, tastemakers, intermediaries, and nonprofit organizations will open new avenues into the factors leading to industry creation. During the incubation stage, regulators (Dobbin & Dowd, 1997) and nonprofit organizations (Shah et al., 2017) may play a fundamental role in influencing the future industry's knowledge base and shaping investment incentives. Further, while industry and professional associations focal to an industry may channel new resources toward the industry (Sine & Lee, 2009) and impact the regulatory landscape (Hiatt et al., 2009; Hiatt & Park, 2013) after industry inception, their role during incubation stage is also deserving of attention. Likewise, given that the standard-setting organizations may help the emergence of an industry's collective identity by helping firms and customers unite around a converging theme after inception (Lee, Hiatt, & Lounsbury, 2017), future research may focus on understanding their role during industry incubation. The dual role of social movements during industry incubation also deserves attention, given that they can both propel and delegitimize industry growth (Weber, Rao, & Thomas, 2009).

Factors leading to successful (or unsuccessful) incubation of industries. Although triggers may be followed by the actions of various and multiple actors, not all such investments may result in the emergence of new industries. For example, among multiple industry applications of plant biotechnology science such as bioremediations and food nutritional enhancements, only enhanced agricultural productivity applications have proceeded beyond the incubation stage into the agricultural biotechnology industry (Kirsch, Moeen, & Wadhwani, 2014). Similarly, electric cars were a viable alternative to internal combustion engine dating back to the late 1890s, but failed to emerge as a viable industry for much of the twentieth century (Kirsch, 2000). More recently, the mobile money industry has emerged in some countries (Shah et al., 2017), but not in others (Ozcan & Santos, 2015). The incubation stages of these might-have-been-industries may serve as counterfactual examples, thereby enabling comparison of inception versus non-inception instances. Rosenberg (1974, p. 106) noted that "our understanding of inventive activity (and perhaps of social change generally) is excessively rooted in success stories…yet it is highly relevant to ask why it took so long to do

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

certain things, and why inventors failed for so long at some inventive efforts while they succeeded quickly in others."

Industry emergence and concomitant firm investment in new industries may also hinge on successful resolution of various uncertainties during incubation. Regarding technological and demand uncertainties, additional empirical contexts and systematic theoretical focus may shed light on the mechanisms leading to their resolution. Moreover, under conditions of institutional voids, entrepreneurial attempts during the incubation stage may focus on shaping and navigating the uncertain institutional environment (Shah et al., 2017). Integrating insights from institutional economic theory (North, 1990) into industry evolution may advance our understanding of how entrepreneurs overcome such challenges and, in turn, influence industry emergence. Analysis of socio-cognitive uncertainty is another area of interest. With at most a commercial prototype available during incubation, the confusion around its label, collective identity of producers, and customers' perceptions of its functionality may turn challenging (Bingham & Kahl, 2013; Grodal et al., 2015).

Resource and capability investment and reconfiguration. The incubation stage is by definition a pre-production period, wherein actors leverage resources and capabilities that are not self-sustained by revenue. Future research may examine the financing needs during the incubation stage for start-ups and established firms. High levels of uncertainty pose challenges for start-ups seeking financial capital, under conditions that make the nature of the product unclear and difficult to articulate, but also preclude financial investors from having necessary benchmarks and data points to evaluate start-ups. An area of future inquiry, thus, relates to how entrepreneurs address their financial needs by attracting investment from angels, public loans, crowdfunding, venture capital, and other sources of financial capital (Goldfarb, Kirsch, & Shen, 2012; Kerr & Nanda, 2015) as well as relying on alternative modes of economic value capture (Moeen & Agarwal, 2017; Teece, 1986). A parallel set of questions pertains to diversifying entrants, as these firms need to convince their shareholders and stock market analysts of the virtues of investing in an industry that is not yet in existence (Benner & Ranganathan, 2013).

It may also be the case that while access to resources are necessary, actors rely on mechanisms other than monetary incentives and the profit motive to attract resources. Triggers associated with unmet user needs and mission-driven research underscore that resources can be bricolaged and that public and nonprofit institutions can service the resource needs of a nascent industry. However, these resources are not free, and how they are assembled and funded remains a critical question. Together, the breadth of actors participating in and actions undertaken during the incubation stage highlight the necessity of looking beyond firms and systematically accounting for alternative forms of organizing and the incentives that drive these forms during the formative years of an industry (Langlois & Robertson, 1992; Shah & Mody, 2014; Shah & Tripsas, 2007).

