System Interactions in Sociotechnical Transitions: Extending the Multi Level Perspective

ABSTRACT

This paper discusses contextual issues in sociotechnical systems and transitions under the Multi Level Perspective (MLP). It emphasises inter system interactions, for which a typology is developed drawing on a review and meta level analysis of published transition case studies. The typology is subsequently associated to the MLP transitions pathways. A novel transition pathway, is derived through this process, namely new system emergence, for systems that emerge from contributions of existing antecedent sociotechnical systems.

Keywords: multi regime, sociotechnical transitions, system interactions

1. Introduction

Sociotechnical systems frameworks are developed to conceptualise and understand large scale complex processes of technology, production, and social change. Transition studies provide a rich account and understanding of such system changes. Lately a particular emphasis has been placed on transitions towards sustainability. In systematizing the knowledge regarding sociotechnical transitions, a number of transition typologies based on different criteria have been proposed. They include: (i) the transition pathways typology (Geels and Schot, 2007) following the Multi Level Perspective (MLP), (ii) the multi regime interaction approach (Raven and Verbong, 2007), (iii) the transition contexts approach (Smith et al., 2005), (iv) the framework of de Haan and Rotmans (2011), and (v) the framework of Rotmans and Loorbach (2010).

This paper concentrates on the MLP transition typology which draws mainly on explanations of historical transitions (Smith et al., 2010) and utilises two criteria: the nature and timing of intra system element interactions. These can take place between regimes and niches that are internal to a sociotechnical system. A sociotechnical system can be thought of as a set of heterogeneous interlinked elements that fulfil a societal need through technology. The dynamic, stable state of these elements constitutes a regime, whereas novel configurations and states deviating from it constitute niches which form around markets or technologies. In the majority of published studies to date, the MLP considers system transitions as stand alone processes i.e. as a result of interactions taking place internally in a single focal sociotechnical system, with additional system elements situated in external landscape, regimes, or niches. However, given the complexity of our world, this perspective is rather limited. It is very rare to find societal and sociotechnical system transitions which are not influenced at any stage of the transition by processes taking place in other interrelated systems (Shove, 2004; Loorbach, 2007; Smith et al., 2010). This has resulted in some critique of the MLP regarding its application, the view that transition processes originate primarily in niches and that they are single system processes (Geels, 2011; Smith et al, 2005; Genus and Coles, 2008).

While there have been some attempts towards the study of multi system element interactions, they were mostly focused at interactions between regimes of the same or similar sociotechnical or societal systems. For example, Smith et al. (2005) argued towards more inclusive, not just niche based, explanations of sociotechnical transitions. They stressed the role of internal/external agency and resources to the regime and viewed transitions as a function of the selection pressures that the regime faces, and the coordination of the available internal or external resources for responding to these pressures. In the same line Raven and Verbong (2007) proposed a framework that conceptualised four types of interactions across regime boundaries: (i) competition between regimes, (ii) symbiosis of regimes with a mutually beneficial interaction, (iii) integration of regimes into a single entity and (iv) spill over where rules are transferred from one regime to another.

This paper focuses on the interactions taking place among sociotechnical systems during transitions. It aims to explore, describe and classify sociotechnical system interactions by reviewing and analysing a number of cases reported in the literature of sociotechnical system transitions. The intention is to bridge the gap between the analysis of single system transitions with the MLP, for which it has been critiqued (Smith et al., 2005; Genus and Coles, 2008), and the need for analysis of multi system cases, an issue that is particularly relevant to sustainability transitions (Geels, 2011; Konrad et al., 2008). From a systems perspective, the study of multi system interactions poses two challenges: (i) to define the boundaries of the systems under study (usually there is more than a unitary system - regime relation, as components of other external systems are involved in the formation or transformation of regimes), (ii) to identify the mechanisms, processes and actors, which influence the evolution of a sociotechnical system and may or may not be part of it. A fundamental issue in this regard is distinguishing between regimes and niches that are internal or external to the focal system of analysis. This distinction is necessary in order to make the analytical step from intra to multi system interactions and transitions.

In order to meet these challenges the paper derives by induction a typology of transition system interactions from thirteen published transition cases on which the development of MLP transition pathways was based (Geels and Schot, 2007). Two additional multi system cases are included in the paper. In developing the typology of interactions the aim is to include all possible sociotechnical system interactions and to associate them with transition pathways. The underlying hypothesis is that these interactions are an important characteristic of sociotechnical system transitions. Therefore instead of focusing on a single case that would provide an in-depth description of a phenomenon (Siggelkow, 2007), multiple case studies are analysed to provide a wider scope for theory development (Yin, 1994).

