

Essays on the role of knowledge, R&D, and Technology-based firms in the evolution of socio-techno-economic system

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SUMMARY

Technological change is a central topic in the field of economics and management of innovation. This thesis proposes to combine the *socio-technical* and *techno-economic* perspectives of technological change in a gestalt system, hereby termed as the *socio-techno-economic system (STES)*. The aggregate technological change that manifests in transformative changes in the structure of STES is particularly important due to the scope and magnitude of its impact. Identifying the locus of transformative technological change (TTC) and determining its direction is an important problem from the perspective of public policy as well as business strategy. Following Peter Drucker's insights, this PhD thesis proposes that this problem can be solved by shifting the focus from the product space to the knowledge space as the 'place' scientific inquiry. It posits that knowledge as the DNA and ideas as genes determine the evolution of STES and that structural change in this system follows the structural change in the universe of knowledge that is broadly organized in two domains, science and technology. Accordingly, useful knowledge is mainly produced by two groups of actors, universities and the technology-based firms (TBFs). The knowledge produced by universities largely flows into the domain of science whereas the knowledge produced by TBFs mainly flows into the domain of technology, though both sets of actors draw on extant knowledge from both domains. In general, TBFs tend to be more effective and efficient than universities in sensing the need for useful knowledge and responding to it in a timely fashion because they are driven by the need to earn profit on their investments in the production of knowledge.

In order to capture the most important aspects of change in the structure of the universe of knowledge, we set out to examine changes in the nature of knowledge production from input/output perspective on the one hand and changes in motivations and conduct of the producers of knowledge, on the other. To this end, we asked four substantive questions to guide our research. These are:

1. How *scientific* domains emerge and co-evolve?
2. How *technology* domains emerge and co-evolve?
3. How emergence and co-evolution of scientific and technology domains lead to structural changes in the techno-economic system?
4. Why do firms enter multiple domains and how do they benefit from a multi-technology multi-product capability base?

Accordingly, this PhD thesis is comprised of four empirical essays corresponding to these questions.

Essay 1: Thinking inside the box? Intellectual structure of the knowledge base of innovation research. Science is purportedly becoming increasingly inter-disciplinary and the inter-disciplinarity is generally considered as the source of

growth in scientific knowledge, particularly among social sciences. In order to test this conjecture, we selected the “innovation studies” as an empirical case. We collected the publication data of innovation-related papers that were published in top twenty journals in four major social science disciplines—economics, sociology, psychology, and management—during the 21-year period between 1988 and 2008. We used scientometric approach and bibliometric method to perform longitudinal and structural analysis of the publications. The co-citation analysis helped us identify major research traditions in the field, determine the content and disciplinary composition of each tradition, and map the changes in the intellectual structure of the field over time. To our surprise, we found that innovation research is becoming increasingly compartmentalized between economics and management disciplines and each segment is becoming increasingly self-contained. This finding, coincidentally, provides yet another reason to integrate relevant knowledge from multiple disciplines to develop a more holistic understanding of the co-evolutionary dynamics of social, technological, and economic changes. This essay has been published as a research article in *Strategic Management Journal*.

Essay 2: Co-evolution of technologies: A historical perspective on the emergence and convergence of information and communication technologies. Technology is the outcome of experimentation with different ideas and pieces of knowledge that tend to be scattered in time and place. The temporal and spatial proximity and prior relationship of ideas and relevant knowledge greatly affect the rate of creation and speed of diffusion of new technologies. This signifies the relevance and importance of those technologies that facilitate the preservation and transmission of information. Therefore, in order to understand the locational and combinatorial dynamics of inventive activity, we used historical approach and explored the origins and timing of the discoveries and inventions related to information and communication technologies during the 18th and 19th centuries. This essay presents the historical account of major information and communication technologies and describes how these technologies co-evolved. We found that inventive activity tends to be contextualized by the societal and technological problems prevailing at a given time that are pursued by scientists and engineers working in the domains of science and technology. The insights from the study are put in the context of Hebert Simon's idea of nearly decomposable hierarchical systems and neo-Schumpeterian perspective of clusters of technologies. We find that the former is more practical from an artifact-based perspective of technology while the latter is more useful from the knowledge-based perspective of technology. We conclude that the latter perspective can help solve the problem of measuring the rate and direction of technological change in STES.

Essay 3: Structure of transformative technological change. Structural change in the STES is a matter of interest from the perspective of public policy as well as business strategy because it essentially involves the well-known "creative destruction". Conventionally, structural changes have been studied *ex post* using the context of industries, that is, the product space as a frame of reference. These changes are always underway in the realm of industrial system due to the processes of innovation. However, STES periodically undergoes structural changes of great magnitude that alter not only the structure of industrial system but also the institutional and social structure of society. Accordingly, we refer to this kind of change as "transformative technological change" (TTC).

