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How Do Innovation Ecosystems Emerge? The Case of Nanotechnology in Israel

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ABSTRACT Research on innovation ecosystems has identified their evolution phases but neglected their emergence, which we know little about. We offer inductive theory to explain the emergence of the nanotechnology ecosystem in Israel. Our theory suggests that ineffective bureaucracy, resource constraints, and the conflicting agendas of the government and universities create organizational bottlenecks that impede the ecosystem's emergence. Only once these actors establish related dedicated units that are immune to these deficiencies and transition to simultaneous competition and cooperation does the innovation ecosystem begin to emerge. We further reveal how enabling and governing mechanisms legitimize the innovation ecosystem, facilitate its emergence, and direct its evolution trajectory. Hence, we extend research that has centered on subsequent phases of evolution and explain how actors interact to facilitate the emergence of the ecosystem following technological discovery. Our study contributes to strategy research on interfirm coopetition by applying this concept to government and university actors, and by alluding to its multiple facets: identity, direction, administration, and resources. We also complement innovation research on the post-formation dynamics of ecosystems by providing insights into the missing link between technological discovery and the creation of an innovation ecosystem that brings together stakeholders to commercialize that technology.

Keywords: coopetition, ecosystem, emergence, innovation, organizational metamorphosis, nanotechnology

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INTRODUCTION

How do innovation ecosystems emerge? An ecosystem refers to 'the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize' (Adner, 2017, p. 40). This definition fuses the perspective of 'ecosystem as structure', which views the ecosystem as a configuration of value-creating activities, with the perspective of 'ecosystem as affiliation', which conceptualizes it as a community of affiliated actors defined by their networks (Adner, 2017). Scholars distinguish 'business ecosystems', which focus on firms embedded in their environment, from 'platform ecosystems', in which actors organize around a platform, and from 'innovation ecosystems', which center on the commercialization of a particular technological innovation and the actors that support it (Jacobides et al., 2018). We define an innovation ecosystem as the alignment structure of government, university, and other actors that interact to promote innovation and commercialization of a core technology as their common value proposition. Prior research has focused on business ecosystems and platform ecosystems (Chen et al., 2014, 2016; Gomes et al., 2018; Spigel and Harrison, 2018) rather than on innovation ecosystems, which makes it difficult to isolate the factors that drive ecosystem emergence from the intertwined industry emergence. This prior research has also predominantly studied subsequent phases of evolution, with the emergence phase left understudied.

Innovation ecosystems have gained increasing attention as many commercial applications of technologies, such as nanotechnology, artificial intelligence, emotion detection, bioinformatics, and cleantech, originate in ecosystems that give rise to innovative technologies (e.g., Hannah and Eisenhardt, 2018; Krafft et al., 2014). In the USA alone, the National Nanotechnology Initiative invested more than $27 billion in nanotechnology research (Leonard, 2017), aiming to revolutionize the medicine, energy, water purification, manufacturing, and food industry sectors. Although the global nanotechnology market was valued at only $1.8 billion in 2020, it is expected to reach $33.6 billion by 2030 (Tewari and Kumar, 2021). The emergence of innovation ecosystems around such technologies is a critical phase that shapes the structure of relations among ecosystem members and sets the ground for entrepreneurs and firms to leverage these technologies in subsequent phases of evolution. The ecosystem may take years to materialize following the technological discovery, with some ecosystems failing to emerge, as in the case of the commercialization of nanotechnology in India (Koshy and Sethi, 2013). The emergence of an innovation ecosystem entails coordination among various actors with conflicting agendas that may lack the needed resources for commercialization. This makes it difficult to strive for a common value proposition that promotes commercialization.

What brings these actors together at the emergence phase? Scholars tend to take the emergence phase for granted and assume that once the technology becomes available, stakeholders can gather to commercialize it. Yet this is often not the case. Without studying the emergence phase, one cannot understand how the needed technological infrastructure and relations among proponents that drive the evolution of the ecosystem come into being. Little is known about how innovation ecosystems come about, since 'no studies have captured the emergence of the ecosystems' (Suominen et al., 2019, p. 335). Rather, most studies have highlighted the actions of firms (Dattée et al., 2018) that join only in subsequent phases of evolution, and thus cannot explain the emergence phase. Thus, prior research has not focused on innovation ecosystems and, in particular, on their emergence phase, in which firms play a limited role. This omission restricts understanding of the dynamics that hinder the emergence of an innovation ecosystem and enable the ecosystem members to coordinate technology development despite inherent organizational challenges. To understand how innovation ecosystems emerge, one must identify the barriers for their emergence and understand how actors manage to overcome these barriers and direct and accelerate the emergence of the ecosystem.

We develop an inductive grounded theory for the emergence of an innovation ecosystem based on a longitudinal case study (Corbin and Strauss, 1990; Suddaby, 2006) of the nanotechnology ecosystem in Israel. Nanotechnology is an excellent context for studying an innovation ecosystem (Granqvist et al., 2013; Kaplan and Radin, 2011; Mangematin and Walsh, 2012; Wry and Lounsbury, 2013). Prior research has considered nanotechnology (or 'nano') as an emerging innovation ecosystem that involves university research centers, scientists, and government agencies (e.g., Foley and Wiek, 2017; Lavie and Drori, 2012; Meyer et al., 2005). We study the nature of interdependence among these actors as well as the underlying dynamics that led to the emergence of this innovation ecosystem. We compile a chronicle of the emergence that reveals a complex interplay of the government, various interest groups, and academic institutions. Our findings uncover that it is organizational bottlenecks rather than technological bottlenecks that hinder the ecosystem's emergence and are critical at that phase. These bottlenecks involve ineffective bureaucracy in the form of fragmentation, rigidity, myopia, discoordination, and administrative void as well as resource constraints imposed by shortage, suboptimal priorities, and scattering of resources. The findings also guide our explanation of how organizational metamorphosis and coopetition,[1] which have not been considered in prior research on the emergence of ecosystems, enable actors to align their interests and pool their resources in order to dislodge the ecosystem from these bottlenecks. Finally, our findings reveal unique enabling and governing mechanisms that facilitate the emergence of the ecosystem and direct its evolution in a trajectory that departs from the natural inclinations of some actors. Hence, we shed light on the underlying dynamics that endogenously shape the emergence of the innovation ecosystem.

Our study offers several contributions. Our primary contribution is offering a novel theory for how a new innovation ecosystem comes about. By underscoring how the interaction between government and universities shapes the emergence of the innovation ecosystem, our theory complements theories of ecosystem evolution that have highlighted the roles of firms and entrepreneurs in subsequent phases of evolution of business and platform ecosystems. Besides their limited applicability for innovation ecosystems that do not center on value capture, such research has taken for granted the availability of technological infrastructure and studied arising technological bottlenecks. Instead, our theory considers how actors can unblock organizational bottlenecks that impede or delay the emergence of the ecosystem. Hence, our theory explains not only how ecosystems emerge but also why they may not emerge despite technological discovery. Without analyzing the anatomy of failure, it is impossible to understand what drives the evolution of innovation ecosystems and how actors overcome resource constraints and conflicting interests that hinder this evolution. Our second contribution is revealing the roles of organizational metamorphosis and coopetition, which have been previously overlooked by prior research on ecosystem emergence. We explain how metamorphosis and coopetition enable actors to unblock organizational bottlenecks by facilitating organizational alignment and striving for a shared mission that is followed by coordination and pooling of resources, thus supporting the commercialization of a technology. Hence, our study informs research on ecosystem evolution and provides guidance for how to facilitate the emergence of innovation ecosystems. Our final contribution is advancing broader streams of research on strategy and innovation. For instance, our theory extends the notion of coopetition to encompass behavioural and organizational aspects beyond the narrow strategic aspects relating to firms' resource competition and pooling. Furthermore, our notion of metamorphosis suggests that to overcome organizational bottlenecks, actors can maintain their ineffective bureaucracy in parallel to operating under a new set of rules and practices. These are essential contributions that shed a new light on the emergence of innovation ecosystems, inform our understanding of ecosystem evolution, and generate new insights for strategy and innovation research.

THEORETICAL BACKGROUND

The notion of innovation ecosystem has been used loosely (Gomes et al., 2018), but scholars typically relate it to coordinated knowledge creation, dissemination, and potential use, whereby actors 'interact to catalyze creativity, trigger invention and accelerate innovation across scientific and technological disciplines, public and private sectors (government, university, industry and non-governmental knowledge production, utilization and renewal entities)' (Carayannis and Campbell, 2009, pp. 202–3). In all ecosystems, actors create value by structuring relations and adapting to the environment. But business and platform ecosystems mostly involve interactions among firms that interdependently deliver a product or service, whereas innovation ecosystems involve university research centers and government agencies that strive to develop and promote a technology. Unlike business ecosystems, in which firms engage in value creation and capture, innovation ecosystems focus on value creation (Gomes et al., 2018). In innovation ecosystems, the linear model applies: 'first, there is basic university research. Later this basic research converts into applied research of intermediary organizations (university-related institutions). Finally, firms pick up, and transform applied research to experimental development, which is then being introduced as commercial market applications' (Carayannis and Campbell, 2009, p. 210). Hence, firms' involvement in the emergence of innovation ecosystems is limited.