There are multiple research opportunities to link the capability reconfiguration literature with industry incubation. Capability reconfiguration efforts through adding, redeploying, recombining, or divesting capabilities are often entangled with firms' ability to expand and innovate (Karim & Capron, 2015). During the incubation stage, not only do industry emergence and firm-level economic value capture hinge on early entrants achieving a desired capability portfolio, but also the capability reconfiguration process becomes more challenging (Moeen, 2017). For entrepreneurial start-ups, future research may address their capability addition decisions such as the initial founding team formation and further reliance on alliances and acquisitions. For diversifying entrants, it is valuable to study how they add and redeploy capabilities using alliances and acquisitions, university collaborations, or hiring of employees and scientists.

Methodological Considerations

Identification of industry boundaries. Scholars will need to consider carefully the boundaries of a nascent industry. Industries are typically defined as centering on the particular products or services being offered. However, for the incubation stage, this definition is typically tractable retrospectively. The variety of categories and labels *ex ante* associated to an industry may further complicate this task. In addition, the distinction between a new industry and a new generation of an existing industry may not be always apparent. Contextual information about whether each industry "makes a large discontinuity from what has existed before" or "is

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

sufficiently large and distinct to be classified as an industry in its own right" (Helfat & Lieberman, 2002, p. 278) may guide researchers in discerning new industries. This also implies the need for careful distinguishing between the incubation and subsequent evolution of underlying technologies (e.g., plant biotechnology) from the incubation and subsequent evolution of specific industries based on those technologies (e.g., agricultural biotechnology versus bioremediations).

In identifying key actors, conventional industry evolution studies have relied largely on datasets of producer firms in an industry. However, a lack of any product commercialization during the incubation stage necessitates that scholars look for identifying involved firms in other novel ways. One possibility is to track actors building on an initial trigger event. Further, regulatory requirements may create a paper trail, thereby supporting data collection on the incubation stage (Lomi, Larsen, & Wezel, 2010; Moeen & Agarwal, 2017; Navis & Glynn, 2010). Alternatively, when key foundational patents are required for advancing a research program in industries, early stage actors and the technological advancements they make may be identified by tracking initial patent licensees (Eggers, 2016). More generally, business historical archives such as tax records, business press, job postings, and telephone listings may offer opportunities for retrieving information about firms not involved in product commercialization (Forbes & Kirsch, 2011).

Choice of methodology. Depending on the research scope and questions, scholars may rely on a variety of methods. Given the early stage of our understanding of industry incubation, inductive theory-building efforts are remarkably helpful (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Van Maanen, 1979). Several understudied research areas related to industry incubation such as the motives of a wide variety of actors, actors' relationships to one another, actions undertaken and their effects on uncertainty, and the pathways forged in the incubation stage may particularly benefit from inductive methods. In particular, the collection of primary source data (such as through interviews) may be an effective way to identify as-yet-unknown actors and their actions. Techniques such as snowball sampling and the use of open-ended questions with follow-on questioning that seeks to reveal details about the informants' experiences can allow for theory development that illuminates the complex and multifaceted social structures of the incubation stage (Shah & Gorbatai, 2015). In addition, field studies and observations of technologies currently in the incubation stage can also help capture the variety of actions undertaken and their effects.

Historical methods and analytical narratives may also lead to useful insights. When real-time observation and documentation are not possible, reconstruction and interpretation of past events may be impacted by retrospective reordering and myopia. This is particularly relevant for studying industry incubation, given that researchers in the present may view and sensemake of the past in the light of their knowledge of how the industry has unfolded since then (Kirsch et al., 2014). The paths not taken, the uncertainty experienced, and the variety of challenges faced by actors may be eluded given the passage of time. However, by offering contextualized accounts of past events, historical methods may enable *ex post* analysis of antecedents, processes, and causes of industry incubation (Braguinsky & Hounshell, 2016).

