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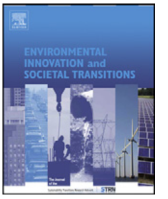

Branching innovation, recombinant innovation, and endogenous technological transitions

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We propose a model of technological transitions based on two different types of innovations. Branching innovations refer to technological improvements along a particular path, while recombinant innovations represent fusions of multiple paths. Recombinant innovations create "short-cuts" which reduce switching costs allowing agents to escape a technological lock-in. As a result, recombinant innovations speed up technological progress allowing transitions that are impossible with only branching innovations. Our model replicates some stylised facts of technological change, such as technological lock-in, experimental failure, punctuated change and irreversibility. Furthermore, an extensive simulation experiment suggests that there is an optimal rate of innovation, which is strongly correlated with the number of recombination innovations. This underlines the pivotal role of technological variety as a seed for recombinant innovation leading to technological transitions.

1. Introduction

Among the most challenging questions in the social sciences is the question how one can explain societal transitions. Transitions range from transitions in norms, in opinions, in preferences, and in technology use. It is the latter case we will refer to in the following though we reckon that some elements of the model developed below may be more generally applicable.

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We characterise transitions as large-scale changes that occur suddenly yet endogenously. This implies that the time-scale at which a transition takes place in a particular context is considerably smaller than the time-scale at which such transitions are absent, which is characteristic of a pattern of punctuated change. Our approach also implies that we do not invoke an external cause (shock) to explain transitions.

Understanding the endogenous forces of technological transitions is particularly important in the design of policies, as for instance innovation policy or environmental policy. In this view, a policy can attempt to render transitions more likely given the underlying endogenous dynamics of technological change at hand, rather than to force a transition through exogenous policy shocks. Deepening our theoretical understanding of the dynamics of technological transitions is particularly relevant given the current challenge to promote sustainable technologies in energy, transportation and agriculture sectors alike.

A salient feature of technology concerns the network externalities that adopters enjoy from using the same technology. Previous models of network externalities (David, 1985; Arthur, 1989; Bruckner et al., 1996) only explain how a technology becomes dominant in a population, and do not explain the emergence of new technological paths. Put differently, while we have a good theoretical understanding of the dynamics of path dependence, we still lack models of path creation. The call for models that combine path creation and path dependence is thus legitimate (Garud and Karnœ, 2001; Garud et al., 2010), as they are fundamental aspects of transitions to sustainable technologies.

To explain the dynamics of technological transitions, we develop a model where agents enjoy positive network externalities from using the same technology, while some agents, called innovators, ignore these externalities and introduce new technologies. After a new technology has been created, the remaining agents make decisions about technology adoption. Adopting agents only adopt a new technology if it gives higher returns net of the switching costs. In the event that all agents switch to a better technology, we speak of a technological transition.

We assume that technologies form a graph, as in Vega-Redondo (1994) and Carayol and Dalle (2007). In these two models the graph is a tree, while a specific feature of our model holds that technologies can be recombined. Models of recombinant innovation proposed hitherto are rare, both theoretical (Silverberg and Verspagen, 2005; van den Bergh, 2008; Zeppini and van den Bergh, 2011; Enquist et al., 2011) and empirical (Fleming, 2001; Fleming and Sorenson, 2001; Schilling and Green, 2011). Recombinant innovations create short-cuts which speed up technological progress, allowing transitions that are impossible otherwise. Different from previous models, our network of technologies is endogenously evolving through the actions of agents, which means that we do not need to make any *a priori* assumptions about the nature of the technology graphs that agents are exploring.

Our model replicates some stylised facts of technological transitions, such as technological lock-in, experimental failure, punctuated change and irreversibility. Lock-in and experimental failure are a consequence of new innovations developed by entrepreneurs being rejected by adopters because of the strong network externalities associated with the old technology (Bruckner et al., 1996). Recombinant innovation underscores the importance of technological diversity as a key feature of technological transitions. Punctuated change is reflected by rare occurrence of transitions, which are irreversible in nature.

From our model, we conclude that neither too low nor too high efforts are advisable for innovation policy. A too low innovation effort does not allow society to escape the current lock-in as all new paths creations are rejected by adopters. A too high innovation effort is wasteful as the marginal returns to an increase in innovation rate quickly approach zero. The optimal innovation effort in between is strongly correlated with the number of recombinations, which indicates how recombinant innovation is important in achieving a sustained technological progress at relatively low costs.

The paper is organised as follows. Section 2 presents the model. Section 3 provides a qualitative analysis of the model results illustrated by some exemplary simulations. In Section 4 we turn to the numerical analysis of an extensive simulation experiment. Section 5 concludes, also indicating the direction for possible extensions of the model.