Prior research has focused on business and platform ecosystems more than on innovation ecosystems (Adner and Kapoor, 2010), identifying phases of evolution

(Moore, 1993) during which firms develop technologies and corresponding capabilities (Chen et al., 2014, 2016; Jha et al., 2016; Leong et al., 2016). It has highlighted location choices and the need for supportive infrastructure (Pitelis, 2012; Spigel and Harrison, 2018), noting that business ecosystems attract members via experimentation and interaction (Overholm, 2015; Pera et al., 2016), while platform ecosystems evolve with the leader's dynamic capabilities, capacity to mitigate tensions (Helfat and Raubitschek, 2018; Wareham et al., 2014), and pluralism and knowledge sharing among members (Mantovani and Ruiz-Aliseda, 2015; Toh and Miller, 2017; Vakili, 2016). In studying ecosystem emergence, Jacobides et al. (2018) identify modularity and firms' proactive effort as necessary conditions. However, firms' involvement in the genesis of business and platform ecosystems makes it difficult to isolate the emergence of those ecosystems from industry emergence.[2] Besides, with very few exceptions (e.g., Dattée et al., 2018), this research has not focused on how ecosystems come about. Dattée et al. (2018) examine how a firm steers a collective process for envisioning a blueprint for its ecosystem, withholds resources under uncertainty, and secures its share of the created value. These insights cannot inform the study of innovation ecosystems, in which firms play a limited role at the emergence phase and where the challenge is not the orchestration of firm-centric value capture, but the pooling of national resources by government and university actors to establish the needed technological infrastructure for innovation. Unlike business and platform ecosystems, innovation ecosystems typically call for the intervention of the government and academia that can furnish the needed infrastructure. However, most of the research on innovation ecosystems sets aside the question of emergence and focuses on post-formation dynamics that take place after commercialization has begun (e.g., Adner and Kapoor, 2010; Mantovani and Ruiz-Aliseda, 2015; Tiwana et al., 2010). This research explains how an established ecosystem overcomes technological bottlenecks as it transitions across technology generations (Adner and Kapoor, 2010, 2016; Hannah and Eisenhardt, 2018), and how its structure changes as new entrants introduce disruptive technologies (Ansari et al., 2016).

The few studies on the emergence of innovation ecosystems identify the roles of different stakeholders in this phase (Dedehayir et al., 2018; Pekkarinen et al., 2020) and underscore the availability of technological infrastructure and engineering expertise, such as in the form of national labs (Best, 2015) and accelerators (Goswami et al., 2018; Wright and Drori, 2018). This research alludes to the need for a technological infrastructure and identifies different stakeholders that promote the innovation ecosystem, but does not explain how this infrastructure emerges in the first place and assumes that the ecosystem architecture is self-reinforcing (e.g., Best, 2015; Mantovani and Ruiz-Aliseda, 2015). It does not attend to the core issue of the dynamics that enable such ecosystems to emerge, and thus it falls short of identifying the pitfalls that may prevent the ecosystem from emerging. In sum, scholars have begun to study conditions for the evolution of innovation ecosystems, unpack the characteristics of evolution phases, and identify the actors that shape it. Nevertheless, there remains a missing link between the discovery of a technology and the emergence of the innovation ecosystem that supports its commercialization (e.g., Perkmann et al., 2013). How an innovation ecosystem emerges remains an unresolved puzzle (Autio and

Thomas, 2014). Our study offers insights into the underlying dynamics in this under-studied emergence phase.

METHODS

Research Setting

We follow an inductive approach for qualitative analysis of a longitudinal case study (Corbin and Strauss, 1990; Gioia et al., 2013; Suddaby, 2006) of the nano ecosystem in Israel during its emergence phase. Nanotechnology refers to science, engineering, and technology conducted at the nanoscale level, i.e., 1 to 100 nanometres. It has applications in disciplines such as chemistry, biology, physics, and materials science. The multidisciplinary nature of this technology and its applications ensures that the underlying processes are not linked to a particular industry. Nanotechnology has been developed in an ecosystem that primarily involves university research centers rather than firms (Avenel et al., 2007; Lavie and Drori, 2012). Being mostly small-to-medium-sized, Israeli firms tend to fund only scientific projects that could yield immediate applications, and thus were not involved in the emergence phase: 'then, both the initiative and the activities were exclusively academic';[3] 'The industry is not deeply involved. Few small firms were established. The industrial development is very limited'[1] (Table I in the Appendix S1 lists interview sources). An interviewee elaborated: 'The industry needs to become more scientific and adopt advanced technologies that are typically found in universities … there are no large firms, … no research labs. There is a gap between the point to which you can bring university research and the point from which the industry can take this forward. In nanotechnology, this gap is very noticeable because … the timeframes are very long and a much greater level of sophistication is needed'.[1] Hence, our context is suitable for studying an innovation ecosystem as opposed to a business or platform ecosystem and for isolating its emergence phase from processes ascribed to industry evolution.

Nanotechnology was introduced to the Israeli scientific community in 1989 with the purchase of an atomic force microscope by the Israel Science Foundation (ISF). During the 1990s, funding was scarce, and the needed investment was beyond the capacity of government ministries. This prompted the president of the Israel Academy of Sciences and Humanities (IASH) to establish a Forum for Research and Infrastructure (FRI) in 1997. In 2001, FRI appointed the Maydan Committee to assess the prospects for nano, identify needed infrastructure, examine possibilities for cooperation, and recommend actions. The program was set for $300 M, and FRI appointed the Israel Nanotechnology Advisory Board (INAB) to prepare a plan for nano research infrastructure. The Israel National Nanotechnology Initiative (INNI) Board was appointed in 2003 to oversee this initiative. The Ministry of Science and Technology (MOST) challenged FRI but realigned in 2005. FRI raised less than $10 million from its members' budgets by 2004. That year, however, the Technion University received $26 million from the Berrie Foundation with matching funds from the Technion and the government. In 2006, FRI approved the Triangle Donation Model (TDM) for funding nano initiatives based on the Technion's model. The $220 million budget was also allocated to Bar-Ilan University (BIU), Tel-Aviv University (TAU), Hebrew University of Jerusalem (HUJI), Ben-Gurion University (BGU), and the Weizmann Institute. Without statutory authority, INNI oversaw the distribution of funds, monitored the research centers, and developed and enforced procedures. In 2012, the second nano program was launched to further build the infrastructure needed for supporting the university research programs and achieving the commercialization goals. The five-year budget was set at $180 million, and the TDM was altered. The second program directed universities toward applied research in focal technology areas (FTAs), and the universities hired 'golden-egg hunters' to promote commercialization.

Vibrant and multidisciplinary nano communities evolved in the six universities, featuring graduate programs, seminar series, and conferences as the ecosystem's activities continued to grow: the number of nano scientists in the six centers increased to 482 in 2011, and then to 587 in 2016; between 2007 and 2016, the number of junior scientists and postdoctoral students increased from 132 to 2925, and the number of graduate students increased from 700 to 9609; the number of published articles increased from 1783 to 14,015; the number of joint university-industry projects funded through the Ministry of Industry and Trade (MITL) increased from 196 to 2025; the number of patent applications increased from 207 to 1931, of which 819 were granted during that period; the number of commercial 'success stories' (e.g., commercially used patents, transferred knowledge) also increased, from 66 to 321; the investment in nano equipment increased from $40 million to $157 million, with the total funding received from research grants, government, and industry reaching $897 million; equipment utilization increased to 39 per cent, and by 2017, 140 nano start-up firms had been initiated mostly by university scientists, of which 109 survived. These outcomes demonstrate the achievement of the commercialization goals of the innovation ecosystem. Figure 1 depicts these emergence trends by 2016.

Data Collection and Analysis

Our data covers the Israeli nano ecosystem from 1989 through 2016, when the second national nano program ended. We relied on a variety of comprehensive data sources, triangulating across them (Eisenhardt, 1989) to compile a rich historical narrative of ecosystem emergence. Table SII describes our data sources and their use in the inductive analysis. Our analysis followed five steps: (1) developing a chronology of events, (2) temporal bracketing, (3) identifying emerging constructs, (4) categorization, and (5) developing a theory of ecosystem emergence (see Appendix S1).

FINDINGS AND THEORY BUILDING

Our findings reveal that in the arising bottlenecks process, inefficient bureaucracy and resource constraints create barriers and conflicts that delay the ecosystem's emergence. The ecosystem begins to emerge as these impediments are subdued by the unblocking process, in which metamorphosis and transition to coopetition enable the actors to pursue joint interests, coordinate actions, and pool resources. In parallel, the shaping process introduces enabling and governing mechanisms that legitimize the ecosystem and accelerate and direct its emergence.

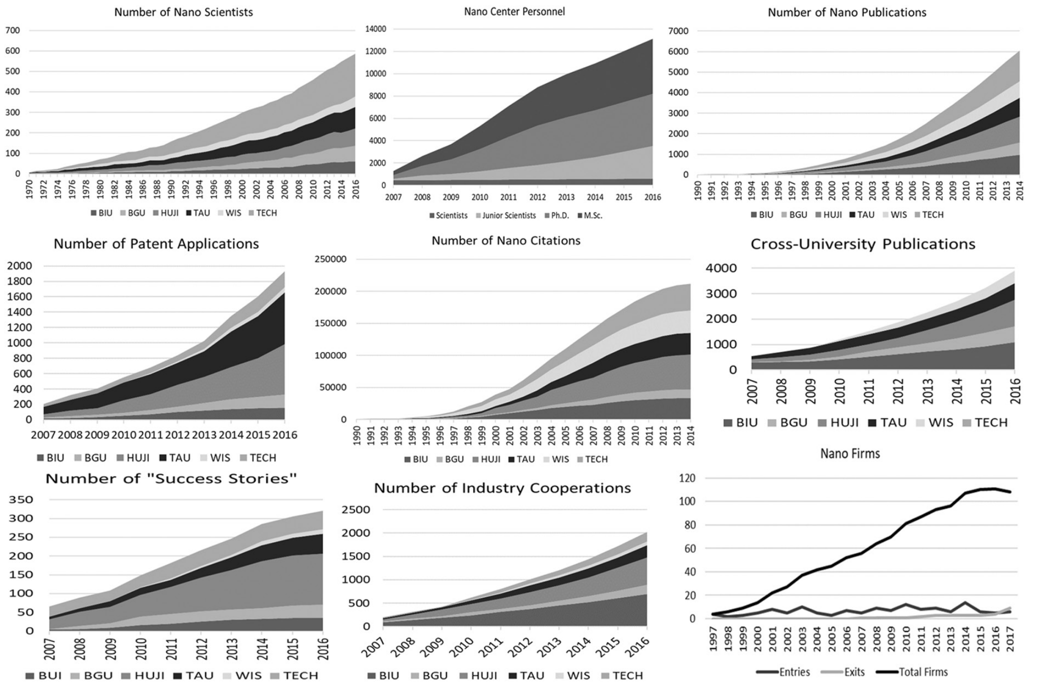

Figure 1. Indicators of emergence of the nanotechnology ecosystem in Israel

Arising of Organizational Bottlenecks

Nearly two decades passed between the purchase of the nanoscale microscope and the establishment of nano centers. During that time, nano received scant attention from policymakers, and the scientific infrastructure was underdeveloped. Our evidence reveals how ineffective bureaucracy and resource constraints inhibited the ecosystem's emergence.