In this way the concept of system interactions is well grounded to published MLP cases in the literature and an increased emphasis is placed on multi system interactions. In a manner analogous to laboratory experiments, the proposed concept of system interaction is systematically and iteratively applied to each case, in order to assess how well or poorly it fits with it (Eisenhardt, 1989). The result of the comparison enables an informed judgement on whether the concept of system interactions is idiosyncratic to a specific case study or is consistently found in several cases (Eisenhardt, 1991). This process enables the selection and retention of system interaction types with the greatest possible descriptive range while keeping their total number low, thus increasing the theoretical parsimony of the concept (Weick, 1989).

The analysis of the cases and the derived system interaction typology led logically to the definition of an additional transition pathway to those proposed by Geels and Schot (2007). This is a reflection of the multi system focus of the paper and is discussed in the second part in order to address a gap in the current version of the MLP: there is no MLP transition pathway that accounts for multi system interactions which lead to the emergence of a new system. Transitions are portrayed as single system transitions taking place as stand alone processes i.e. without explicitly considering the contingencies of the wider context. The additional pathway aims to cover this gap. Furthermore, it adds a realistic possibility to the MLP i.e. a change in the number of extant sociotechnical systems. The integration of the system interaction typology in the sociotechnical transitions discourse and the additional transition pathway provide an extension to the MLP.

The remainder of the paper is structured as follows. An overview of the MLP and the associated transition pathways typology is given in section 2. Section 3 introduces the conceptual framework used to systematically describe and characterise transitions in terms of four different types of sociotechnical system interactions. Section 4 provides a review of four exemplary transition cases with particular emphasis on the inter and intra system interactions.

Section 5 provides a typology of system interactions. It associates them to the typology of transition pathways and derives a new transition pathway that draws on them. Section 6 introduces and discusses the new transition pathway. Section 7 discusses the results of the secondary case analysis and section 8 concludes the paper.

2. Transitions of Sociotechnical systems

Structurally, a sociotechnical system comprises of three interrelated elements (Geels, 2004): (i) a network of actors and social groups, (ii) formal, cognitive, and normative rules that guide their activities and, (iii) material and technical elements as artefacts and infrastructures. Social groups influence the trajectory of the sociotechnical system and its stability, by adhering to specific sets of rules that constitute the sociotechnical regime under which they operate. The regime follows an incremental innovation trajectory which is hard to change or break, due to lock in and path dependence (Unruh, 2000; Garud and Karnoe, 2001).

In the MLP, a system transition to a new regime comes as a result of interactions between three levels: *landscape*, *regime* and *niche*. The landscape at the macro level provides long term gradients for the established sociotechnical regime where technologies develop incrementally, and for the niche(s) where radical innovations incubate and proliferate. The dynamic stability of the regime can be perturbed by innovations that develop in niches, pressures from the landscape that act on the regime, or from the build up of internal regime tensions. Social groups within the regime can mount an endogenous response so as to absorb the pressures and/or niche innovations. In some cases however, this response to persistent problems/pressures, is not sufficient and a system transition to a completely new regime takes place. In a transition, the prevailing attitudes, practices of technology production, and its use in the system are gradually substituted by new ones that originate in niches (novel small scale sociotechnical systems) (Schot and Geels, 2008). A transition ends when changes in the social and technical elements of the regime become embedded in the institutional, production and user subsystems of the sociotechnical system. However, the outcome of a transition is not predetermined.

The transition typology of Geels and Schot (2007) details the conditions under which a transition follows a certain pathway. Inevitably, in transition analysis, the boundaries of what follows the trajectory i.e. the system, have to be defined, in effect creating a dichotomy between it and the environment. However, actors and/or elements from different systems are integrated, directly or indirectly in the analysis. They are outsiders i.e. groups of actors located in different systems at the level of sociotechnical regime or niche. They can be firms, entrepreneurs, activists or societal groups. The current paper highlights their involvement in extant literature of transition cases. The fact that the MLP draws on these cases is reflected in that outsiders are also implicated in the MLP transition pathways.

In the *transformation pathway*, niche innovations cannot take advantage of landscape pressures acting on the regime because they are not sufficiently developed and cannot overcome the resistance of regime incumbent actors (Geels and Schot, 2007). Hence, the regime is transformed endogenously by regime actors that alter the direction of development paths and innovation activities. An exemplary case is the hygienic transition to sewer systems in the Netherlands where system outsiders were doctors from the medical system and engineers (Geels, 2006a). This case illustrates that it is possible for outsiders to influence the conditions that regime incumbents face and reorientate the trajectory of the regime by creating a niche, or by translating landscape pressures and drawing attention to the negative externalities of the regime.

