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Diversity in technology competition: The link between platforms and sociotechnical transitions

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ABSTRACT

There is an urgent need for a fast transition to a low-carbon economy, which will involve behavioural change and new technologies. This paper focuses on the technological dimension of the transition. Low-carbon technologies usually have a modular architecture that utilize standards to enable interfacing of components. These standards contribute to transition inertia. An important question addressed in this article is whether maintaining technological diversity can help overcome inertia. This requires keeping options open and foregoing returns to scale. It is a trade-off which has technological as well as spatial dimensions which are important because different geographical areas may provide institutional or other advantages to the emergence of distinct technologies. In order to explore this, the platform competition and transitions literature are reviewed, links between them are established, and a system dynamics model is developed where multiple new technologies compete with an incumbent. It is used to answer two questions: Will a larger portfolio accelerate or delay a transition to a new technology, and under which conditions will such an acceleration occur? does spatial differentiation matter to the outcome? The model results show that technological diversity and spatial differentiation matter for the speed of transitions. The challenge is to create a level competitive field for all technologies accounting for the distinct institutional advantages their spatial differentiation may provide. This opens a range of future research directions.

1. Introduction

Our society needs to make a rapid transition away from the current fossil-fuel dominated economy towards renewable energy sources such as biofuels, solar and wind, and as a result considerably increase the energy efficiency of all processes. An effective solution requires technical, organizational, economic, institutional, social-cultural and political changes. Such pervasive system change is referred to as a socio-technical transition to sustainability [1–3]. For example, the electrification of the transport sector is one of several solutions put forward to address the issues associated with growth in travel demand, and the associated greenhouse gas emissions and oil demand at a global scale [4,5].

Transitions initiate when new technologies and related practices are introduced and improved, rendering them sufficiently competitive to compete with incumbent technologies [6,7]. New technologies may arise in different socio-technical systems and then speciate from one niche-domain of application to another, thus increasing the variety of competing technologies [3,8]. Spatial considerations are relevant as supporting actor networks arise in particular geographical locales where often specific or even unique conditions apply [9,10].

New technologies introduced in a system have a higher chance of succeeding in protected niches because they enable learning and network development [11,12]. This allows the exploration of several technological trajectories or promising options in parallel [11]. The example from the transport system is the range of hybrid, plug-in hybrid, electric, hydrogen, and biofuel vehicles available for public or private transport [13,14]. The increasing number and diversity of firms becoming involved in an emerging new technological trajectory increases technology competition, and this in turn stimulates innovation and development [15]. Organizational and technological diversity is critical to the emergence and development of new technologies, including renewable energy technologies, and large system change [16–20].

It is argued that greater technological diversity catalyzes technological development and increases the potential for technology recombination [21]. Diversity can break the lock-in of established technologies. They have a competitive advantage arising from self-reinforcing increasing returns to scale which comes from demand and supply factors such as economies of scale in production, compatibility with complementary technologies, standardization, learning effects, and network externalities [22,23]. Diversity enables higher system flex-

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ibility by keeping multiple options open, which increases the likelihood of finding good technical or organizational solutions in the face of high uncertainty about long-term economic, political and social conditions [24]. However, maintaining diversity comes at the cost of fragmented market shares of technologies and low increasing returns to adoption [21].

This is where a policy dilemma for socio-technical change arises [7,25]: maintain high diversity of new technology solutions in niches, or maintain a lower diversity to rapidly achieve increasing returns to scale. The first option involves supporting a high diversity of expensive but promising new technologies in niches. This option facilitates learning and avoids suboptimal solutions. The scale-intensive option involves supporting a lower diversity of technologies. This option may enable relatively few fast maturing new technologies to compete with, and replace the older technologies.

Wide diversity may hamper scaling up as it fragments resources and impedes rapid innovation of the important alternatives. In addition, it increases the uncertainty about candidate technological solutions which prevents investors from fully committing to them. Low diversity can lead to an early lock-in in a suboptimal technology. Thus, the choice of niche maintaining or scale-intensive strategies presents a serious dilemma for policy making.

The competition between old and new technologies is characterized by two selection processes [26]: the replacement of established technologies by emerging ones, and the rivalry between alternative new technologies. An illustrative example is the urban transport system. In early 20th century, it went through a transition from horse drawn carriages to cars [27]. It involved several technologies: bicycles, electric trams, electric cars, gasoline and steam cars. All of them competed in separate niches and distinct locales, and against the dominant technology of horse drawn carriages.