Ineffective bureaucracy. Five bureaucratic inefficiencies created organizational bottlenecks that hindered the emergence of the nano ecosystem at the outset. First, we identified *fragmentation*, i.e., a separation of functions and responsibilities across organizational actors. In particular, government ministries operated as silos, each pursuing its own goals while 'haggling for their share of the budget'.[20] University scientists were also fragmented, dispersed across separate departments, with minimal cross-departmental communication. Even when working on similar problems, they avoided collaboration in hope of winning recognition: 'University A is working on it, and also University B. Do they talk to each other? No! One has the bolt. One has the nut. And a third has the lockwire and adhesives to lock them in place. And yet no one is talking to each other. Everyone wants to receive a Nobel Prize on their own'.[4] In cases where collaboration might have evolved naturally, such as between chemistry and physics departments in a university, it seemed that there was a 'fence around the building, with a "Do Not Disturb" sign'.[6] Thus, although nano is interdisciplinary and requires collaboration, the 'integration of many different technologies into one platform was very unnatural',[2] and research remained largely within disciplines. An effort to build the infrastructure for nano failed because the fragmentation of government ministries with conflicting agendas, much like the fragmentation within and across universities, hindered cooperation and coordination of related tasks that were needed for promoting this national endeavor.

Second, actors exhibited *rigidity*, that is, inflexibility with respect to organizational objectives, structures, and tasks. Budgetary constraints and legal advisors were often blamed for the rigid bureaucracy at government ministries. Consequently, no project could be performed beyond the narrow mandate of each ministry. Ministries dismissed attempts to change the status quo by shifting responsibility: 'You approach the MITL with an important national initiative, and they say "it is none of my business, talk to the Council for Higher Education (CHE), talk to the Ministry of Science"'.[10] This rigidity created barriers that inhibited substantial cross-departmental collaborative effort by government ministries. Similarly, university scientists revealed rigidity, refusing more applied research: 'We conduct research, reach some results, and then have two options: either leaving everything in the drawer, or trying to make a startup. But the second option requires more time and intellectual effort than many of us are willing to invest… For us, the criteria are first and foremost scientific';[11] 'Scientists don't want to be service providers to industry';[35] 'Scientists do what they want, and we are proud of this'.[30] This rigidity reveals an inherent conflict that sets a barrier to collaboration.

Third, actors displayed *myopia*, i.e., short-term or narrow focus. Most ministries did not consider long time horizons and planned only as far as the next election: 'If a ministry wants to do something that is longer than one year and needs to commit to scientists and to industry, they cannot do it'.[10] This myopia resulted in a failure to furnish the required scientific infrastructure and capital for nano. There was 'no way for the government to set national priorities for [large infrastructure] projects'.[10] Similarly, scientists were narrowly focused on their research agenda, paying limited attention to applications: 'The thing that interests academic researchers is to … prove their research question and publish the results … receive international recognition, climb the academic ladder'.[37] Many scientists 'don't want to be bothered'.[6] Thus, the majority of nano scientists showed no interest in commercialization. This conflicted with the stated mission of the government, which imposed bureaucratic barriers and failed to invest in nano infrastructure.

Fourth, actors experienced *discoordination*, i.e., an impaired ability to orchestrate joint activities. Whereas fragmentation implied that a responsibility was split across actors, discoordination meant that these actors could not align their actions, which was more consequential. For instance, ministries were so unaccustomed to collaboration that working together was 'mission impossible'.[34] Although several forums such as the Ministers' Forum for Science and Technology involved multiple ministers, 'It is unreal. Nothing gets decided there. Each minister comes with pre-cooked decisions, or objects to someone else's pre-cooked decisions… Because it is formal, everyone represents his or her ministry. Everyone is against everyone else'.[10] Thus, it was challenging for the ministries to coordinate national R&D. This was compounded by MOST's inability to orchestrate national R&D because it was 'too small a player in the Israeli R&D ecosystem. There are giants, such as the military, the CHE, and the Chief Scientist at the MITL. So when the MOST tried to take over, it just did not work: "a small mouse cannot tell lions what to do". They just kick it or ignore it'.[10] The lack of ministerial coordination left unresolved conflicts and mounted barriers for the ecosystem. For example, when a ministry failed to furnish funds and operations halted, an INNI board member donated $17,000 from his personal funds, and noted: 'Getting several government offices to work together is an impossible mission… If the behemoths in Jerusalem [i.e., government officials] will not solve the problems we have here and this terrible mess continues, we'll all live abroad and that's it!'.[4] Similarly, scientists were uncoordinated, remaining within their disciplines and failing to launch interdisciplinary forums, centers, and conferences. There were 'no strategic collaborations'[6] between scientists and industry, so knowledge failed to transfer. This lack of coordination reinforced conflicts and barriers.

Fifth, there was an *administrative void*, i.e., no one was assigned the responsibility for the specific organizational task of supporting the national nano initiative. Ministries lacked an overall responsibility for building the required infrastructure. While the MOST was officially responsible for setting direction for national R&D initiatives, no one was responsible for building the R&D infrastructure, with ministries lacking the authority or power to do so. There was no 'council that would look ahead and say what is needed … there are limited resources, so what should be prioritized?'.[10] Likewise, no one was assigned the responsibility for nano infrastructure at the universities. The research endeavors of nano scientists in the late 1990s were largely unorganized. Efforts to organize were all 'bottom-up … but did not gain much traction'.[27] This void in the government and universities imposed friction and barriers for coordination.

In sum, to emerge, innovation ecosystems require the formation of an alignment structure that supports coordination among a set of actors with distinct agendas (Adner, 2017). However, the ineffective bureaucracy, characterized by fragmentation of organizational units, rigidity of their agenda, and myopic outlook, coupled with lack of coordination and unassigned responsibilities, perpetuates conflicts and imposes organizational barriers that lead to inertial paralysis. Unlike studies that underscore technological barriers and the lack of technical expertise as impediments to ecosystem emergence (e.g., Best, 2015), our theory points to ineffective bureaucracy that makes it difficult to establish the infrastructure for the emerging ecosystem, regardless of the actors' goodwill. Accordingly, these organizational bottlenecks inhibit the emergence of the innovation ecosystem.

Resource constraints. Resource constraints, exemplified by a shortage of resources, prioritization problems, and the scattering of resources, also created bottlenecks for emergence. First, *shortage*, i.e., insufficiency of resources allocated for performing organizational tasks, was a major challenge for the emergence of the ecosystem: 'some national needs require heavy infrastructure and thus become orphans with no one able to fund them. The needed budget is so large that everyone is scared off'.[10] Although the MITL was eager to fund a nano program in the early 2000s, it lacked the necessary budget. Similarly, the MOST, which was 'the last in line to receive funds, kept getting its budget reduced'.[6] Neither ministry could fund a nano initiative on its own, which imposed a major barrier for the ecosystem. At the universities, funds were so scarce that 'everything was kept on a small flame',[3] and research progress was slow. There was a critical mass of about 120 nano scientists, but the limited funding hindered their initiatives. The meagre resources allocated to nano led PhD graduates to leave the country for positions abroad. Those scientists who returned had to both 'limit their dreams and work very slowly',[3] e.g., building a new lab took three years instead of one. Attempts to organize nano scientists in research centers barely took off because of the severe shortage of resources. Finally, even if scientists saw commercial potential, the lack of funding for maturing the technologies for industry use created an impassable barrier: the 'distance between a research finding and a commercial application is tremendous… Many projects are stuck … because universities and their technology transfer offices lack the needed funds'.[37]

Second, there was *suboptimal prioritization* of objectives for resource allocation. No ministry prioritized national R&D that crossed ministerial boundaries or was willing to put forth any funds for it. Each asked, 'Why me? It is important, so why should I be the one to fund it? Someone else should fund it. And then these initiatives never get funded'.[10] Projects that bridged industry and academia were left orphaned: 'The industry says that it is not their business, so these projects never get funded'.[10] Even when ministries sought funds to meet national goals, they were unable to secure them. The Budgeting Department at the Ministry of Finance, which is in charge of planning, 'does not release funds because so many ministers come to them and ask for money for the same things that they just don't know what the priority is. They sit like a brooding hen on its eggs all day, and say, "Why waste money?"'.[10] Hence, overarching goals were not set, and allocation of scarce resources was suboptimal. The inability of ministries and universities to agree on priorities for resource allocation created barriers for initiatives supporting the emerging ecosystem.