In the *dealignment realignment* pathway the sociotechnical regime comes under high landscape pressure quickly. The intensity of the problems it experiences leads to its erosion, and regime members lose faith on whether an adequate response can be mustered. The misalignment of regime rules obscures the prospects of its future trajectory and leads to the development of different niche innovations, one of which eventually emerges as dominant. The case of the American urban transport system transition to automobiles illustrates this pathway (Geels, 2005b). In this case, there were internal niches to the system supported by the system’s horse-tram firms like taxis, and others such as the electric tram that were supported by electric light firms that originated in external systems.

In the *technological substitution* pathway, niches attain a level of development that enables them to influence the regime when it comes under pressure. One of the niches eventually breaks through and substitutes the dominant regime. The illustrative case for this pathway is the transition to steamships (Geels, 2002). In this case, the construction of new iron hull steamships drew on agent competences external to the system (iron workers and boiler makers) where the design and production of ships relied exclusively on wood.

Finally, in the *reconfiguration* pathway, the trajectory and the architecture of the regime changes during the transition. Niches symbiotic to the regime are absorbed and their integration may allow new combinations of system elements and learning from regime members. This pathway is illustrated in the American factory transition to mass production (Geels, 2006b) which was driven by a sequence of multiple component innovations enabled by developments outside the focal system, linked to elements of external systems related to housing and construction materials, iron and steel making and energy supply resources.

The exemplary cases of each pathway illustrate the concept of system interactions in the MLP transition pathways. Additional evidence in support of integrating system interactions exist in published transition cases. Technologies that eventually become involved in transitions are embedded in regimes and/or niches that are internal or external to the focal system of analysis. These inter system interactions can bring about radical changes to the sociotechnical system being analysed. They can also lead to the emergence of a new one as in the case of the emergence of the digital computer (Van den Ende and Kemp, 1999) which emerged out of the computing, data processing and the electrical engineering regime, in response to growing computation needs, the improvement of punch card technology and the tendency to plan, schematize and divide computational work.

In summary, outsiders are involved in the majority of transition cases. Nevertheless, their involvement in transitions has not attracted much interest so far, neither has the extent to which niches and regimes of external systems influence transitions. In order to fill this gap, a meta analysis of fifteen published cases of sociotechnical transitions is used for their classification on the basis of a consistent conceptual framework. This provides a better understanding of how system interactions dynamically influence a sociotechnical transition because it prompts the researcher to come up with an explicit answer to the question: ‘where do influential actors, technologies, processes and events that influence the variety of focal system elements reside?’. The answer requires a rigorous identification of the network of resources and capabilities that actors have access to, and the rules under which they operate.

3. A Conceptual Transition Framework for Mapping Inter-System Interactions

Generally, transitions involve changes in rules and institutions, as well as in the social and technological subsystems related to the fulfilment of a societal need. Hence, a sociotechnical transition can be initiated from, and involve developments in any of these domains. The seeds of change do not necessarily reside within the system, they can be exogenous. This concerns both social change as well as technology development, which is not an isolated, stand alone process but it is influenced by social processes and its development often requires knowledge derived from disparate fields. Put succinctly, inventions and technology development are partly explained by social and other processes that do not necessarily reside within the focal system of analysis (Mokyr, 2002; Arthur, 2009).

Consequently, influential actors, resources, processes and events, can reside in niches(s) and regime(s) or system(s), inside or outside the system. Understanding transitions, requires a consideration of how they are related to change processes in the sociotechnical system under study. In this context, the notion of boundary is necessary and inevitable. It draws attention to what is perceived as lying beyond the boundaries of the focal system and it calls for a consideration of the wider context within which the transition takes place. This can be just as important as that which lies inside the system. Both are part of the critical assumptions the researcher makes in considering the focal system. Clearly outlining the boundary of the system is a matter of subjective judgement although system theorists have proposed more objective criteria based on the set of activities to which a commonly accepted meaning is assigned (Luhmann, 1995).