Finally, large-scale empirical documentation and statistical analyses may reveal critical stylized findings and patterns. In doing so, construction of longitudinal datasets is important, as the incubation stage typically spans many years, over which actors and actions appear to evolve. These analyses may benefit from both single- and multi-industry studies. When pursuing multi-industry studies, there is an opportunity to identify common patterns about the attributes of the incubation stage, examine their pervasiveness in a variety of industries, or study industry-level contingency factors. Despite these benefits, scholars are often limited in the measurement of variables with similar interpretations across a set of industries. When focusing on a single industry, a deep contextual knowledge may permit the creation of rich data with multiple unique variables to provide an in-depth theoretical investigation. In addition to retrieving secondary data from archival sources, these efforts may focus on surveys of industries that appear to be on the path to becoming stand-alone industries and focus on perceptions about real-time technological and demand uncertainties.

Conclusion

Similar to the pre-history of Athena's birth, new industries are not suddenly born at the time of the

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

first product commercialization. Instead, as we begin to illuminate in this article, complex interactions of various actors and actions during the incubation stage not only precede, but also shape the birth and subsequent structure of new industries. From a policy perspective, this heterogeneity in actors and actions is critical (Agarwal & Shah, 2014; Etzkowitz & Leydesdorff, 2000): incubating new industries requires multiple actors—not just firms. Hence, social action and policy may also pay attention to cultivating the wide variety of actors who set the stage for the commercial development of new industries. Because new industry emergence is related to entrepreneurial dynamism, economic growth, and national competitiveness, we believe that research directed toward understanding the precursors of industry formation will greatly enhance our ability to support, harness, and mobilize the variety of actors that spark and incubate new industries and, thereby, prime these engines of upward mobility and social well-being.

Acknowledgements

This paper is written in memory of our friend, colleague, and mentor: MB Sarkar. He passed far too early; we hope to continue our research with the same energy, dedication, and spirit of collaboration he devoted to his work. We thank the Kauffman Foundation for their funding and support of our research. We thank Serguey Braguinsky, Shane Greenstein, Michael Jacobides, Franco Malerba, Richard Nelson, Steven Sonka, and Sidney Winter for their thoughtful feedback. These ideas also benefitted from the comments of participants at the 2016 ICC Conference at UC-Berkeley and guidance from the editor, Gary Dushnitsky, and two reviewers. We also thank Hyeonsuh Lee for excellent research assistance.

References

Abernathy, W., & Utterback, J. M. (1978). Patterns of industrial innovation. *Technology Review*, *80*(7), 40–47.

Achilladelis, B. (1993). The dynamics of technological innovation: The sector of antibacterial medicines. *Research Policy*, *22*(4), 279–308.

Agarwal, R., Audretsch, D., & Sarkar, M. (2007). The process of creative construction: Knowledge spillovers, entrepreneurship, and economic growth. *Strategic Entrepreneurship Journal*, *1*(3–4), 263–286.

Agarwal, R., & Bayus, B. L. (2002). The market evolution and sales takeoff of product innovations. *Management Science*, *48*(8), 1024–1041.

Agarwal, R., & Gort, M. (2001). First-mover advantage and the speed of competitive entry, 1887-1986. *Journal of Law & Economics*, *44*(1), 161–177.

Agarwal, R., & Shah, S. K. (2014). Knowledge sources of entrepreneurship: Firm formation by academic, user and employee innovators. *Research Policy*, *43*(7), 1109–1133.

Agarwal, R., & Tripsas, M. (2008). Technology and industry evolution. In S. Shane (Ed.), *The handbook of technology and innovation management* (pp. 1–55). West Sussex, England: John Wiley and Sons.

Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, *60*(2), 323–351.

Aldrich, H. E., & Fiol, C. M. (1994). Fools rush in? The institutional context of industry creation. *Academy of Management Review*, *19*(4), 645–670.

Anthony, C. C., Nelson, A. J., & Tripsas, M. (2016). "Who are you?... I really wanna know:" Product meaning and competitive positioning in the nascent synthesizer industry. *Strategy Science*, *1*(3), 163–183.

Audretsch, D. B., & Stephan, P. E. (1996). Company-scientist locational links: The case of biotechnology. *American Economic Review*, *86*(3), 641–652.

Balakrishnan, S., & Wernerfelt, B. (1986). Technical change, competition and vertical integration. *Strategic Management Journal*, *7*(4), 347–359.

Baldwin, C., Hienerth, C., & Von Hippel, E. (2006). How user innovations become commercial products: A theoretical investigation and case study. *Research Policy*, *35*(9), 1291–1313.