Third, there was *scattering* of the scarce resources across actors: 'each ministry and public body, such as the CHE, has its own budget and funds the activities that are important for its sector'.[10] Each minister represented his or her ministry and '[fought] against everyone else over the budget, trying to secure as much money as possible at the annual government budgeting meetings'.[10] The scattering of resources and funding battles among ministries created barriers for a substantial government-wide initiative in nano. Resources were also scattered across university departments. The high equipment price makes scattering harmful: 'the microscope in the building next door costs $4 million. Just one microscope!'.[11] Thus, most nano scientists in the 1990s could not purchase equipment. In sum, resource constraints hindered the ecosystem's emergence.

In sum, we reveal that insufficient, dispersed, or suballocated resources deprive the emerging ecosystem of necessary support. Prior research has identified resource accessibility as a necessary condition for ecosystem evolution (e.g., Spigel and Harrison, 2018), but we allude to nuanced bottlenecks that concern not only resource scarcity, but also the difficulty in orchestrating resources (Sirmon et al., 2011), whose suboptimal configuration across actors prevents their accumulation and allocation to support the emergence of the innovation ecosystem.

Overall, in the aforementioned process, our theory suggests that ineffective bureaucracy and resource constraints amplify actors' conflicting interests and create organizational bottlenecks. These bottlenecks do not concern the nature of technology, i.e., 'components that constrain the overall growth or performance of the ecosystem due to poor quality, weak performance, or scarcity' (Hannah and Eisenhardt, 2018, p. 3164). Rather, they refer to a broader set of organizational impediments characterizing the ecosystem members and their interrelations. Moreover, these bottlenecks do not merely constrain the growth of the ecosystem, but also hinder its emergence. Prior research mostly focused on identifying the complementary roles of actors that enable the emergence of the ecosystem (e.g., Dedehayir et al., 2018), assuming away their conflicting interests and bureaucratic hurdles, which create bottlenecks. Either ineffective bureaucracy or resource constraints can create organizational bottlenecks, but their combination makes these bottlenecks more challenging to unblock. By introducing these bottlenecks, our theory provides the missing link between technological discovery and ecosystem emergence (Moore, 1993). We direct attention to organizational impediments rather than to technological or economic barriers, which have received attention in theories of ecosystem emergence (Adner and Kapoor, 2010, 2016; Jacobides et al., 2018; Tiwana et al., 2010). Thus, we explain why an ecosystem may fail to emerge despite technological discovery, or why its emergence phase may be prolonged.

Unblocking Organizational Bottlenecks

Barriers and conflict ascribed to ineffective bureaucracy and resource constraints inhibited the emergence of the ecosystem for two decades. Next, we reveal how metamorphosis and transition to coopetition enabled actors to align their interests and pool resources, and hence dislodge the ecosystem from its immutable position. Metamorphosis created the organizational setting for unblocking the bottlenecks, while coopetition motivated that unblocking.

Organizational metamorphosis. Organizational metamorphosis refers to the creation of a new organization that is derived from an antecedent organization, which continues to exist. Unlike that established organization, it manages to perform a certain task as a result of its altered organizational traits. Informalizing metamorphosis yields an informal arrangement, whereas formalizing metamorphosis leads to a statutory institution. Through these metamorphoses, actors overcame the organizational bottlenecks. The most important instance of *informalizing organizational metamorphosis* was the 1997 creation of FRI, which emerged from the dysfunctional organizational silos of the government. The president of IASH 'looked for an ad hoc solution'[10] – an unofficial forum for planning national initiatives that would fill the administrative void, overcome the fragmentation, and facilitate coordination. Relying on his academic gravitas and outsider status, he gathered the 'knights of national R&D'[11] and established FRI. These 'knights' were the directors of the ministries with stakes in national R&D, including the MOST and MITL. At FRI, the members functioned as a collective, leaving aside their official roles, participating not because of an official requirement, but 'because they want[ed] to push forward projects that they think are important'.[10] The forum deliberated on the R&D infrastructure and pooled the members' governmental resources. FRI was an informal body without statutory authority; its power derived from its members' official roles and resources. The members resisted several attempts to turn FRI into an official governmental unit, 'realizing that bureaucracy has ruined everything'[11] and that 'voluntary action increases the personal responsibility of FRI members and their freedom to make decisions and is thus superior to formal organization'.[39] Hence, operating without official status enabled FRI members to circumvent their ministries' rigidity. Members could envision projects beyond their individual roles, and 'do what they felt was truly necessary without being coerced or forced by any government decision, but out of an honest will to cooperate'.[11] Once they decided on an initiative, they pooled their resources, which allowed for prioritization and more optimal resource allocation. As the representative of the Ministry of Finance (MOF) was also a member of FRI, this ministry no longer felt compelled to 'brood over their resources'.[10] They could coordinate activities and prepare a long-term budget. Once members committed funds to support an initiative and formed a steering committee to oversee the project's execution, FRI discontinued its involvement. However, because FRI's tenure did not end at each election cycle, it was able to set a long-term agenda. Some attribute FRI's success to its unofficial nature: 'This is why it all works. Over-formalization and over-regulation are big problems… An informal organization is a prerequisite for entrepreneurship. It is impossible to initiate something really new when you are chained up within an existing framework'.[11] In sum, from the ministerial silos emerged an informal organization that transcended these silos while retaining their representation. It filled an administrative void and enabled government actors to cooperate, align interests, and pool resources, in an effort to support the emerging nano ecosystem.

The *formalizing organizational metamorphosis*, in contrast, enabled efficient implementation of new procedures, as in the case of granting an official status to INAB. This ensured that the initiative would not fall victim to bureaucratic inefficiencies and resource constraints after FRI's withdrawal: 'we had to ensure that there was continuity to this initiative. Once FRI closed the deal and funding was in place, we turned INAB from an advisory committee to FRI to a body that continues to professionally advance the initiative. Formally, their statutory power is from the Chief Scientist at the MITL'.[10] INNI was another official organization established to fill the void in the initiative's operations. FRI, which funded and was responsible for managing the nano initiative, created INNI to overcome bureaucratic hurdles while leveraging the authority of the Chief Scientist of the MITL. As an outsider, INNI was free to 'kick and scream whenever bureaucrats fell asleep'.[39] In the case of universities, a formalizing metamorphosis involved establishing official nano research centers to regulate and govern the spontaneous initiatives of various academic faculties under one roof.

Hence, informalizing metamorphosis transcends established structures and puts in place organizational infrastructure that enables actors to overcome barriers, align interests, and pool resources. In turn, formalizing metamorphosis reintegrates these initiatives and introduces official authority for their implementation using resource pooling and alignment. Overall, metamorphosis enables actors to unblock the bottlenecks that impeded the ecosystem's emergence. First, actors establish informal voluntary organizations that are nimbler than the formal organizations from which they emerged, thus relaxing constraints. Once these voluntary organizations achieve their mission, the actors re-create formal statutory organizations that are reintegrated into the bureaucracy from which they originated. This notion departs from the traditional idea of metamorphosis: 'change in organizational structure is occasionally punctuated by abrupt, major transformations which sharply distinguish one period of organizational history from another' (Starbuck, 1971, p. 275). Although Starbuck's notion refers to a sudden organizational change as evident in the switch from government ministries to FRI, unlike this idea, in our theory the old organizational form survives the metamorphosis and continues to coexist with the new organizational form. The same actors that created bottlenecks that hindered the emergence of the ecosystem are involved in dislodging the ecosystem and unblocking these bottlenecks. The ineffective bureaucracy gives way to informal organizations that manage to overcome its deficiencies and enable both governmental and university actors to agree on a common agenda and pool their resources.

Whereas prior research on ecosystem evolution suggests that the internal organization of the ecosystem may change as a result of shifting bottlenecks (Hannah and Eisenhardt, 2018), our theory reveals how change in the internal organization can lead to unblocking some bottlenecks. In particular, the switch to an informal structure via which actors interact enables them to subdue bureaucratic constraints and dislodge from inert positions, while identifying common interests and defining a collective agenda. Unlike models of ecological change (Hannan and Carroll, 1995; Tushman and Anderson, 1986) in which superior organizations replace deficient ones, following the metamorphosis, the ineffective bureaucracy prevails in parallel to the informal organizations that adopt a new set of practices. Once the need arises to implement the agreed-upon decisions, a formalizing metamorphosis transplants the informal units back into the bureaucracy, resulting in an organization that enjoys both nimbleness and authority. Such formalizing metamorphosis overcomes the caveat of interstitial spaces that enable actors to temporarily escape from an established organization and experiment, but fail to institutionalize new practices (Furnari, 2014). Since the antecedent organization is left intact and the same actors are involved in the new organization, conflict is mitigated. Instead of sacrificing the collective identity when striving for legitimacy (Lee et al., 2017), metamorphosis promotes a shared identity.

Transition to coopetition. While organizational metamorphosis explains how actors organize to align interests and pool resources, transition to coopetition explains the impetus to do so. *Coopetition* entails simultaneous competition and cooperation between actors (Bengtsson and Kock, 2000). Our evidence reveals how cooperation emerged despite the inherent preliminary state of competition, giving way to distinct types of coopetition: coopetition for resources, direction, administration, and identity.