Alternatively, the criterion for deciding whether a niche or regime can be considered as external to the focal system is the fulfilment of different societal needs. Differing societal needs lead to the development of technology specific knowledge pertaining to the supply of these needs. This inevitably differentiates the innovation patterns of external niches and regimes (Van de Poel, 2003; Schot and Geels, 2007)[1]. The application of this criterion, requires consideration of the locus of knowledge development and thus acknowledging the dialectical relationship between knowledge and the system in which it is situated (Cilliers, 2000). They both continuously transform and feed one another. Core system members are delineated from non-members by the degree to which each actor can influence the reproduction of the system's regime. However, system membership cannot be sharply outlined as many actors (for example consumers) can be members in more than one system or eventually some actors may become insiders (Smith et al., 2005; Geels, 2006a). For example, in the case of digital computing, actors of the electrical engineering system became also involved in the digital computer system (Van den Ende and Kemp, 1999). This is a neglected issue in the current version of the MLP (Geels and Schot, 2007; Geels, 2010).

Figure 1 presents a conceptual framework that can be used for describing the involvement of external entities (regimes, niches) in transitions. This framework can facilitate the description

[1] For alternative criteria on outlining regimes see Holtz et al., 2008

of the nature of interactions (reinforcing or disruptive) between the elements of a focal system (S_1 in Figure 1) and a number of external systems. While interactions in typology types can be bi-directional, and involve more than two systems and/or regimes, for illustration purposes, S_1 and R_1 are regarded as the focal entities of the analysis. The interactions can be the result of endogenous developments (an internal niche N_1), or the result of some exogenous influence (for example a crisis, a social trend, or a technology) from niches (N_2) or regimes (R_2) of a different system. It is also possible to have direct interactions between two regimes R_1 and R_2 or more, that are part of the same system (i.e. they serve the same social function) or belong to different systems as shown in Figure 1. The result of these inter-system regime interactions, may be the emergence of a new niche (N_3) as in the case for the emergence of functional foods (Papachristos et al., 2010) and the digital computer regime (Van den Ende and Kemp, 1999). Clearly, a number of niches and/or regimes can exert conflicting influences on the focal system without implying that multi regime or multi system interactions and developments are always relevant and thus necessary in order to explain a transition. They can only be considered as potential drivers of transition processes on a case by case basis. Figure 1 illustrates the four interaction types that have been identified following a meta analysis of the transition cases: (i) Niche Transfer, (ii) Niche Interference, (iii) Niche Autonomy and, (iv) Niche Emergence. The cases presented in section 4 illustrate how the concept of system interactions is integrated in the MLP framework in order to enhance its analytical power.

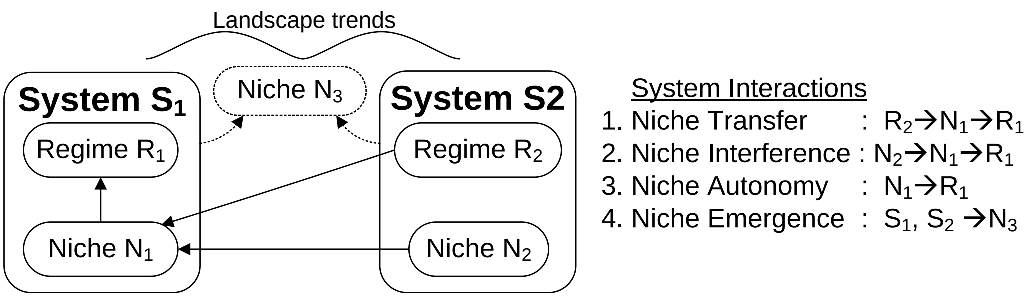

Figure 1 Types of transition system interactions

4. A Meta Analysis of System Interactions in Published Transition Cases

In this section a description of the four exemplary case studies is presented under the prism of system interactions. The analysis is based on the conceptual framework in Figure 1. The focal system is always designated as S_1. Regime(s) and niche(s) in the focal system are designated as “internal R_1” and “internal N_1”. Additional regimes internal to a system are designated as “internal R_2” etc. External regimes situated in different systems are designated as “external

R_2" and external niches as "external N_2". Case descriptions are not intended to convey all the crucial details but only to highlight system interactions in each transition case.

4.1 The hygienic transition from cess pools to sewer systems (1840 - 1930) (Geels, 2006a)

The Dutch waste-disposal regime (internal R_1) faced the problem of large waste quantities that accumulated in cesspools in streets and canals. Initially, no action was taken because health was seen as an individual responsibility and city governments had limited resources. This changed when cholera epidemics struck the Netherlands in 1832 and 1848. The development of medical statistics about cholera epidemics in the Netherlands and elsewhere, demonstrated correlations between hygienic conditions and cholera. This pressure from the medical regime (external R_2) resulted in cognitive changes about infectious diseases. Along with the development of sewer designs by engineers, it resulted in an influx of knowledge, into the waste disposal regime, as doctors and engineers acquired insider positions. The medical community suggested that local authorities should reduce waste-accumulation, although the causal mechanisms of the epidemics were identified later. The diffusion of knowledge in the waste disposal regime was facilitated by the institution of local health inspectors.