In the following decades the current urban transport system will undergo a new transition to low-carbon transport modes [28,29]. This transition is used as a motivating case throughout the paper and relevant literature is reviewed where appropriate. The transition may involve new conceptions of mobility, more sustainable travel patterns, and new forms of spatial planning, and new ensembles of low-carbon technologies like electric vehicles (EVs) [30]. The California Zero Emissions Vehicle mandate sparked an interest in EVs during the 1990s, and several manufacturers developed production models [31]. Its momentum was cut after the court amendment in 2003, but it did pave the way for hybrid electric vehicles and other low emission technologies [32].

At present, the dominant technology is still the internal combustion engine (ICE). A range of alternative technologies is developing, and some have entered the market, including plug-in hybrid and electric vehicles (EV) [13,14,33–35]. Most established carmakers have developed a range of alternative fuel vehicles, along with diversifying firms and startups like Tesla developed higher performance cars [14,36]. These technologies are not stand alone products. They are technology platforms, i.e. modular technology architectures requiring complementary products and services for their operation [37–39].

This platform architecture raises a number of issues for the transition of the transport system [40]: renewable energy integration, EV participation in electricity markets, standardization of battery types, vehicle to electric grid connection and scheduling technologies, disposal and recycling of batteries, and the specifications regarding cables and plugs for recharging. Several competing technical standards, for vehicle to grid and vehicle to vehicle interfacing have been developed reflecting a local context (US, Europe and Japan) [4,41–43]. Due to different institutional advantages that distinct geographical areas offer, it is possible that the diversity of existing and future standards and platforms remain locked in niches and do not scale up, resulting in a fragmented rather than a winner takes all outcome [44,45].

The automotive industry is just one industry where technologies have a platform architecture [46]. Other technologies have a platform architecture and face challenges of similar nature e.g. telecommunications [47], computer software [48], and solar energy [20]. All of these are instrumental in implementing cleaner production processes. Thus, it is worth revisiting the dilemma stated earlier of diversity versus achieving increasing returns to scale, but from a platform competition perspective [38,49].

Technology competition in niches is an evolutionary process. Therefore, its study requires an evolutionary perspective. The present article develops an evolutionary model of technology diffusion using system dynamics [50]. The model takes into account spatial differentiation [9,10] and technology lifecycle considerations [51] in answering the question: Does the required time to transition diminish with a larger number of platform technologies? Moreover, does time diminish when different platforms are favoured in different geographical locales?

Several evolutionary models of technology adoption explore the effect of user preference heterogeneity using a variety of modelling approaches [52,53]: diffusion models with increasing returns [54–58], co-evolutionary models of users and producers [59–61], and extensions of the Nelson and Winter model [62]. Other kinds of modelling approaches have also been applied to sociotechnical transitions [63–66].

This paper builds upon the work of Loch and Huberman [67] because it offers a useful, relatively parsimonious evolutionary model where an incumbent and a new technology compete with repeated user choice, externality benefits, and learning by doing technology improvement. Their study explores the conditions under which the candidate technology replaces the incumbent. In this paper, the model is adapted to a platform setting and extended to increase its realism using: (i) a range of competing technologies rather than just one, (ii) spatial differentiation and associated unique conditions, and (iii) dynamic performance ceilings for competing technologies to account for learning.

The present paper reviews relevant parts of the sociotechnical transition and platform competition literatures, and develops a simulation model with which to address this dilemma. The paper makes three contributions. It clarifies the conceptual link between platforms and technology standards, and their relevance for transition research. It explores the dilemmas discussed above through the use of a simulation model that combines technology performance competition and spatial considerations. It replicates and extends an existing model in the literature. The model is used to explore how the number and variety of competing platforms can potentially delay scaling up processes, and result in spatially fragmented outcomes.

The paper is structured as follows. Section 2 reviews the technology platform literature and establishes its relevance for studying transitions to a low-carbon economy. Section 3 presents the model. Section 3.2 discusses simulation results. Section 4 concludes the paper.

2. Theoretical basis

This section provides the conceptual basis upon which the proposed model presented in Section 3 is based. This is done in three parts. Section 2.1 reviews the link of platforms and standards to sociotechnical systems and transitions. This is the starting point for Section 2.2 to consider sociotechnical niches as places where new platforms develop and compete against established platforms. Finally, Section 2.3 discusses the five essential factors which influence platform competition. These factors are then integrated into a model in Section 3.

2.1. A review of the links between platforms, standards and sociotechnical transitions

Technology platforms research spans engineering design and economics perspectives [39]. Gawer and Cusumano [68] define platforms as: “products, services, or technologies developed by one or more firms, which serve as foundations upon which a larger number of firms