Benner, M. J., & Ranganathan, R. (2013). Divergent reactions to convergent strategies: Investor beliefs and analyst reactions during technological change. *Organization Science*, *24*(2), 378–394.

Benner, M. J., & Tripsas, M. (2012). The influence of prior industry affiliation on framing in nascent industries: The evolution of digital cameras. *Strategic Management Journal*, *33*(3), 277–302.

Bijker, W. E. (1997). *Of bicycles, bakelites, and bulbs: Toward a theory of sociotechnical change*. Cambridge, MA: MIT Press.

Bijker, W. E., Hughes, T. P., & Pinch, T. (1987). *The social construction of technological systems: New directions in the sociology and history of technology*. Cambridge, MA: MIT Press.

Bingham, C. B., & Kahl, S. J. (2013). The process of schema emergence: Assimilation, deconstruction, unitization and the plurality of analogies. *Academy of Management Journal*, *56*(1), 14–34.

Braguinsky, S., & Hounshell, D. A. (2016). History and nanoeconomics in strategy and industry evolution research:

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

Lessons from the Meiji-Era Japanese cotton spinning industry. *Strategic Management Journal*, *37*(1), 45–65.
Brown, W. L. (1983). HA Wallace and the development of hybrid corn. *Annals of Iowa*, *47*(2), 167–179.
Charles, D. (2001). *Lords of the harvest: Biotech, big money, and the future of food*. Cambridge, MA: Basic Books.
Clark, K. B. (1985). The interaction of design hierarchies and market concepts in technological evolution. *Research Policy*, *14*(5), 235–251.
Cohen, W. M. (2010). Fifty years of empirical studies of innovative activity and performance. In B. H. Hall & N. Rosenberg (Eds.), *Handbook of the economics of innovation* (Vol. 1, pp. 129–213). Amsterdam, The Netherlands: Elsevier.
Cortada, J. W. (1993). *Before the computer: IBM, NCR, Burroughs, and Remington Rand and the industry they created*. Princeton, NJ: Princeton University Press.
Crow, J. F. (1998). 90 years ago: The beginning of hybrid maize. *Genetics*, *148*(3), 923–928.
David, R. J., Sine, W. D., & Haveman, H. A. (2013). Seizing opportunity in emerging fields: How institutional entrepreneurs legitimated the professional form of management consulting. *Organization Science*, *24*(2), 356–377.
Dobbin, F., & Dowd, T. J. (1997). How policy shapes competition: Early railroad foundings in Massachusetts. *Administrative Science Quarterly*, *42*(3), 501–529.
Dosi, G. (1988). Sources, procedures, and microeconomic effects of innovation. *Journal of Economic Literature*, *26*(3), 1120–1171.
Eggers, J. P. (2014). Competing technologies and industry evolution: The benefits of making mistakes in the flat panel display industry. *Strategic Management Journal*, *35*(2), 159–178.
Eggers, J. P. (2016). Reversing course: Competing technologies, mistakes, and renewal in flat panel displays. *Strategic Management Journal*, *37*(8), 1578–1596.
Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.
Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, *50*(1), 25–32.