Coopetition for *resources* refers to the pooling and sharing of resources for which actors compete. Intense coopetition for resources was a distinctive characteristic of FRI members: 'each member represents his or her ministry and everyone fights with everyone else for money',[10] a fight that peaked at annual budgetary meetings in which 'the decisions on how much each ministry receives were completely political'.[10]

However, once they convened as FRI members, they pooled millions of dollars: 'we cannot afford to duplicate resources… It is crucial to have specific goals to avoid fragmentation… An infrastructure project such as nanotechnology is so expensive that one ministry simply cannot fund it'.[42] Complicating matters was the fact that FRI members bring in funds 'from their operating budgets. They do not receive any additional funds from the government for FRI's initiatives',[11] so the allocated funds come at the expense of other initiatives: 'it is not a trivial matter, to take money that was supposed to support industries and give it to universities, but that is what the Chief Scientist at the MITL did'.[11]

Coopetition for resources also transpired among universities and scientists. Universities competed with one another 'intensely … over the best faculty, which was a critical asset'.[1] Universities also made efforts to attract donors and competed with one another over funding. In particular, the Berrie Foundation's donation to the Technion motivated other universities to raise funds for their nano centers: 'there was intense competition between universities … everyone jumped on board the nanotechnology ship despite the high price. No university could afford to be left out of the game and have another university become the leader in nano'.[11] At the same time, they could not afford the required equipment for nano research, so they had to share that equipment. Also, given the community's small size, universities 'shared' international speakers and visiting scholars who were invited to conferences and seminars instead of 'hiding them only at one university'.[27] The university centers collaborated and helped each other in times of need, such as when equipment malfunctioned. Coopetition was most evident among scientists, who competed for recognition and over research funds. At the same time, they collaborated on research projects to obtain needed resources – financial, equipment, and knowledge assets: 'When we engage in collaboration, we reach out to teams that possess skills or equipment that can contribute to our research … collaboration has become one of the hallmarks of the nanotechnology culture'.[16] Thus, competition for resources among government ministries and within and among research centers was accompanied by cooperation that enabled the pooling of resources and alignment of interests.

A second novel form of coopetition is coopetition for *direction*, wherein actors with conflicting interests and objectives strive for a unified mission. Competition was the natural state of government ministries that battled over policies but could not concur on building a national R&D infrastructure. In contrast, FRI members participated in only those projects that 'they viewed as important and aligned with their self-interest',[11] so they were highly motivated to influence their direction, and cooperation was essential to that aim. Thus, despite their adversarial relationships, FRI members cooperated to achieve a unified mission for the nano initiative. To ease tensions and facilitate shared objectives, FRI involved all the ministries with stakes in R&D and purposely stayed out of the limelight, so 'no one's ego got hurt'.[10] Consequently, FRI members could agree on major initiatives. Nonetheless, efforts to craft a unified mission were often fraught with conflict, primarily between the MOST and the other FRI members. Although the MOST was unable to coordinate the actions of larger organizations, its leadership felt that this was their duty: 'they do not have money, but they have the pretension to tell everyone what to do'.[10] Yet, despite this competitive tension, the MOST eventually cooperated in funding the nano initiative because it did not want to be left out: 'someone who doesn't pay does not have the right to decide anything'.[36]

Coopetition for direction also transpired between INNI and the universities. INNI wanted to commercialize nano, whereas universities sought to promote academic research. At the same time, universities needed resources for nano research, while INNI could not promote industrial applications without the universities' insights. Thus, INNI and the universities fostered a complex relationship that eventually enabled them to better align their missions. Universities appreciated the support: 'what INNI did is amazing… It made a real revolution'.[21] But given their divergent goals, tensions mounted: Scientists appreciated INNI's support but resented being micromanaged. INNI sought to direct scientists, who were accustomed to academic freedom, toward specific industrial applications, outlining the main industry they should focus on. For instance, INNI wanted BGU to focus on irrigation technologies simply because of their physical proximity to the Negev Desert. But 'with all due respect, no one can walk into the backyard of one of the scientists and start telling her, "research this, don't research that". At the end, we have academic freedom'.[21] Some scientists even claimed that 'INNI came in to steal the good people and the good ideas from the universities'.[17] Thus, while appreciative of INNI's funds, scientists tended to view INNI as 'a group of bureaucrats'[30] who tried to control them. A center director noted: 'On the one hand, INNI is our evaluator … they make sure we don't waste the money they gave us. On the other hand, it really wants to advance the industry. There is a kind of collaborative dance: when someone evaluates you, you treat them in a certain way; if you march together and strive to achieve joint goals, then the relationship is different. These two roles do not always go together, but INNI managed to walk between the drops'.[27] This 'walk' entailed seeking a middle ground between misaligned directions that could still serve the agendas of both parties. Hence, the tension between basic and applied research gradually decreased.

Additionally, coopetition for direction transpired between the university research centers. The collaboration between nano centers strengthened while 'friendly competition' continued between them. For example, the Center Directors' Forum met to manage the competition and define the 'rules of the game'[25,27] for the FTAs, advocating a rule whereby scientists would only be allowed to submit one proposal. During the FTA application period, directors circulated the proposal summaries and consulted with their counterparts on how to manage the process. Finally, coopetition for direction was evident across university departments. Their modus operandi was to compete over control and direction of the nano centers. For example, at the Weizmann Institute, the head of the chemistry department served as the director of the nano center, but the chemistry and physics departments, while both involved in nano research, acted 'like two political parties'.[3] To ease these tensions, nano research at Weizmann was dispersed, and central management was largely non-existent, with individual scientists and departments enjoying freedom. At TAU, the nano center was managed by a board with representatives from four departments. In all these cases, university departments cooperated to set direction for the nano initiative despite their traditional rivalry. Coopetition for direction prompted goal alignment and the pooling of resources in the government and universities.

Another unique form of coopetition was coopetition for *administration*, defined as coordinated joint action involving competing administrative functions. Unlike coopetition for direction, which centers on setting a joint agenda, coopetition for administration concerns the means for pursuing that agenda. Among FRI members, coopetition for administration revolved around disagreements about how to oversee the nano initiative. For instance, while taking part in FRI, the MOST criticized FRI's administrative procedures for assessing proposals and for operating without an accountant or legal counsel to ensure proper control. It also objected to FRI's slow pace of making decisions and notifying universities about their proposals for nano centers. The MOST's frustration with and contempt toward FRI's administrative leadership was probably rooted in the MOST's inability to execute its formal role: 'the conflict between the Ministry of Science and FRI is built-in'[11] because of the bureaucratic antecedents; the ministry 'sees FRI as a competitor but still cooperates'.[11] For the other FRI members, jointly executing the nano initiative was a smoother process. This cooperation among natural competitors is 'an example of goodwill of the remaining good bureaucrats… FRI members understand that to advance matters in these difficult conditions is only through cooperation. This way, they secure some of their interests'.[11] In sum, coopetition for administration also helped actors pool resources and align their interests.

Finally, a novel form of coopetition for *identity* refers to distinct actors' creation of a shared identity that coexists yet conflicts with their original identities. For example, FRI members had dominant individual identities, stemming from their distinct government ministries, but at FRI they created a shared identity. They experienced constant shifts between this collective identity and the ministerial identities. Although they funded the nano initiative as FRI members, the directors of the ministries who participated in FRI signed documents with their official roles, since FRI had no statutory standing. FRI members often experienced a 'split personality, whereby at one time they lead their own ministries, but at another time, they are members of a collective whose interests are not always aligned with their individual interests'.[11] Coopetition for identity also transpired at the universities. In the 1990s, no one used the term 'nanotechnology', and research was carried out in biology, chemistry, physics, etc. But as the term became popular, scientists began to develop a 'nanotechnology identity' in addition to their disciplinary identity. They identified themselves as 'nano' scientists 'because it was a lot sexier than their traditional disciplines, and many more resources were allocated to nano'.[29] Thus, as the resource constraints began to ease, more scientists adopted the 'nano identity', and the nano community became more vibrant, with seminar series, conferences, study program, and events that lured more scientists to shift their identities to 'nano'. The notion of coopetition for identity is distinct from that of transitional identity whereby existing identities are dissolved as the organization transitions into an emerging new identity (Clark et al., 2010). In coopetition for identity there is no dissolution of the original identities, which continue to coexist and thus impose a tension with the new identity. This tension can be more pronounced than in the case of multiple identities that individuals maintain by virtue of their distinct roles' imposition of conflicting demands (Ramarajan, 2014). Here, the identities relate to the same role, and the tension is internally induced rather than imposed by external stakeholders. In sum, coopetition for identity, much like other forms of coopetition, motivated competing actors, ranging from scientists and universities to government ministries, to align their interests and pool resources, thus unblocking the bottlenecks.

Whereas organizational metamorphosis provides the organizational setting for dislodging the nano ecosystem from constraining conditions that hindered its emergence, our theory reveals that the transition to coopetition motivates the actors to subdue traditional rivalries and align their divergent interests and pool scattered resources. This transition is prompted by the actors' realization that competition has prevented them from implementing their private agendas and that a compromise is inevitable. In turn, the four facets of coopetition enable the actors to maintain their separate interests while collaborating in the pursuit of a common goal, that is, the promotion of the innovation ecosystem. We show how by striving toward a shared mission, pooling their resources, and aligning their interests around this common agenda, the actors overcome bureaucratic hurdles and resource constraints. Hence, coopetition is not limited to sharing resources among competing ecosystem members that strive for cost savings and synergies (Mantovani and Ruiz-Aliseda, 2015). Rather, such coopetition for resources among government ministries and universities is complemented by alignment of mission, coordinated action, and even a shared identity, which are essential for the emergence of the innovation ecosystem. Prior research on coopetition has focused on firms that simultaneously cooperate and compete (e.g., Bengtsson and Kock, 2000, 2014; Bouncken et al., 2015; Gnyawali et al., 2008) by leveraging their counterparts' resources, competencies, and knowledge (Bouncken et al., 2015; Gast et al., 2014) and creating value via a 'win-win' solution (Liu, 2013). We inform this research that has focused on coopetition for resources by demonstrating that coopetition can apply more broadly to the simultaneous competition and cooperation for direction, administration, and identity of the actors. Coopetition is more profound than assumed and involves convergence of identities and meeting of the minds, which precede the alignment of behaviours and pooling of resources. Recognizing the superiority of the shared mission over the actors' private objectives is a prerequisite for resource pooling in the emerging ecosystem. Hence, the transition to coopetition begins with a cognitive process, which is followed by an operative process.

