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Special Issue Introduction

Three Faces of Technology's Value Creation: Emerging, Enabling, Embedding

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Technology has been conceptualized in many ways, ranging from scientific and engineering knowledge to business enterprise “production functions” to physical artifacts that fulfill a particular purpose. These different conceptualizations underscore technology as a multifaceted construct that encompasses production know-how, problem solving, and functionality. Although new technologies present significant opportunities for value creation, the realization of those opportunities varies across firms, industries, and technologies over time. An understanding of the sources of this variation can help firms with their strategic decision making and offer guidance to policy makers on how they can facilitate technological progress to help spur economic growth. It requires recognizing the important distinction between invention and innovation that goes back to Schumpeter (1934). Whereas inventions represent scientific discoveries that encompass new knowledge within a technological domain, innovation represents the subsequent commercialization of those inventions so as to create value—and, hopefully, capture some of it as well. Therefore, situating the technology in its commercialization context and identifying the features that can have a significant impact on its value creation are pivotal to understanding how firms and policy makers can contribute to technological progress and generate superior performance.

The first of these features relates to the *emerging* nature of the technology (Dosi 1982, Sahal 1985, Basalla 1988). Many new technologies cast a trajectory that is sculpted through breakthrough inventions and by a multiplicity of actors and that promises to yield significant benefits to users over the technology's life cycle. However, the path toward commercialization of an emerging technology is resource intensive and fraught with uncertainty, making it very challenging to navigate for innovating firms. There are often

several initial variations of a new emerging technology vying for dominance (Abernathy and Utterback 1978, Anderson and Tushman 1990), and there is significant heterogeneity among firms in terms of the knowledge and the complementary assets required to achieve successful commercialization (Teece 1986, Tripsas 1997). Publicly funded basic and generic research, with inevitable spillovers, plays an important role in facilitating technological progress in emerging technologies (Rosenberg and Nelson 1994, Kapoor and Klueter 2020). Such support is critical for ensuring progress in an emerging technology and for complementing the commercialization efforts of innovating firms.

The second of the features relate to the *enabling* nature of the technology, which corresponds to its commercialization across multiple application domains over time (Bresnahan and Trajtenberg 1995, Teece 2018). This feature underscores that any given technology can vary with respect to its reach. Some technologies can emerge and have limited applicability, whereas others can improve and evolve over time to enable a wide array of applications and spawn complementary innovations. Although the enabling trajectory of a technology has the potential to generate significant economic and societal impact, the broad applicability requires innovators to develop an array of complementary assets for commercialization, which can be challenging and costly. This can create problems of underinvestment and may limit the technology's growth and slow its widespread adoption. In such cases, policy makers may need to offer additional support for the development of enabling technologies such as public funding of research and development (R&D) and public-private R&D partnerships, and to consider that some antitrust actions might impede incentives for innovation in such technologies.

The third feature relates to the *embedding* nature of the technology in terms of the business model

(Chesbrough and Rosenbloom 2002, Teece 2010) and the ecosystem within which the technology gets commercialized (Teece 2006, Adner and Kapoor 2010). Firms can use different business model designs to commercialize a given technology, and the choice of the business model can have a significant impact on firm performance. The commercialization success of a technology and the focal innovators is also bound by the technology's ecosystem (Adner and Kapoor 2016). Hence, the embedding nature of the technology exemplifies the system of firm-level and ecosystem-level activities that enables a technology's value creation and capture. It also raises important policy-level questions around individual- and corporate-level rights and regulation. For example, it raises issues of privacy with respect to the business model and the ecosystem around digital information platforms, issues of contract and labor laws with respect to sharing economy-oriented business models, and issues of standards for interoperability and coordination within the ecosystem of a technology.

Each of these three features—emerging, enabling, and embedding—reference a distinct source of technology's value creation and sometimes its value capture, too. The emerging feature captures novelty in terms of radical new knowledge and discontinuity in terms of improved functionality while recognizing significant resource commitment under conditions of high uncertainty. The enabling feature captures the impact of any technology as it relates to the multiplicity of applications that the technology can spur over time while recognizing the need for extensive coordination and specialized investments across the different applications for that potential to be realized. The embedding feature captures the surrounding business model and the ecosystem that encompass a technology's commercialization while recognizing the need for alignment within the complementary activities and technologies for innovators to derive value from the focal technology. Together, these features identify the technology context and help draw specific strategy and policy implications. The articles in this special issue showcase this perspective of technology by illustrating how firms' strategies and outcomes interact with the emerging, the enabling, and the embedding features of the technology while highlighting the role of policy in facilitating technological progress. We next provide a brief account of each of the articles.

Gans et al. (2021) consider the emerging nature of technology as a canonical S-shaped progress trajectory (technology S-curve) and explore its implications for the strategy of entrepreneurial start-ups. Instead of viewing the technology S-curve as a function of the technology per se, they offer a choice-based framework in which the technology S-curve is a function of start-ups' strategic choices with respect to exploration

or exploitation. An exploitation orientation emphasizes near-term commercialization based on initial knowledge, whereas an exploration orientation emphasizes long-term knowledge accumulation with the goal of commercializing a higher-performing technology. This choice-based approach is formally modelled to examine start-up's technology strategy and explore the role of technological uncertainty, start-ups' resource constraints, and the possibility of imitation.