Enos, J. L. (1962). Invention and innovation in the petroleum refining industry. In N. Rosenberg (Ed.), *The rate and direction of inventive activity: Economic and social factors*. (pp. 299–322). Princeton, NJ: Princeton University Press.
Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and “Mode 2” to a Triple Helix of university–industry–government relations. *Research Policy*, *29*(2), 109–123.
Fenster, J. (1999). The woman who invented the dishwasher. *American Heritage of Invention & Technology*, *15*(2), 54–61.
Feynman, R. P., & Leighton, R. (2010). *"Surely You’re Joking, Mr. Feynman!:" Adventures of a curious character*. New York, NY: W. W. Norton & Company.
Foray, D., Mowery, D. C., & Nelson, R. R. (2012). Public R&D and social challenges: What lessons from mission R&D programs? *Research Policy*, *41*(10), 1697–1702.
Forbes, D. P., & Kirsch, D. A. (2011). The study of emerging industries: Recognizing and responding to some central problems. *Journal of Business Venturing*, *26*(5), 589–602.
Franke, N., & Shah, S. (2003). How communities support innovative activities: An exploration of assistance and sharing among end-users. *Research Policy*, *32*(1), 157–178.
Franz, K. (2000). *Narrating automobility: Travelers, tinkerers, and technological authority in the twentieth century*. (Unpublished doctoral dissertation). Brown University.
Galbraith, J. R. (1977). *Organization design*. Reading, MA: Addison Wesley Publishing Company.
Garud, R., & Rappa, M. A. (1994). A socio-cognitive model of technology evolution: The case of cochlear implants. *Organization Science*, *5*(3), 344–362.
George, G., Howard-Grenville, J., Joshi, A., & Tihanyi, L. (2016). Understanding and tackling societal grand challenges through management research. *Academy of Management Journal*, *59*(6), 1880–1895.
Golder, P. N., Shacham, R., & Mitra, D. (2009). Innovations’ origins: When, by whom, and how are radical innovations developed? *Marketing Science*, *28*(1), 166–179.
Goldfarb, B., Kirsch, D., & Shen, A. (2012). Finance of new industries. In D. Cumming (Ed.), *The Oxford handbook of entrepreneurial finance* (pp. 9–44). Oxford, U.K.: Oxford University Press.
Gort, M., & Klepper, S. (1982). Time paths in the diffusion of product innovations. *Economic Journal*, *92*(367), 630–653.
Greenstein, S. (2015). *How the internet became commercial: Innovation, privatization, and the birth of a new network*. Princeton, NJ: Princeton University Press.
Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica*, *25*(4), 501–522.
Grodal, S., Gotsopoulos, A., & Suarez, F. F. (2015). The coevolution of technologies and categories during industry emergence. *Academy of Management Review*, *40*(3), 423–445.
Hannan, M. T., & Freeman, J. (1977). The population ecology of organizations. *American Journal of Sociology*, *82*(5), 929–964.
Helfat, C. E., & Lieberman, M. B. (2002). The birth of capabilities: Market entry and the importance of pre-history. *Industrial and Corporate Change*, *11*(4), 725–760.
Hiatt, S. R., & Park, S. (2013). Lords of the harvest: Third-party influence and regulatory approval of

