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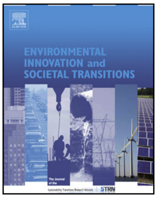

Thresholds models of technological transitions

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A B S T R A C T

We present a systematic review of seven threshold models of technological transitions from physics, biology, economics and sociology. The very same phenomenon of a technological transition can be explained by very different logics, ranging from economic explanations based on price, performance and increasing returns to alternative explanations based on word-of-mouth recommendation, convergence of expectations, or social mimicking behaviour. Our review serves as a menu for future modelling exercises that can take one or more elementary transition models as a basis, and extend these model to fit more specific sectoral, technological or territorial contexts.

1. Introduction

The question how technological transitions occur is an old one (Schumpeter, 1942). Nevertheless, it is only since the turn of the century that the study of transitions has gained momentum (Grübler, 1998; Rip and Kemp, 1998; Geels, 2002). The increased attention can be understood in the light of the pressing need to reform energy, housing, transportation, agriculture and health sectors given resource scarcity, climate change and environmental justice. It is commonly agreed that such reforms necessitate fundamental changes in the socio-technical systems that are currently dominant in these sectors. In this context, one speaks of the need for sustainability transitions (Grin et al., 2010; Markard et al., 2012).

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A common notion underlying transition thinking is that of "technological regime" (Nelson and Winter, 1977) and "lock-in" (Arthur, 1989). A lock-in into a technological regime can be defined as a state in which one technology is dominant in a particular application domain, and resistant to competing alternatives, even if the latter can be considered socially desirable (David, 1984). Underlying the lock-in phenomenon are increasing returns to adoption: a technology tends to be more attractive, the more fellow users already use a technology.

To further our understanding of the mechanisms underlying technological lock-in, and the possibilities to successfully introduce alternative technologies to promote transitions, we look into various threshold models in complexity theory. Such models identify "tipping points" that lead a system to transit from one state (here one dominant technological regime) to another state (here, an alternative technological regime). Understanding the nature of such tipping points is important, as it may be informative regarding transition policies at the level of individual actors, groups of actors, and government.

In the past two decades, several complexity-theoretic models of technological transitions have been proposed. Reviewing these contributions, it becomes clear that the sources of technological lock-in may vary, and that the possible mechanisms leading towards technological transitions are multiple. In the built up of a substantively interpretable theory of technological transitions, we find it helpful to clarify the various assumptions of different models and how these models are related. Hence, a systematic review of elementary models of technological transitions is useful in order to discern the various mechanisms underlying causing transitions or the absence thereof in empirical work. What is more, our review also serves as a "menu" for future modelling exercises that can take one or more elementary models as a basis, and elaborate on these to fit more specific contexts.

Our paper is structured around seven core models of technological transitions. Each of these addresses the same question (the conditions under which a population of agents switches from a technology to an alternative technology) but from different angles. We start in Section 2 with the hyperselection model, which includes the classic Fisher–Pry substitution model as a special case. The hyperselection model contains a tipping point that specifies the critical mass required for a new technology to successfully replace the old. One can also derive such tipping points using a modified Arthur-model of increasing returns to adoption (Section 3), or using an informational cascade model (Section 4), or else a coordination game model (Section 5). The widespread notion of technological transitions as a co-evolutionary process between various interdependent technologies is taken up in Section 6 where we discuss the NK-model, which in turn bears resemblances with game theory. In Section 7 we go into transitions as percolation processes in social networks. We finally go into sociologically-inspired transition models in Section 8. We end with a comparison of the various models and discuss the usefulness in probing the complex phenomenon on technological transitions theoretically and empirically and discuss their relevance for the study of technological transitions in general and sustainability transitions in particular.

2. Hyperselection

Bruckner et al. (1996) developed a general model of substitution, considering the case of an already existing technology 1 with N_1 users, and an innovative technology that enters the market with N_2 early adopters. The model assumes a constant number of adopters $N = N_1 + N_2$, which suggests that the two technologies are perfect substitutes. Because of this assumption the innovative technology can succeed only by substituting the old one. The dynamics of substitution, then, follows from the differential equation:

$$\frac{dN_i}{dt} = (E_i + B_i N_i)N_i - k_0 N_i, \quad i = 1, 2.$$

Here the coefficients E_i and B_i set the growth rate of each technology, and, hence, reflect the quality of each technology. To assure that N is constant, the decay rate must fulfil the condition:

$$k_0 = \frac{(E_1 + B_1 N_1)N_1 + (E_2 + B_2 N_2)N_2}{N}$$