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Adoption dynamics of increasing-return technologies in systemic contexts

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ABSTRACT

Many systemic, complex technologies have been suggested to exhibit increasing returns to adoption, whereby the initial increase in adoption leads to increasing experience with the technology, which drives technological improvements and use, subsequently leading to further adoption. In addition, in the systemic context, mimetic behavior may lend support to increasing returns as technology adoption is witnessed among other agents in the systemic context. Finally, inter-dependencies in the systemic context also sensitize the adoption behavior to fundamental changes in technology provisioning, and this may lend support for the increasing returns type of dynamics in adoption. Our empirical study examines the dynamics of organizational technology adoption when technology is provisioned by organizations in another sub-system in a systemic context. We hypothesize that innovation, imitation, and technological change effects are present in creating increasing returns in the systemic context. Our empirical setting considers 24 technologies represented by 2282 data points in the computer industry. Our results provide support for our prediction that imitation effects are present in creating increasing returns to adoption. We further discuss the managerial and research implications of our results.

1. Introduction

This paper explores the dynamics of technological innovation adoption at the firm level and subsequent resource allocation under increasing returns conditions. Namely, we study firms' adoption of technologies that displays increasing returns and hypothesize the more the technologies are adopted the more they will be adopted due to the accumulating experiences and positive feedback loops (following Ref. [1]), learning by using [2], learning by imitating [3], and influence by demand-side increasing returns [4]. Specifically, we study the dynamics of technology provisioning and adoption of these technologies in a systemic, high-technology context.

1.1. Adoption of innovations and increasing returns

Technological innovation adoption has been applied to thousands of empirical studies concerning an individual's innovation adoption and organizations' innovation adoption [see e.g. Refs. 5–10]. These studies have found that resource allocation and technology adoption at the firm level are influenced by a number of factors, for example, ease of use, performance in relation to other technological alternatives, and end-users' market preferences. Subsequently, many firms lending support and using a technology lead to customers being encouraged to buy that technology, and this behavior leads more firms to adopt and use the technology in question [11]. This positive feedback loop creates an increasing returns type of dynamics between the firm's adoption and the end-user's use.

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At the same time, competition takes place not only between companies producing technologies, or adopting these technologies, but also at the level of technologies competing for end-users' attention and adoption [12]. Competition between technologies is determined, at least partially, with a group of products that follow the same technological paradigm [13] following a compatible design path. Further, this competition is also determined by the organizational support this design gains as it is adopted, which is influenced by the positive feedback loops from the demand side (the organizations using the design and the end-users who prefer it). Competition between technologies is due to the existence of multiple organizations using and supporting compatible products that suggest to the market a possible industry standard [11], at least for a brief duration. This support further gives customers confidence that future products will be based on this technology, and therefore increases the likelihood of customers adopting the technology in question.

1.2. Technological systems

Technological systems are complex by nature, consisting of various nested levels [14] and comprising various technical and social components [15]. In the PC (personal computer) technological system, for example, we identify technical elements such as hard disks, processors, monitor screens, application software, and operating system programs [16,12,17,18]. In turn, the social components of this system constitute the organizations that nurture the aforementioned artifacts, the employees and managers in these organizations, as well as government, institutional, and legal bodies that directly or indirectly guide technological development. In this manner, we view the technological system as a socio-technical system [e.g., 15,19,20].

The literature studying technological systems identifies different types of socio-technical systems, including complex product systems (CoPS), large technical systems (LTS), systems of innovation, and modular systems. As technological systems, all of these systems exhibit a common set of properties [21,22]. First, technological systems have a hierarchically nested structure, whereby a given system is seen as a composition of smaller sub-systems that are themselves systems comprising further sub-systems [e.g., 23,14]. In this system structure, some organizations specialize in producing particular sub-systems, while other organizations specialize in integrating sub-systems into holistic technical systems [24,25]. Second, technical sub-systems, which are specialized in delivering particular functions, are interdependent within the same as well as across different levels of the system hierarchy [e.g., 23]. This fundamental property of all technological systems also links organizations whereby the performance of any systemic organization depends on the performance of other organizations. And, third, technological systems are goal-seeking [e.g., 15,19,26] at the sub-system and holistic system levels. Driven by objective orientation, holistic technological systems evolve over time to attain higher performance levels.

Within the hierarchical structure, this system-level evolution depends on the reciprocated and interdependent cause-and-effect processes taking place among all technical and social sub-systems [15]. In this light, this paper focuses on the decisions made by organizations (i.e., social actors) to adopt technological innovations made available by other organizations within the same evolving system. Specifically, as one organization delivers a higher level of performance in a technical sub-system, the organization creates the potential for organizations producing interdependent sub-systems to adopt and use this performance in their own offering [27,28]. The rate and pattern of adoption of these new technological innovations, within the systemic context, are therefore important to study, because they affect the evolution of the socio-technical system, in which organizations are embedded.

1.3. Adoption of innovations in technological systems

In the systemic context, positive feedback loops emerge, ranging from technology development to adoption of the technology and use of its potential, and finally to the end-user's preference for the technology due to the initial support for the technology through organizational adoption. This leads us to consider the adoption process at the firm level within a systemic context, namely, the diffusion of innovations in socio-technical systems.

Following Bass [29], the adoption of innovations can be formally modeled with the diffusion model as

$$\frac{dF}{dt}(t) = (p + qF(t))(1-F(t)),$$

where $F(t)$ is the installed base fraction. Following established definitions, p is the coefficient of innovation, and q is the coefficient of imitation. The closed-form solution is [see Ref. 29]

$$F(t;p,q) = \frac{1-e^{-p(p+q)t}}{\left(\frac{q}{p}\right)e^{-(p+q)t}+1},$$

where time $t>0$.

Adoption of technological innovations by organizations in socio-technical systems may be viewed as technological learning at multiple levels [3], and the learning can take place as learning by doing and learning by studying and developing (i.e., R&D), as well as learning by imitating. The imitation process has been found in empirical studies on adoption of technological innovation in firms [30], especially when firms have information on the behavior of their counterparts and the firms are able to imitate their