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A retroductive systems-based methodology for socio-technical transitions research

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ABSTRACT

Socio-technical system transitions research describes and categorizes transitions and explains and identifies their driving causes. In the literature, transition research frameworks have received some critique on whether they can facilitate the search for transition causes. As a response, and in order to cater for the complexity and contextuality of multi system transitions, this paper proposes a retroductive systems-based methodology. The methodology relies on qualitative case study development and quantitative simulation modelling. Retroduction along with modelling and simulation can contribute to the shift from researching single system/technology transitions to multi system/technology transitions. Thus the paper offers a step towards coping methodologically with sustainability transitions that often concern multi system interactions. We demonstrate the use of the methodology by adopting the Multi-Level Perspective on transitions to explain the emergence of the functional foods as a niche in the food/nutrition socio-technical system.

1. Introduction

Research in sociotechnical transitions and system innovation aims at understanding social and technological change by analyzing the causes that enable or inhibit such long term, system level processes. Research in this area faces two challenges (Genus and Coles, 2008): (i) how to create and improve the understanding of historical transitions, and (ii) how to advance and refine the frameworks and tools used for the analysis of contemporary sociotechnical transitions in order to inform and/or propose interventions related to governance and technology policy. These challenges are interrelated and involve generating and systematizing knowledge about how transitions initiate, unfold and finish.

From a systems perspective, transitions can be thought of as changes of state of socio-technical systems. They are transient social phenomena generated by dynamic interactions between system elements and result in long-term structural changes, which permeate the majority of the elements of the system. Although socio-technical systems and system innovation research focus on understanding systems, in reality theoretical frameworks like the Multi-Level Perspective (Geels and Schot, 2007; Geels, 2004) make little use of systems approaches, methods and tools in addition to case studies (Coenen and Diaz Lopez, 2010). In transition research methodologies, the notion of system has been employed only to account for interconnectivity and other static, spatial, conceptual properties of socio-technical systems while system-theoretic and dynamic, quantitative, behavioral approaches have received little attention (Holtz, 2011; Safarzynska et al., 2012).

The Multi-Level Perspective (MLP), in particular, has been criticized as offering a heuristic device with which transition events can be organized (Genus and Coles, 2008). It has also been argued that it is limited to single system transitions while in reality, the majority of transitions involve interactions between more than one systems (Papachristos et al., 2013). The existence of single system transition typologies (Geels and Schot, 2007) and the relative lack of multi-system transitions research (Raven and Verbong, 2007; Raven, 2007a; Geels, 2007b) can be partly attributed to the limited use of suitable systems-based research methodologies to handle the increased complexity of interactions and their generative mechanisms. Nevertheless, inter-systems interactions are expected to be important in transitions to sustainability (Mancarella, 2014). For example, biofuels for transport link the agrifood, energy and transport systems, and electric or plug in hybrid vehicles link transport and electricity systems.

It follows that a shift from single system/technology to multi system/technology transition frameworks is necessary in order to remain relevant for the future (Geels, 2010; Lauridsen and Jorgensen, 2010; Konrad et al., 2008). In researching transitions, there is no other way of inferring their causes except by constructing a plausible narrative about them and assessing its validity on the basis of the outcomes it produces. We argue that this requires: (i) the application of a retroductive inference mode under a critical realist philosophical perspective and

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(ii) modeling and simulation for handling the increased complexity of multi system transitions (Davis et al., 2007; Harrison et al., 2007; Papachristos, 2014). This paper proposes a research methodology for socio-technical systems transition that retains case studies but also integrates retroduction with simulation modeling putting an emphasis on multi-system transition cases. The combination of models and case studies will yield clearer insights with greater confidence (Buthe, 2002; Kopainsky and Luna-Reyes, 2008; Eisenhardt and Graebner, 2007).

Retroduction has been previously applied in several research areas, for example in technology innovation policy (Gao, 2015). Retroduction is associated with the critical realist philosophical perspective (Peirce, 1958; Bhaskar, 2008) and differs from induction and deduction in that it is a process of forming explanatory hypotheses about the generative mechanisms of an observable phenomenon and then testing them in order to determine their validity (Wuisman, 2005). Retroduction 'is the only logical operation which introduces any new idea and leads to new knowledge' (Peirce, 1958, quoted in Fischer, 2001). In research, it overcomes the limits of induction which are associated with the long transition periods which are difficult to observe directly, as well as those of deduction which relies on a limited number of variables isolated from the complex, dynamic, systemic contexts of socio-technical systems through a series of debatable assumptions.

The methodology presented in the paper, operationalizes retroductive hypothesis testing through system dynamics modeling and simulation. The methodology is applied to a novel multi-system transition case concerning the functional foods niche, which emerged through interactions of event producing mechanisms in the converging socio-technical systems of food and pharmaceuticals (Curran et al., 2010). The question posed for the case was: 'which were the operative (underlying) mechanisms in the pharmaceutical and food systems whose interaction resulted in the emergence of the functional food niche in the food socio-technical system?'. This question was answered by forming a qualitative hypothesis about the mechanisms operating in the two systems and testing possible variations through modeling and simulation. It allowed us to see whether specific instantiations of the explanatory mechanisms for the phenomenon form internally consistent hypotheses and are sufficient for generating the observed emergence of functional foods. It also allowed the investigation of the effect of timing and intensity of interactions on the emergence of the functional foods niche, something not possible through a case study.