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

genetically modified organisms. *Academy of Management Journal*, *56*(4), 923–944.
Hiatt, S. R., Sine, W. D., & Tolbert, P. S. (2009). From Pabst to Pepsi: The deinstitutionalization of social practices and the creation of entrepreneurial opportunities. *Administrative Science Quarterly*, *54*(4), 635–667.
Jacobides, M. G., & Winter, S. G. (2005). The co-evolution of capabilities and transaction costs: Explaining the institutional structure of production. *Strategic Management Journal*, *26*(5), 395–413.
Jovanovic, B., & Macdonald, G. M. (1994). The life-cycle of a competitive industry. *Journal of Political Economy*, *102*(2), 322–347.
Kapoor, R., & Furr, N. R. (2015). Complementarities and competition: Unpacking the drivers of entrants' technology choices in the solar photovoltaic industry. *Strategic Management Journal*, *36*(3), 416–436.
Karim, S., & Capron, L. (2015). Reconfiguration: Adding, redeploying, recombining and divesting resources and business units. *Strategic Management Journal*, *37*(13), E54–E62.
Kerr, W. R., & Nanda, R. (2015). Financing innovation. *Annual Review of Financial Economics*, *7*, 445–462.
Kim, S. (2016). *DARPA and industrial evolution: Evidence from the prosthetic industry* (Working paper). Temple University.
Kingston, W. (2000). Antibiotics, invention and innovation. *Research Policy*, *29*(6), 679–710.
Kirsch, D. A. (2000). *The electric vehicle and the burden of history*. New Brunswick, NJ: Rutgers University Press.
Kirsch, D., Moeen, M., & Wadhwani, R. D. (2014). Historicism and industry emergence: Industry knowledge from pre-emergence to stylized fact. In M. Bucheli & R. D. Wadhwani (Eds.), *Organizations in time: history, Theory, Methods* (pp. 217–240). Oxford, U.K.: Oxford University Press.
Klepper, S. (2016). *Experimental capitalism: The nanoeconomics of American high-tech industries*. Princeton, NJ: Princeton University Press.
Kline, R., & Pinch, T. (1996). Users as agents of technological change: The social construction of the automobile in the rural United States. *Technology and Culture*, *37*(4), 763–795.
Langlois, R. N., & Robertson, P. L. (1992). Networks and innovation in a modular system: Lessons from the microcomputer and stereo component industries. *Research Policy*, *21*(4), 297–313.
Lechevalier, S., Nishimura, J., & Storz, C. (2014). Diversity in patterns of industry evolution: How an intrapreneurial regime contributed to the emergence of the service robot industry. *Research Policy*, *43*(10), 1716–1729.
Lee, B. H., Hiatt, S., & Lounsbury, M. (2017). Market mediators and the tradeoffs of legitimacy-seeking behaviors in a nascent category. *Organization Science*, *28*(3), 447–470.
Lomi, A., Larsen, E. R., & Wezel, F. C. (2010). Getting there: Exploring the role of expectations and preproduction delays in processes of organizational founding. *Organization Science*, *21*(1), 132–149.
Lounsbury, M., Ventresca, M., & Hirsch, P. M. (2003). Social movements, field frames and industry emergence: A cultural–political perspective on U.S. recycling. *Socio-Economic Review*, *1*(1), 71–104.
Merton, R. K. (1973). *The sociology of science: Theoretical and empirical investigations*. Chicago, IL: University of Chicago Press.
Min, W. K., & Sarkar, M. (2015). *How does knowledge evolve?: Evidence from solid-state lighting*. Paper presented at the Academy of Management Proceedings, volume 1, 2015.
Mody, C. C. (2006). Corporations, universities, and instrumental communities: Commercializing probe microscopy. *Technology and Culture*, *47*(1), 56–80.
Moeen, M. (2017). Entry into nascent industries: Disentangling a firm's capability portfolio at the time of investment versus market entry. *Strategic Management Journal*, *38*(10), 1986–2004.
Moeen, M., & Agarwal, R. (2017). Incubation of an industry: Heterogeneous knowledge bases and modes of value capture. *Strategic Management Journal*, *38*(3), 566–587.
Mowery, D. C. (2010). Military R&D and innovation. In B. H. Hall & N. Rosenberg (Eds.), *Handbook of the economics of innovation* (Vol. 2, pp. 1219–1256). Amsterdam, The Netherlands: Elsevier.
Navis, C., & Glynn, M. A. (2010). How new market categories emerge: Temporal dynamics of legitimacy, identity, and entrepreneurship in satellite radio, 1990–2005. *Administrative Science Quarterly*, *55*(3), 439–471.
Nelson, O. E. (1993). A notable triumvirate of maize geneticists. *Genetics*, *135*(4), 937.
North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge, U.K.: Cambridge University Press.
Oudshoorn, N., & Pinch, T. (2003). *How users matter: The co-construction of users and technology*. Cambridge, MA: MIT Press.
Ozcan, P., & Santos, F. M. (2015). The market that never was: Turf wars and failed alliances in mobile payments. *Strategic Management Journal*, *36*(10), 1486–1512.
Pacheco, D. F., York, J. G., & Hargrave, T. J. (2014). The coevolution of industries, social movements, and institutions: Wind power in the United States. *Organization Science*, *25*(6), 1609–1632.
Phaal, R., O'Sullivan, E., Routley, M., Ford, S., & Probert, D. (2011). A framework for mapping industrial emergence. *Technological Forecasting and Social Change*, *78*(2), 217–230.
Rao, H. (1994). The social construction of reputation: Certification contests, legitimation, and the survival of