Rathje and Katila (2021) consider the enabling nature of technology and explore the role that private firms might play in generating enabling technology trajectories as opposed to conventional wisdom that such trajectories typically originate in the public sector. They use patent data to observe the enabling nature of a given technological invention and draw on federal interest statements in the patent documents to identify whether a given patented invention was a result of private firm-only effort or a result of public-private partnership. The authors use a novel matching approach that involved supervised machine learning to match all of the 33,130 U.S. patents that were a result of public-private partnership during 1982–2002 with a carefully constructed control group of patents that were generated by private firms on their own. The findings suggest that patented inventions stemming from public-private partnerships exhibit more enabling features than those from private-firms themselves. Furthermore, the results offer important insights into partnerships with different types of public agencies—mission-based (e.g., Department of Defense and the National Aeronautics and Space Administration) and science-based (e.g., National Institutes of Health and the National Science Foundation) agencies—as well as the nature of partnerships (financial grants, contracts, and cooperative agreements).

Gambardella et al. (2021) expand the original profiting from innovation (PFI) framework (Teece 1986) to consider innovations that belong to enabling technology trajectories. The core premise is that whereas such innovations exhibit potential for greater applicability, they also require innovators to undertake significant additional costs to ensure usability across the different applications. They are subject to constraints that may limit value in a given application. These trade-offs make it more difficult for the innovator to appropriate value share from enabling technology innovations than in the case of discrete technology innovations with narrow applicability. Accordingly, the strength of the appropriability regime and the availability of the complementary assets are likely to dampen the impact of innovators' commercialization strategies (i.e., contract versus integration) for enabling technology innovations compared with discrete technology innovations—at least compared with the original PFI framework.

The authors find preliminary support for this assertion on a sample of 7,290 patented inventions with survey-based data on firms' commercialization strategies for these inventions. In recognizing the difference between enabling and discrete technology innovations, they offer a modified PFI framework that specifies innovators' commercialization choices with respect to both vertical scope (contract or integration) and horizontal scope (narrow or broad application domain).

Snihur et al. (2020) consider how an emerging technology could be embedded in innovative business models, and they highlight the tension regarding value appropriation that the innovating firm experiences between increasing the legitimacy of its business model within the ecosystem and the increased threat of imitation from competitors. To address this value appropriation dilemma, they suggest a series of strategic design principles grounded in institutional and resource-based theoretical perspectives that business model innovators could incorporate in order to increase legitimacy while deterring the threat of imitation. These include incorporating business model activities that conflict with competitors' existing business models, co-opting potential competitors to become partners in the ecosystem, lowering visibility of key elements of the business model such as those related to software algorithms, and continuously innovating on key business model elements.

Adner and Lieberman (2021) offer a novel perspective on disruption that has long been premised on new entrants pursuing emerging technology trajectories and displacing established incumbents by offering substitute products or services. They expand on this well-established disruption dynamic to include disruption from existing complementors in the ecosystem. Although complementors play an important role in initially enhancing the value of the focal firms' technological innovations, the authors identify three distinct evolutionary processes by which complementors can adversely impact focal firms over time. First, there can be commoditization such that the source of differentiation gradually moves away from focal innovation to the complement, allowing the complementor(s) to appropriate greater value at the expense of the focal innovators. Second, there can be adjacent entry when complementors can diversify over time and be a direct competitor to the focal innovator. Finally, there can be value inversion such that improvements in complements over time can lower the focal innovation's value, eventually eliminating its need. The authors illustrate these disruption dynamics in the ongoing evolution of the automotive industry and offer several conjectures about the industry's future.

Shih (2021) raises the puzzle of why many emerging technologies such as wireless networking, despite being complex and comprising multiple knowledge domains,

undergo rapid adoption. He offers a novel explanation based on the notion of abstraction. Borrowing from the fields of engineering and software development, he defines abstraction as a means to suppress the specific inner workings of the given technology and reveals a relatively simple codified schema that users could readily adopt. For example, several electronics manufacturers use reference designs that hide implementation details but provide users with the information necessary to integrate the functionality of electronic components into their products. Hence, an innovator can raise the level of abstraction of a complex technology to facilitate its adoption. However, abstraction can also have unintended consequences of increased competition among users through commoditization and promote incremental innovations over potentially higher performing systemic innovations.

Finally, Kapoor and Klueter (2021) consider the emerging technology in conjunction with its enabling and embedding characteristics to highlight the potential uncertainties that innovating firms might grapple with as regards the focal emerging technology, the potential applications and users, the technology's ecosystem, and the business model design for commercialization. Moreover, these different sources of uncertainties need not be isolated but may interact in a sequential, pooled, or reciprocal manner. Recognizing these interactions would help shed light on how the uncertainty around an emerging technology might get resolved over time. They illustrate this unbundling approach using the cases of gene therapy and autonomous vehicles, and they discuss the utility of the approach with respect to the cognitive processes and the managerial practices that underlie the strategic management of emerging technologies.

Taken together, these seven articles paint a rich technology development landscape in terms of emerging trajectories, enabling applications, and embedded business models and ecosystems. In so doing, they highlight both the opportunities and the challenges with respect to understanding the value creation and value capture process associated with technological innovation.

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