Additionally, we extend this research, which has been confined mostly to the interfirm context, by shifting focus to the ecosystem context that encompasses government and academic institutions. We also complement research that explains how coopetition drives innovation (Bouncken and Kraus, 2013; Cassiman et al., 2009; Gnyawali and Park, 2009; Ritala, 2012) by linking coopetition to the notion of ecosystem emergence. Finally, coopetition research has neglected the phenomenon's dynamic and process aspects (Hoffmann et al., 2018; Hung and Chang, 2012). We reveal the process by which coopetition motivates joint interests and the pooling of resources in the emerging ecosystem, which in turn enable actors in the ecosystem to unblock organizational bottlenecks ascribed to resource constraints and bureaucratic hurdles. In our theory, organizational metamorphosis and the transition to coopetition serve as complementary catalysts for unblocking these bottlenecks, with the former furnishing the organizational infrastructure that enables the unblocking and the latter creating the impetus to collectively pursue such unblocking.

Shaping the Ecosystem

Crossing the bureaucratic barriers, aligning interests, and pooling resources were necessary for unblocking the bottlenecks, but our evidence reveals a third process in which enabling and governing mechanisms (Adler and Borys, 1996) facilitate and direct the emergence of the ecosystem, while legitimizing its operations. For instance, these mechanisms were pivotal in the promotion of applied research at the universities: 'Think of what INNI did to the universities as a dog race. They put a rabbit at the front. They told the universities, "if you don't want to, you don't need to participate; you can keep doing what you were doing before, but you will not get the rabbit"'.[24] In order to get the rabbit (funding), universities had to follow the rules. INNI and other actors promoted the emergence of the ecosystem through a series of carrots and sticks, i.e., enabling and governing mechanisms. Both types of mechanisms enhanced the legitimacy of the ecosystem, with the former accelerating its growth and the latter directing its evolution.

Enabling mechanisms. Our evidence reveals four *enabling mechanisms* that facilitated ecosystem emergence: roles, allocation models, forums, and evaluation. *Roles* refer to organizational positions, such as the INAB directors and the golden-egg hunters at the university centers. For instance, the golden-egg hunters sought 'brilliant scientific ideas that can be commercialized, but are left unattended by unaware professors'.[33] INNI encouraged university centers to create this role and to fund it. Each center had its own interpretation of the hunter's role and the means to get these elusive golden eggs to the market. For example, the Technion's hunter focused on increasing the industry's involvement in the center and its use of equipment. The HUJI's hunter screened research projects and focused on young and promising scientists seeking to commercialize their research, 'holding their hands'[35,37] along the way. At BIU, the hunter screened the projects, found an excellent one, and left the center to launch a start-up firm based on that project. The hunters directly contributed to commercial activity, including patents, licensing agreements, and start-up firms: 'Requesting that we hire people to help with commercialization, really advanced commercialization here. Without the funds to hire hunters, there is no doubt that there would have been less commercial success'.[27] New roles, such as the hunter, served as enabling mechanisms that legitimized applied university research and accelerated commercialization. These roles supplement traditional roles in ecosystems such as ecosystem leader and complementor (Dedehayir et al., 2018).

The second enabling mechanism was *allocation models*, which refer to procedures and arrangements for resource allocation. The most important allocation models were the TDM and the FTA program. The TDM was the model by which all the university nano centers were funded, i.e., equal contributions from the university, a donor, and the government. Because competition for resources among universities was fierce, when universities realized that the Technion had received $26 million from the government, 'it was as if an earthquake [had] struck the country, and everyone was asking, why the Technion and not us?'.[5] Subsequently, FRI extended this funding model to all other universities, which sought funds to establish nano centers. This model advanced FRI's mission to develop nano infrastructure in Israel. The TDM was the most significant enabling mechanism that accelerated the emergence of the nano ecosystem: 'It is clear that had it not been for the TDM, the nanotechnology initiative would have progressed much slower'.[10] The TDM encouraged universities to raise matching funds and submit proposals, which dramatically accelerated universities' efforts to establish nano centers. Through the TDM, the universities built a research infrastructure that attracted scientists from abroad: 'A promising young nano scientist came to HUJI and said that he got everything he needs for his research. He doesn't need anything else'.[10]

Another important allocation model was the FTA. INAB's directors were dissatisfied with the progress of the centers in the first nano initiative. Although INAB no longer challenged scientists' right to choose their research subjects, INAB was only willing to fund research with commercial applications: 'if scientists want to study the effects of rays of sun on bee reproduction, they can do so on their own time, not [with] taxpayers' money'.[4] However, INAB realized that trying to coerce scientists to study specific topics was ineffective. To better align the universities with the initiative's mission, INAB introduced the FTA model: 'the FTAs were expected to bridge between high-quality, mission-oriented research in … academia and innovative product development programs in the industry'.[42] Funds for infrastructure were distributed equally to universities, whereas the FTA funds were allocated on a competitive basis in areas such as nanophotonics, nanomedicine, and nanocoating. Hence, the FTA accelerated the emergence of the ecosystem by calling for research with immediate commercial applications that were relevant to the industry. The funding was based on competitive bids but fostered cross-university collaborations. Per INAB's report, the FTA successfully produced tangible outcomes such as products, prototypes, applications, and start-up firms, while facilitating collaborations of scientists from different universities (Jortner et al., 2017). Hence, allocation models served as enabling mechanisms that brought nano research to the forefront and accelerated the commercialization of the technology.

A third enabling mechanism was *forums* that created common platforms for interaction, such as the. INNI convened the first meeting of the directors' forum, but the directors continued to meet in order to decide 'how to deal with INNI, their common enemy'.[21] The forum sought to influence the centers' direction rather than blindly follow INNI's direction, so it met 'whenever there was something they needed to protest or agree on'.[30] The forum enabled nano centers to coordinate initiatives, share resources, and influence the allocation of funds. The bi-annual Nano Israel Conference was another forum initiated by INNI and INAB board members to serve the entire nano community and supplement events held at the centers: 'there is collaboration. It really helps us bring conferences to the country. It helps that we have a large number of researchers overall. We try to create that kind of collaborative atmosphere'.[27] Consequently, the conference grew, and the number of participants nearly doubled by the fifth gathering in 2016. Forums such as the Center Directors' Forum and the Nano Israel Conference signalled the importance of nano research and increased the legitimacy of the emerging ecosystem: 'a real nanotechnology community was created. We nurture this all the time through seminars … we have an annual social event … and we have a world-class degree program. The conference attracts over two hundred scientists, and it is very lively'.[26] Hence, forums served as enabling mechanisms that legitimized nano research by facilitating exchange of ideas and research findings, as well as promoting collaborative initiatives, which accelerated the emergence of the ecosystem.

Finally, the *evaluation* mechanism refers to professional assessment by authorities of alternative courses of action. An example is the Maydan Committee's feasibility study, which set the stage for the national initiative and was critical for the emerging ecosystem. The committee members were selected to provide legitimacy: 'They have two roles. The first role is to assess. The second is for us to use their reputation. Their names market this whole business'.[11] Hence, the Maydan Committee prompted FRI members to invest an unprecedented amount by national standards. Another evaluation mechanism was INAB's assessment of the university proposals for nano centers. After evaluating the Technion's proposal, INAB created a uniform methodology to evaluate proposals, which accelerated investments and thus advanced the emergence of the ecosystem. Working in tandem, the enabling mechanisms – roles, allocation models, forums, and evaluation – contributed to the legitimacy of the ecosystem and accelerated its emergence.

Governing mechanisms. Besides the enabling mechanisms, we identified four governing mechanisms – monitoring, sanction, public scrutiny, and regulation – that, while not directly enhancing commercialization, shaped the emergence of the ecosystem and directed its evolution trajectory. *Monitoring* refers to tracking and governing sponsored activities to ensure the meeting of milestones and objectives. In addition to requiring the centers to submit annual reports, INNI monitored the centers on an ongoing basis. Its representatives visited the centers, developed informal ties, and consulted them: 'formally, INNI is the controller of nano activities on behalf of the government, and they do their work faithfully';[26] INNI 'is our controller … a watch-dog … they inspect our activities, give us grades and scores'.[27] INNI's monitoring often led to resentment: 'INNI's management comes from the industry and the money comes from various government ministries … so they think they have a say in what should be done in academia… They come in and ask us what we are working on, whether it is applied, why it is not applied'.[30] INNI sought to align the centers with its mission, so to enable scientists to proceed with research, 'the center directors acted as buffers between INNI and the scientists'.[32] Still, by monitoring the centers, INNI managed to incentivize commercialization and legitimize applied nano research.

In cases in which INNI was discontented with the centers' performance, it applied sanctions. *Sanction* refers to the administration of penalties for deviation from stated objectives. An example is the penalties that INNI imposed on BGU and the Weizmann Institute in 2009 after they failed to fully comply with its requirements. INNI cut their funding by \$200 K and \$1 million, respectively. This sanction was enough to 'make everyone realize that INNI means business'.[34] The threat of sanctions worked 'extremely well because everyone knew that if they do not behave as they should, well, … the fact is that center directors who did not cooperate in the beginning are cooperating today'.[4] Whereas the BGU director was dismissed and the center was completely restructured following INNI's penalty, Weizmann 'straightened up a bit and pretended'[30] to make changes. To advance its agenda, 'INNI often pushed and threatened indirectly that if the centers do not comply, then they will not receive funding for the next five years … and so everyone complied'.[37] As a result, sanctions directed the university centers toward more applied research and legitimized it: 'today, there are scientists, and … their number is growing, who are aware of the importance of commercialization. When they conduct their research, they already think about its applications'.[37]

Another governing mechanism is *public scrutiny*, which refers to auditing of practices vis-à-vis regulation or social norms. An example was the MOST's attempt to terminate FRI by appealing to the State Comptroller in 2004: 'there is no room for FRI to exist in its current form, because [the MOST with its authority over the] the National Civil R&D Committee was the only official body authorized to make recommendations to the government about R&D infrastructure and the execution of projects in science and technology'.[42] This attempt did not yield the results the MOST had hoped for, since the State Comptroller's support reinforced FRI's legitimacy. Another example concerns the complaints of university presidents following FRI's decision to match Russell Berrie's donation to the Technion. The other university presidents complained about improper procedures of releasing funds without an open call for proposals. Internal debate concerning equal opportunities led FRI to offer similar criteria for assessing proposals by other universities. This scrutiny promoted the legitimacy of the TDM and a more egalitarian approach in subsequent funding decisions, thus directing the evolution path of the emerging ecosystem.