System dynamics simulation modeling and simulation of mechanisms was chosen to reproduce the observed phenomenon because: (i) it is suited to modeling cases developed in a narrative style (Kopainsky and Luna-Reyes, 2008), (ii) as a systems methodology is conducive to retroduction (Mingers, 2000, 2004); (iii) it can be used to overcome the limitations of human cognition in assessing feedback, delays and accumulation (Sterman, 1989a, 1989b; Diehl and Sterman, 1995; Cronin et al., 2009), and (iv) it can be used for the development of middle range theory (Kopainsky and Luna-Reyes, 2008; Schwaninger and Grosser, 2008) which is the expressed aim of the MLP (Geels, 2007a). Finally, from its inception, system dynamics has dealt with large scale, long-term issues (Forrester, 1961, 1969; Meadows et al., 1972) precisely the kind of processes that transitions are.

The contribution of the paper is fourfold. First, a retroductive methodology to transition research that can be applied both in MLP related and Innovation Systems research is proposed. It is applied in the functional foods case and allows an in depth exploration and validation of the identified causal mechanisms thus increasing the confidence in the proposed explanation of functional foods emergence. Second, a novel multi system interaction case is presented which adds to the existing literature on transitions. Third, to the best of the authors knowledge, it is the first multi-system modeling effort in transition research as existing models in the literature concern single regime transitions (Kohler et al., 2009; Bergman et al., 2008; Safarzynska and van den Bergh, 2010). Finally, by reproducing the functional food emergence the paper substantiates the proposed new MLP transition pathway proposed in Papachristos et al. (2013).

The rest of the paper is structured as follows: Section 2 presents an overview of systems approaches to innovation and socio-technical transitions, while Section 3 discusses related research design issues. Section 4 discusses retroductive inference and outlines a methodology that integrates modeling and simulation. Section 5 presents the functional foods case and Section 6 develops the hypothesis of how interacting mechanisms result in the new system emergence. This is followed by the development of the system dynamics model and the presentation of the results of its simulation. Finally, Section 7 concludes with discussion of results and suggestions for further research and development.

2. System approaches to innovation and technical change

Extensive literature exists on conceptualisations of system innovation and technical change (Freeman, 1987; Lundvall, 1992; Nelson, 1993). There are several strands of innovation systems research: sectoral, regional and national (Mowery, 1998; Carlsson et al., 2002; Lundvall, 2010). They differ from traditional black-box economic approaches that emphasise spending/input. The common ground in their systems perspective is that innovation, technological and economic performance are contingent on the interactions and learning between system elements (institutions and/or organizations) (Edquist, 1997). In the same line, Technological Innovation Systems (TIS) (Carlsson and Stankiewicz, 1991), and Functions of Innovation Systems (Bergek et al., 2008; Hekkert et al., 2007), emphasize the dynamic analysis of system functions and their interactions: knowledge development and diffusion, influence on the direction of research, entrepreneurial experimentation, market formation, legitimation, resource mobilization and development of positive externalities.

Socio-technical systems approaches differ from the above in that they broaden the unit of analysis from the firm level to the organizational field (DiMaggio and Powell, 1983), they introduce societal processes (e.g. consumption and use), and have an overall sociological, rather than economic, orientation (Coenen and Diaz Lopez, 2010). For example, the MLP is concerned with the interconnections and the dynamics of social groups that influence technological change and system inertia. In general, a socio-technical system comprises of the elements that are necessary for fulfilling a societal need such as nutrition and includes the corresponding industrial organization. The system is the "product" of the activities of actors who are embedded in interdependent social groups, each with its own set of operating rules and behavioral norms.

In the MLP discourse, the socio-technical regime is the central concept for analyzing actor activities and how they reproduce or change the system. It is where incremental technological development and consumer preferences co-evolve defining the trajectory of the regime. The regime can be considered as a specific state in the trajectory of a socio-technical system, which is contingent to intangible and underlying institutional structures e.g. engineers' heuristics, institutions and social expectations (Geels, 2011). There are two additional levels in the MLP-based analysis (Geels, 2004): the landscape, at the macro level, which provides long-term gradients for the regime trajectories, and the niche, at the micro level, where radical innovations incubate and proliferate.

A transition takes place when the regime is destabilized through pressures and interactions that develop between the three levels until a new system state is reached (Geels, 2010). Regime stability can be perturbed by Geels and Schot (2007)): (i) innovations that develop in niches through learning processes, price/performance improvements and support from powerful groups, (ii) pressures accumulating from events or trends at the landscape level acting on the regime (economic, cultural, demographic etc.), (iii) internal tensions that can destabilize the regime and create windows of opportunity for innovations in