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259

organizations in the American automobile industry. *Strategic Management Journal*, *15*(S1), 29–44.
Rosenberg, N. (1974). Science, invention and economic growth. *Economic Journal*, *84*(333), 90–108.
Rosenberg, N. (1992). Economic experiments. *Industrial and Corporate Change*, *1*(1), 181–203.
Rosenbloom, R. S., & Cusumano, M. A. (1987). Technological pioneering and competitive advantage: The birth of the VCR industry. *California Management Review*, *29*(4), 51–76.
Rothaermel, F. T., & Thursby, M. (2007). The nanotech versus the biotech revolution: Sources of productivity in incumbent firm research. *Research Policy*, *36*(6), 832–849.
Roy, R., & Sarkar, M. B. 2017. *Genesis of pre-commercialization innovation ecosystem: Knowledge recombination in the pre-commercialization phase of charge-coupled device image sensors* (Working Paper). Chicago, IL: Northeastern Illinois University.
Sanderson, S. W., & Simons, K. L. (2014). Light emitting diodes and the lighting revolution: The emergence of a solid-state lighting industry. *Research Policy*, *43*(10), 1730–1746.
Santos, F. M., & Eisenhardt, K. M. (2009). Constructing markets and shaping boundaries: Entrepreneurial power in nascent fields. *Academy of Management Journal*, *52*(4), 643–671.
Schilling, M. A. (2016). *Strategic management of technological innovation* (5th ed.). New York, NY: McGraw-Hill Education.
Schumpeter, J. A. (1934). *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. New Brunswick, NJ: Transaction Publishers.
Schumpeter, J. A. (1942). *Capitalism, socialism, and democracy*. New York, NY: Harper.
Shah, S. K. (2003). *Community-based innovation & product development: Finding from open source software and consumer sporting goods* (Doctoral thesis). Massachusetts Institute of Technology, Cambridge, MA.
Shah, S., Agarwal, R., & Sonka, S. 2017. *A time and a place: Non-profit engagement in creation of markets and industry emergence* (Working paper). Champaign, IL: University of Illinois.
Shah, S. K., & Gorbatai, A. D. (2015). Structural sampling: A technique for illuminating social systems. In K. D. Elsbach & R. M. Kramer (Eds.), *Handbook of qualitative organizational research* (pp. 251–261). New York, NY: Routledge.
Shah, S. K., & Mody, C. C. (2014). Creating a context for entrepreneurship: Examining how users' technological and organizational innovations set the stage for entrepreneurial activity. In B. Frischmann, M. Madison, & K. Strandburg (Eds.), *Governing knowledge commons* (Vol. 313, pp. 313–339). Oxford, U.K.: Oxford University Press.
Shah, S. K., & Tripsas, M. (2007). The accidental entrepreneur: The emergent and collective process of user entrepreneurship. *Strategic Entrepreneurship Journal*, *1*(1–2), 123–140.
Sine, W. D., Haveman, H. A., & Tolbert, P. S. (2005). Risky business? Entrepreneurship in the new independent-power sector. *Administrative Science Quarterly*, *50*(2), 200–232.
Sine, W. D., & Lee, B. H. (2009). Tilting at windmills? The environmental movement and the emergence of the U.S. wind energy sector. *Administrative Science Quarterly*, *54*(1), 123–155.
Sonka, S., Cheng, C., & Kenney, G. (2014). *Postcosecha program: Metal silos in central America*. ADM Institute for Prevention of Postharvest Loss, University of Illinois at Urbana-Champaign, Urbana, IL.
Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, *15*(6), 285–305.
Tripsas, M. (2008). Customer preference discontinuities: A trigger for radical technological change. *Managerial and Decision Economics*, *29*(2–3), 79–97.
Tushman, M. L., & Anderson, P. (1986). Technological discontinuities and organizational environments. *Administrative Science Quarterly*, *31*(3), 439–465.
Vakili, K., & McGahan, A. M. (2016). Health care's grand challenge: Stimulating basic science on diseases that primarily afflict the poor. *Academy of Management Journal*, *59*(6), 1917–1939.
Van Maanen, J. (1979). Reclaiming qualitative methods for organizational research: A preface. *Administrative Science Quarterly*, *24*(4), 520–526.
Von Hippel, E. (1988). *The sources of innovation*. Oxford, U.K.: Oxford University Press.
Walker, G., & Weber, D. (1984). A transaction cost approach to make-or-buy decisions. *Administrative Science Quarterly*, *25*(3), 373–391.
Weber, K., Heinze, K. L., & DeSoucey, M. (2008). Forage for thought: Mobilizing codes in the movement for grass-fed meat and dairy products. *Administrative Science Quarterly*, *53*(3), 529–567.
Weber, K., Rao, H., & Thomas, L. (2009). From streets to suites: How the anti-biotech movement affected German pharmaceutical firms. *American Sociological Review*, *74*(1), 106–127.
Weintraub, A. (2004, October). Robert Swanson and Herbert Boyer: Giving birth to Biotech. *Bloomberg BusinessWeek*.
Wry, T., Lounsbury, M., & Glynn, M. A. (2011). Legitimating nascent collective identities: Coordinating cultural entrepreneurship. *Organization Science*, *22*(2), 449–463.
Zucker, L. G., Darby, M. R., & Brewer, M. B. (1998). Intellectual capital and the birth of U.S. biotechnology enterprises. *American Economic Review*, *88*(1), 290–306.

Copyright © 2017 Strategic Management Society

DOI: 10.1002/sej.1259