The last governing mechanism is *regulation*, which refers to design and legislation of policies, rules, and procedures. As the overseer of the nano initiative, INNI 'decided on the policies and rules of the nano centers[25] … INNI's unofficial mission was to not only bring money to universities and develop the centers, but to change the way the universities go about their business with regard to infrastructure and working with industry … INNI built the nano centers and was heavily invested in the universities, and tried through that to force the universities to start acting in a certain way.… They told me straight up, "we put so much money in this infrastructure, you are not going to pull the plug now"'.[24] These rules and procedures were geared toward inducing commercial activity. Scientists appreciated the contribution of INNI's instituted regulations to ecosystem emergence: 'In spite of all of my criticisms of INNI, I have no doubt that all the things they did brought about significant change. It fostered collaboration among the universities and helped raise awareness to nano, even to scientists like me. It was extremely helpful in our dealings with the university administration… They promoted educational programs and other activities that they would not have invested in otherwise'.[32] Hence, much like the other governing mechanisms, the regulation mechanism contributed to the legitimacy of nano research and directed scientists toward more applied research.

The enabling and governing mechanisms directed the ecosystem toward commercialization, accelerated its emergence, and legitimized it. At the universities, everyone realized that some research should be applied: 'Back then, doing applied research was not acceptable… Today, everyone is doing applied research'.[29] Whereas enabling mechanisms accelerated the ecosystem's emergence, governing mechanisms directed it to commercialization.

In sum, releasing the ecosystem from organizational bottlenecks that hinder its emergence is insufficient for accelerating and directing the ecosystem's evolution. Per our theory, these aims are achieved by introducing enabling and governing mechanisms that correspondingly provide discipline and incentives for ecosystem members, while legitimizing the ecosystem. In the nano ecosystem, an intricate relationship between government and academia harnessed the university centers and motivated scientists to pursue the agenda of ad hoc voluntary organizations such as INNI. Hence, the evolution of the ecosystem gains traction thanks to new funding models and programs, novel organizational positions, and forums, which serve as enabling mechanisms. These enabling mechanisms are accompanied by governing mechanisms – i.e., public scrutiny, regulation, monitoring by authorities, and sanctions – that further align the actors with the desired trajectory of evolution. By uncovering specific mechanisms that accelerate and direct the emergence of the ecosystem, our theory goes beyond prior work that has described the process of ecosystem evolution without alluding to the means by which the ecosystem progresses from one phase to the next (e.g., Chen et al., 2014, 2016; Jha et al., 2016; Leong et al., 2016; Moore, 1993). Further, besides their primary roles in accelerating and directing the emergence of the ecosystem, both enabling and governing mechanisms help legitimize the ecosystem. This legitimation is essential for securing support for the ecosystem's evolving norms, values, and power structures (Lindgren et al., 2015), while ensuring its continued growth (Lee et al., 2017; Wry et al., 2011). More broadly, the use of these mechanisms extends their application from the context of hierarchies (Adler and Borys, 1996) to that of ecosystems. Our theory suggests that enabling and governing mechanisms that have been studied in the organizational context can be deployed to direct the emerging innovation ecosystem in a trajectory that deviates from the tendencies of actors, as long as these mechanisms take unique forms that are tailored to the ecosystem context. See Figure 2 that presents our emergent framework.

DISCUSSION

Innovation ecosystems have received much attention, but we know little about their emergence (Autio and Thomas, 2014), as technological discovery cannot explain how national actors come together despite inherent conflicts and organizational bottlenecks. Past research has focused on post-emergence dynamics (e.g., Adner and Kapoor, 2010) or identified conditions for emergence (e.g., Leydesdorff and Etzkowitz, 1998), without explaining how these ecosystems come about (Perkmann et al., 2013). Our study explicates the evolution of innovation ecosystems by exposing how the technological infrastructure endogenously emerges from the interplay of impeding and facilitating processes, in which actors coopetitively interact while seeking arrangements that promote scientific innovation.

Our inductive theory acknowledges organizational bottlenecks that delay the emergence of the ecosystem. Whereas the discovery of technological bottlenecks can explain the emergence of platform ecosystems (Shipilov and Gawer, 2020) or hinder the innovation ecosystem's growth in subsequent phases (Hannah and Eisenhardt, 2018), it is

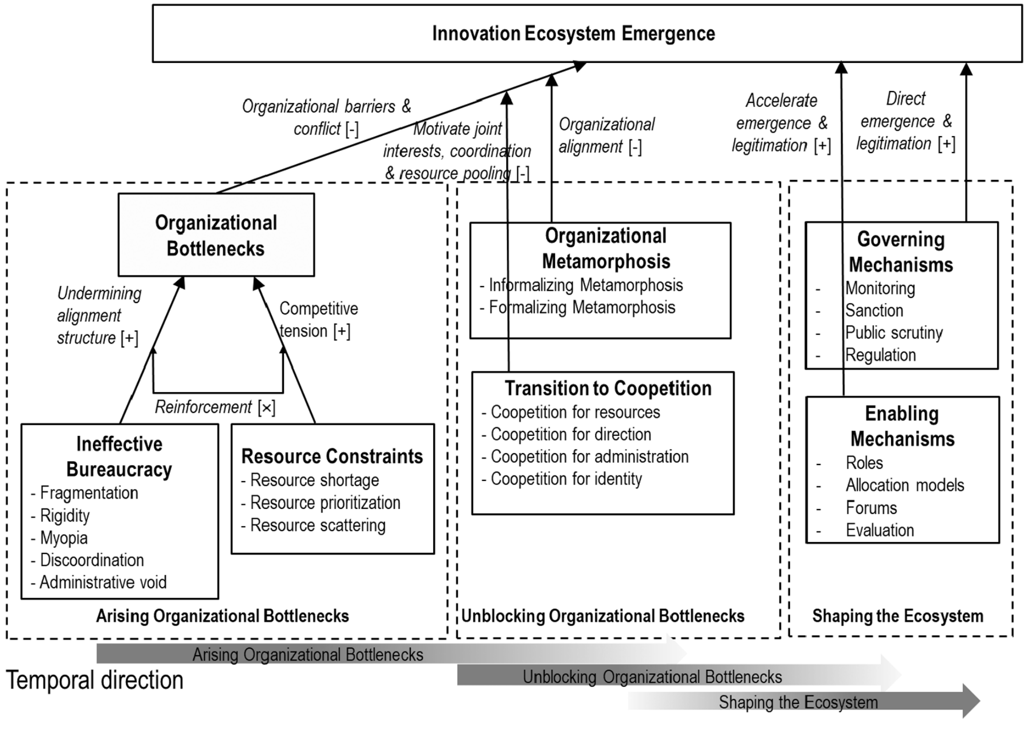

Figure 2. An inductive theory of innovation ecosystem emergence

organizational bottlenecks that transpire in its emergence phase. We reveal how resource constraints and deficient bureaucracy mount organizational barriers and reinforce conflict, which prevent the ecosystem from emerging years after the technology was discovered. For the ecosystem to emerge, these impediments need to be dismantled via metamorphosis and transition to coopetition among the ecosystem's members, who align their interests and pool resources. The metamorphosis creates the setting for dislodging the ecosystem from stagnation, while coopetition furnishes the impetus for unblocking bottlenecks. The emerging informal organizations engage the same actors, but unblock the bottlenecks attributed to their formal incarnations, which were rife with scattered resources, misaligned interests, and conflicting agendas. Our theory suggests that the pace and direction of ecosystem emergence are correspondingly shaped by enabling and governing mechanisms that actors design and institute, which also enhance the ecosystem's legitimacy. Hence, unlike studies that characterize the ecosystem at each phase (Jha et al., 2016; Leong et al., 2016), we underscore the tension between impeding processes that hinder the ecosystem's emergence and those dislodging it from its immutable position. We show how their relative dominance determines the prospects for ecosystem emergence, while the path for emergence is paved by mechanisms that promote and shape its emergence trajectory.

Our theory overcomes the challenge of studying the emergence phase given its transitory and contextual nature (Phaal et al., 2011) by identifying fundamental processes, and thus departs from studies that describe the characteristics of technologies and firms that interact at the growth and maturation phases of the innovation ecosystem (Adner and Kapoor, 2016; Chen et al., 2014, 2016). By studying innovation ecosystems, our work also complements research that explains how firms remove technological bottlenecks in business ecosystems (Jacobides et al., 2006; Masucci et al., 2019). By relating to organizational metamorphosis and coopetition, which have not received attention in the context of innovation ecosystems, we complement research on ecosystem evolution that identifies the actors (Dedehayir et al., 2018) and resources that drive emergence (Spigel and Harrison, 2018). Further, our theory explains how organizational metamorphosis dislodges the ecosystem from stagnation ascribed to bureaucratic impediments and resource constraints imposed by actors with conflicting interests. In so doing it goes beyond prior research, which tends to overlook impairing conditions and thus to underestimate the apparatus needed to support the ecosystem's emergence. Scholars have acknowledged that diverging interests of ecosystem members impose coordination challenges in subsequent phases of evolution (e.g., Jacobides et al., 2018). Our theory, instead, explains how such conflict impedes the emergence of the ecosystem by invoking divergent evolutionary paths, e.g., science versus commercialization. Our theory also identifies enabling and governing mechanisms that provide thrust, steer the ecosystem, and fine-tune its evolution trajectory. Yet the relative importance of specific mechanisms and the applicability of certain elements of ineffective bureaucracy may vary across ecosystems, and thus merit further attention in future research.