In this essay, we attempted to capture the dynamics of such transformative changes through a conceptual framework. This novel framework is based on the Neo-Schumpeterian approach (that can be traced to the contributions of William F. Ogburn) that emphasizes the role of invention due to the fact that it precedes innovation and hence transformative changes in the STES occur due to the emergence of new clusters of technologies. We extend this perspective by proposing that technology space is a better 'place' to locate TTC than the product space, more so because it can help identify transformative changes *ex ante*. Thus, TTC is a manifestation of structural changes in the technology space. We illustrate this framework with the help of all available US patent data till 2009. We found that there occurred three successive episodes of TTC during the 20th century; the first took place around 1950, the second occurred around 1980, and the third took off around 2000 and it is currently underway. The first episode involves migration of locus of inventive activities from mechanical engineering-related technologies to the chemical engineering-related technologies and the second episode involves the migration of locus from the chemical engineering-related technologies to the information and communication technologies. The direction of the third episode may be determinable through further inquiry.

Essay 4: Exploitation, Exploration, or Excursion? When and how technologically diversified firms benefit from technological mergers and acquisitions? Large TBFs perform a key role in creating new technologies and products through R&D and inventive activity has become increasingly concentrating within these firms during the 20th century. TBFs tend to be multi-technology multi-product firms and hence simultaneously operate in multiple domains of knowledge and technological ecosystems. Due to their institutionalized R&D, they also play an important role in the assimilation, creation and diffusion of new technological knowledge in the STES. Accordingly, the structure of their technological capabilities co-evolves with multiple domains of knowledge and technological ecosystems. Therefore, understanding the determinants of structural change in their technological capabilities and portfolios is important to understand the determinants of structural

change in knowledge domains which drive structural change in the STES. This essay contributes towards understanding mergers and acquisitions as a popular strategic tool and an important mechanism through which TBFs enter multiple domains and technological ecosystems.

In this essay we build on prior research that has established that technological M&As positively contribute to the technological output of the acquirers and seek to extend the research that aims to identify the drivers of post-acquisition performance. The extant research based on resource-based and organizational learning theories assumes that organizational search is deliberate and driven by the strategic intent to use existing capabilities of the firm or develop new capabilities through M&As. Accordingly, it is also assumed that organizational search through M&As and the performance outcomes thereof either constitute exploitation or exploration. We argue that these assumptions need to be revisited for two important reasons. First, TBFs ultimately seek technological opportunities rather than technological capabilities *per se*. Second, TBFs also come across unintended and serendipitous opportunities that constitute the emergent aspect of organizational search and performance thereof. In case of M&As, unintended or unexpected technological opportunities are likely to emerge due to technological complementarities and substitutabilities between the technological bases of the acquirer and target and many of these emergent opportunities are likely to fall outside the core domains of the acquirer and the target. We argue that such emergent opportunities constitute "excursion" which are distinct from exploration which involves the pursuit of intended opportunities. Therefore, we argue that exploitation and exploration can be understood better by (i) changing the frame of reference from capabilities to opportunities and (ii) isolating excursion from exploration.

This essay explicates and illustrates these ideas using 160 TM&A deals of large TBFs from global information and communication technology sector during a 21-year period and measuring the post-acquisition inventive output of acquirers. Empirical evidence suggests that excursion is a sizeable contributor to the post-acquisition inventive output of TBFs alongside exploration and exploitation. Results of negative binomial regression analysis of the panel data suggest that technological diversity of the acquirer negatively affects the post-acquisition exploitative and explorative output, exploitative output is negatively affected by technological history of the acquirer, and technological similarity between acquirer and target negatively affects explorative output.

In short, this thesis proposes the use of *technological ecosystem* approach and establishment of an integrated global intelligence system to monitor TTC. The technological ecosystem approach suggests that *knowledge* is not only the quintessential input but also the principal output that determines the quantity and quali-

ty of solutions to the societal needs and problems. This perspective links the knowledge-base of the society with its problem-suite and may help create greater value and better allocate resources. From this perspective, the nature or *kind* of knowledge being produced and used may be more useful frame of reference for identifying and classifying actors and activities, regardless of the products they are producing. This approach, together with the suggested intelligence system, can also help all stakeholders to be more informed about the developments, including but not limited to the scientific and technological advancements, that may eventually result in the TTC. This approach may also help improve the role of concerned actors in the long run, save them from the perils of ignorant adaptation to their local environments, and help them co-evolve with the STES in a timely fashion.