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A typology of technological change: Technological paradigm theory with validation and generalization from case studies

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ABSTRACT

Shifts in technological paradigms simultaneously disrupt existing industrial organization and raise opportunities for entrepreneurial companies. However, research on technological innovation centers the development of new technological solutions, while largely neglecting changes in customer problems or needs. This paper develops a typology for use as an analytical framework covering technological innovations and variations in market demand. The typology is then applied to the photographic industry, specifically the development of digital imaging technologies which disrupted existing film material and chemistry technologies in a paradigm shift from analog film to digital cameras. Taking a systematic view of product technologies, the typology identifies seven types of technological changes during the photography industry's process of digitalization. Case studies show that disruption of incumbent competencies can be attributed to the interactive effects of technological innovations and variations to market demand. Adaptive strategies corresponding to the identified types of technological changes are reported and discussed. The proposed typology is designed as a generic framework and is validated using an additional set of case studies from the media industrial sector.

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1. Introduction

Technological changes can often disrupt a market or industry's established rules, orders, beliefs, and values. The impact of such disruption can be so profound that it can threaten the survival of firms that fail to adapt. Organizations will succeed only if they are adequately aware of the new conditions and are able to overcome organizational inertia and embrace the change.

Schumpeter [1] defined creative destruction as the process by which entrepreneurs continuously create value while simultaneously destroying old values through the development of disruptive technological innovations. Due to the

complex nature of fast changing technologies, the disruptiveness of technological innovations can be difficult to characterize and recognize. Firms that disregard the disruptive nature of technological innovation could be supplanted by new entrants which dominate the new technological paradigms [2,3]. For instance, IBM disregarded the disruptive nature of the personal computer (PC) and the once dominant computer giant gave way to the two new entrants, Intel and Microsoft. Despite Christensen's prominent work on the subject [2–4], disruptive innovations do not always offer superior performance, but are still able to invade the mainstream market. Utterback argues that radical technologies invade the market in different ways [5]. While technological changes follow different patterns, both Christensen and Utterback strive to explore the strategic implications of technological evolutions [6–11]. A more systematic research approach is needed to investigate the interrelationships among technological innovation, technology paradigms and the wider developmental environment.

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Science and technology (S&T) policy makers in industry and government need to anticipate future technological evolution. Does technological evolution follow some general theories? Is it predictable? If so, what are the policy and strategy implications? This research aims to answer these questions by investigating the interrelationships among technological innovations, changes in market needs or problems, and adaptive strategies. The objectives of this research are:

1. to develop a typology that contains representative types of technological paradigm shifts;
2. to validate the typology's theoretical soundness by applying it to prominent technological transitions.

This study is organized as follows: **Section 2** presents a literature review. **Section 3** introduces the proposed generic typology which serves as an analytic framework. **Section 4** presents findings from a case study on the photographic industrial sector, used to validate the typology's utility. The final section presents conclusions, including strategic implications for managers, generalization of the typology and future applications.

2. Literature review

The study of technological innovation began with Schumpeter's description of the creative destruction process [1]. More recently, the concept of disruptive innovation [3] has attracted renewed attention from researchers and practitioners. The disruptiveness of a technological transition depends on its acceptance by the market and industry. However, the creative destruction process is more than simply introducing an innovative product into an existing market to replace an incumbent, and a thorough analysis of the interaction among scientific advances, economic factors, institutional variables and existing technological trends in the process should yield useful insight for managers [12]. In general, industrial structure and sectoral patterns of innovation are frequently involved in research on technological changes [13–17].

Studies in this field suggest that a typological framework for analyzing technological changes should include constitutional factors of technological paradigms.

2.1. Technological paradigm

Scientific and technological paradigms are comprised of beliefs, assumptions, perceived problems, intended solutions, and the community that contains these components [12,18]. A paradigmatic community is an organization that allocates resources to develop solutions to address a perceived problem. The decision to proceed from perceived problem to solution is constrained by the beliefs and assumptions of the community and is referred to as "strategy" [19]. The implementation of a process selected to resolve the perceived problem is referred to as "organizational behavior" [20,21].

Typological research on strategy and organizational behavior includes Miles and Snow's classical strategy typological identification of four strategy types: prospector, analyzer, defender, and reactor [22]. Porter provides another prominent set of strategic types in his generic strategies: cost leadership, differentiation, and focus [23]. Depending on the environmental settings, many different factors have been incorporated to this

stream of strategy-oriented typological research. The interaction between strategy and the broader environment determines organizational performance [24,25]. Environmental settings may include technology [26], organizational constituents [27] and organizational culture [28]. These critical factors are related to the paradigmatic community and its underlying components. Given this support in the literature, the present study incorporates Kuhn's components, along with the strategy and behavior of the paradigmatic community, to classify technological paradigm types.

2.2. Types of technological innovations

Technological innovations are recognized as improvements on or alternatives to intended solutions. Abernathy and Clark [29] classified innovations as either sustaining or destroying technological capability and market linkages. Market linkages refer to customer relationship management, user applications, market knowledge, and channel and service relationships. Technological capability refers to knowledge related to the design, production, materials, equipment, and management of science and engineering. The Abernathy and Clark's two-dimensional taxonomy classifies innovations as regular, niche, revolutionary, and architectural types.

In their study of patterns of technological changes and their impacts on industrial conditions, Tushman and Anderson [30] found that new and existing firms take different approaches toward technological innovation, with new firms seeking to develop competence-destroying technologies that will disrupt current practices, while existing firms seek to develop competence-enhancing innovations to decrease environmental uncertainty.

Henderson and Clark [31] classified technological changes in terms of their impact on product structures or components. A technological change can either enhance or destroy a product's architecture (links of components) or component knowledge. Their model distinguishes four types of technological changes, namely incremental, modular, architectural, and radical. Architectural innovation poses a subtle challenge to incumbent firms as architectural knowledge is likely to be deeply rooted in the organization, and architectural knowledge can be difficult to recognize and change through organizational learning. Later on, Christensen's work on disruptive innovation added market demand for product performance and the time dimension to clarify the difference between sustaining and disruptive technological innovations [3]. In his model, disruptive innovations are further divided into low-end disruption and new-market disruption.

2.3. Changes in technological problem or need

Nelson and Winter [32] first introduced the concept of "technological regime," which refers to the technologists' beliefs regarding the feasibility and value of developing an as yet unrealized technology. Technological regime has since been adopted by scholars and practitioners to resolve both technical and managerial problems. In general, technological regime refers to the governing environment in which technologies are explored and exploited [33,34].

Malerba and Orsenigo [20] use opportunity, appropriability, knowledge base, and cumulativity as the four core conditions

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