Overall, our inductive theory contributes to the broader literature on ecosystems by highlighting aspects of ecosystem strategy, organization, and operation that are interwoven in the emergence phase. We conclude that in an innovation ecosystem that lacks a leading firm (e.g., Adner, 2017), strategy entails coopetition to align interests and overcome resource constraints. We also extend the notion of ecosystem structure as a set of positioned actors that undertake interlinked activities, by alluding to metamorphosis that creates these positions and interlinkages. This is essential for overcoming bureaucratic hurdles and prompting coordination in the emerging ecosystem. Finally, we allude to ecosystem operation, by identifying mechanisms that can accelerate and direct the ecosystem's evolution. Overall, our theory not only identifies processes that influence the emergence of the innovation ecosystem, but also uncovers their interplay. Specifically, it suggests that ineffective bureaucracy and resource constraints form mutually reinforcing yet sufficient conditions for creating organizational bottlenecks that impede the emergence of the ecosystem. These conditions correspondingly undermine the alignment structure and instigate competitive tension among government and university actors. In turn, organizational metamorphosis establishes the setting for unblocking these bottlenecks and aligns the actors' interests, while the transition to coopetition motivates the actors to overcome their conflicting interests and to pool their resources in the unblocking process. Finally, our theory suggests that governing mechanisms direct the evolution trajectory and enabling mechanisms prompt commercialization, thus accelerating the ecosystem's emergence and the fulfilment of its value proposition.

In our inductive theory, coopetition is essential for motivating the unblocking of organizational bottlenecks. We highlight a neglected aspect of coopetition that is evident not only among firms but also in academia and the government, which are inherently competitive. The alignment of interests and pooling of resources do not merely result from informal coalitions (Stevenson et al., 1985), but rather entail a delicate process via which the actors strive for a common mission, create a shared identity, and coordinate actions, prior to pooling their resources. The 'meeting of the minds' and the formation of mutual perceptions based on identification with the common goal and agreed-upon procedures are organic elements for coordinating activities and sharing resources. Whereas coordination and resource sharing have been central to research on coopetition (e.g., Bengtsson and Kock, 2014), such research has not considered the other facets of coopetition. Our inductive theory reveals their essential role in ecosystem emergence and perhaps also for rivals in business and platform ecosystems (e.g., Jones et al., 2021; Khanagha et al., 2022). The transition from competition to coopetition begins with behavioural aspects relating to identity and direction, proceeds with organizational aspects relating to administration, and concludes with strategic aspects encompassing resource pooling. Our theory further suggests that metamorphosis transcends bureaucratic structures, while coopetition provides the impetus for coordination. Their interplay instigates the emergence of the ecosystem by correspondingly furnishing a nimble organizational structure and aligned purpose that drive coordination and pooling of resources.

Our theory complements the view of ecosystems as an institutional field that encompasses network participation, governance systems, and shared logic that characterize value creation in ecosystems post emergence (Thomas and Autio, 2014). Furthermore, our theory extends research on national innovation systems (e.g., Nelson, 1993) that studies established policies for promoting R&D, by explaining how relations among institutions and organizations are formed and national policies are negotiated in the emergence phase of particular innovation ecosystems. Nevertheless, established national systems and policies fall short of supporting innovation in this context, while organizational design and regulation are insufficient to account for the emergence of the innovation ecosystem. Our theory also complements research on industry evolution, which offers life-cycle models to describe industries and firms at different phases of evolution (e.g., Klepper, 1997; Malerba, 2007; Phaal et al., 2011). By unpacking the ecosystem emergence phase that precedes industry formation, we shift focus from firms' entry, adoption, and commercialization of technologies to actors' interactions that foster the progression from the technology's discovery to its application. We complement research that explains how, in the incubation of an industry, actors focus on solving technological problems 'by significant sharing of knowledge through formal and informal channels' (Agarwal et al., 2017, p. 297). We do so by revealing the lack of cooperation and knowledge sharing, the failure of formal systems, and the unblocking of these bottlenecks during ecosystem emergence. Finally, our theory proposes processes that enable actors to modify impeding conditions and thus counter the path dependence noted by imprinting theories (e.g., Ellis et al., 2017; Marquis and Tilcsik, 2013).

In conclusion, the emergence of an innovation ecosystem entails interdependent actions of actors in the government and academia. We enhance understanding of this phenomenon by identifying the resource constraints and organizational conflicts that impede the emergence of the ecosystem as well as the processes that unblock these bottlenecks, facilitate the ecosystem's emergence, and direct its evolution. Our theory elucidates the underlying processes, strategies, and mechanisms that enable the emergence of innovation ecosystems. By uncovering the social system that guides action, we complement frameworks that highlight structure and affiliation in ecosystems (Adner, 2017; Shipilov and Gawer, 2020). We explain how the actors' interactions promote the ecosystem via organizational arrangements and allocation of resources (Van de Ven and Garud, 1989) that furnish the infrastructure for the ecosystem (Hinings et al., 2017). Thus, our study contributes to literature on the nature of ecosystems (Adner, 2017; Jacobides et al., 2018) by revealing processes that help ecosystems bring innovation from the lab to the market.

Our theory can guide policymakers, universities, and entrepreneurs in identifying bottlenecks that delay commercialization and in shaping the evolution of innovation ecosystems. We underscore the role of informal voluntary organizations in overcoming bureaucratic hurdles and in advocating cooperation among competing actors that strive for a shared mission. We then identify specific practices that can be adopted to facilitate commercialization in an innovation ecosystem following a technological discovery. Hence, to facilitate the emergence of innovation ecosystems, policymakers can strive to unblock bottlenecks by engaging in organizational design that mitigates fragmentation, rigidity, myopia, discoordination, and administrative void in organizational units that support the ecosystem. They can also combine and prioritize resources from different units. If these measures are insufficient to unblock the bottlenecks, the policymakers can strive for organizational alignment by pursuing metamorphosis of established organizational units and by proactively enhancing cooperation at multiple levels, as illustrated in our study. Finally, governing and enabling mechanisms can be selectively adjusted per the particular ecosystem context in order to put in place regulation, monitoring, roles, and forums among other mechanisms that can facilitate the emergence of the innovation ecosystem.

Admittedly, alternative pathways for the emergence of innovation ecosystems may be observed in other contexts, so we discuss the generalizability of our theory in the Appendix S1 and call for further research. We conclude that organizational metamorphosis and coopetition can play a role in different types of ecosystems in which interfirm networks and various stakeholders support the ecosystem (e.g., Planko et al., 2019). Moreover, we see value in studying various dimensions of coopetition – coopetition for resources, direction, administration, and identity – in various contexts. Nevertheless, business and platform ecosystems may follow different genesis scenarios given firms' involvement and their reliance on readily available commercial applications (e.g., Jha et al., 2016; Leong et al., 2016). Finally, our theory does not portray the dynamics in more mature innovation ecosystems that have evolved beyond commercialization (Chen et al., 2014, 2016). Nevertheless, despite these limitations, we offer novel theory that sheds new light on the question of how innovation ecosystems emerge.

Future research can test our inductive theory with a multiple-case study design that documents the emergence of various innovation ecosystems in different countries. Such design can incorporate longitudinal analysis of patents, start-up firms, and commercialized products as indicators of successful emergence. Comparisons to failed emergence attempts can corroborate the roles of metamorphosis and coopetition in dislodging from organizational bottlenecks. An intriguing question concerns the possible roles of metamorphosis and coopetition in subsequent phases of evolution and in other types of ecosystems. Another opportunity relates to extending research on coopetition by examining its identity, direction, and administration aspects that precede resource pooling. A better understanding is needed of these prerequisites for transitioning from competition to coopetition in ecosystems and other interorganizational contexts.

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NOTES

[1] Organizational metamorphosis refers to the creation of a new organization with altered traits that is derived from an antecedent organization, while coopetition intertwines competition and cooperation.

[2] A tangential literature on industry evolution studies how firms anticipate and lead technological changes (e.g., Moeen and Agarwal, 2017; Tushman and Anderson, 1986) and converge on a dominant product design (Suarez et al., 2015). This literature identifies industry life-cycle phases (e.g., Abernathy and Clark, 1985) and the firms that operate in them (e.g., Hannan and Carroll, 1995) as well as those that enter nascent markets (Navis and Glynn, 2010; Santos and Eisenhardt, 2009). Imprinting theories (e.g., Marquis and Tilcsik, 2013; Romanelli, 1991) posit that conditions at the emergence phase persist, while scientific discovery, an unmet need, or grand challenge trigger industry incubation (Agarwal et al., 2017). Finally, research on industry clusters alludes to geographical agglomeration of firms, which is driven by heredity and spin-offs that shape industry evolution (Klepper, 2010). This literature does not directly inform our inquiry because an industry refers to a collection of firms that produce a particular good for a market (Tirole, 1988). In contrast, innovation ecosystems often cut across industry boundaries and lack a coherent set of products, firms, and customers. For example, nanotechnology can be applied in a variety of industries, with research conducted in various scientific disciplines. Most importantly, firms take part in subsequent phases of evolution, with limited involvement in the emergence of an innovation ecosystem, so studying their characteristics and actions is premature.

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