This knowledge diffusion had an add on character as knowledge about pipes and underground water flows was not disruptive to existing knowledge in the waste disposal regime. Rather it involved identifying the best way to combine solutions and reduce costs. It brought about the exploration of alternatives for waste handling in niches, by subsidizing experimental projects (internal N_1). The costs and benefits of different waste disposal configurations were influenced by other developments as well. The diffusion of piped water and water closets (internal N_1) resulted in reduced economic feasibility of the collection system. Finally, the expansion in the housing regime (external R_2) and the construction of new neighbourhoods, provided the impetus for the integration of sewer pipe construction into house designs.

This case corresponds to the transformation transition pathway (Geels, 2006a) and the first type of system interactions: niche transfer, as knowledge and technologies originating in different systems, in this case the medical and housing construction systems, contributed to the creation of niches inside the focal system of waste disposal. The latter eventually transformed into the sewer system after the emergence of a dominant solution through a process of absorbing and testing this knowledge and technology in niches inside the system. Published cases with similar interaction types include the transition of the Dutch highway system (Geels, 2007a), the transition from mixed farming to intensive pig husbandry (Geels, 2009), the co-evolution of waste and electricity regimes in the Netherlands (Raven, 2007), and the use of ICT in car sharing (Papachristos, 2011).

4.2 The transition from horse-drawn carriages to automobiles (1860-1930) (Geels, 2005b)

In the second half of the 19th century, American cities grew in size as a result of immigration and industrialization. Middle class families gradually developed a preference for living in less crowded city suburbs. The ensuing rapid urbanization led to the growth of urban horse-drawn transport (internal R_1). This regime faced problems of increasing costs, traffic congestion, safety and pollution from horse manure which created a window of opportunity for the use of the electric tram in the early 1880s (internal N_1). The growth of the electric tram, was enabled by the widespread enthusiasm of society for electricity. Electric light companies (external N_2) actively supported it as they saw an additional market. However, this niche faced wage and material costs problems, while the level of service deteriorated. This eventually led to declining passenger numbers in the 1930s. Another transport alternative at the time was the bicycle (internal N_2). Bicycles developed in the 1830s and their popularity peaked in the 1890s, followed by a collapse which lead bicycle producers to diversify into automobiles.

Early automobiles used petrol, steam or electric motors (external N_1, N_2 and N_3). The potential of these transport alternatives was explored in four niches: taxi, promenading, racing and touring (internal N_1-N_4). Gasoline and electric cars were tried in the taxi niche. However, the company that operated electric taxis went bankrupt and this forestalled any further development. Furthermore, as a dominant design did not emerge, scale economies and lower cost were not achieved. The second niche was the luxury niche of promenading in parks, and driving to picnics and tea parties. The third niche was racing, where gasoline cars had an advantage in long distances, as electric vehicles had to overcome the limitations of battery duration, and low reliability. The fourth niche of touring in the countryside, linked up with the cultural values of adventure and technical prowess. Gasoline cars had an advantage, as petrol was available at general stores throughout the country. The number of gasoline automobiles also increased, as touring in the country side became popular. Further growth came as farmers used gasoline cars to market their products themselves, and overcome the social isolation of rural communities.

Gasoline car development stabilised in a dominant design in the form of Ford's Model T. Its mass production allowed further incremental product innovations and improvements to bring down car prices which further accelerated its diffusion. An important innovation was electric ignition with batteries which made starting gasoline cars as easy as in electric cars. In contrast, there was no dominant design for electric automobiles while the problem of weak electric motors and heavy batteries was not resolved. Hence, scale economies and lower costs were not realized. Steam engines also had problems as they were heavy, cumbersome, slow to start, and prone to boiler explosions. Technical improvements were not able to eradicate these problems. Furthermore, public resistance and regulation proved insurmountable for them. This left the gasoline car in direct competition with the electric tram. However, the problems the tram faced, public and policy opposition, and the perception of it as being slower than the car, eventually tilted the balance in favour of the gasoline car.

This case corresponds to the de-alignment re-alignment transition pathway (Geels, 2005b). It illustrates the second system interaction type: niche interference, as niches external to the urban transport system of horse drawn carriages formed around technologies (steam, gasoline and, electric batteries and motor technology) and were used in automobiles in four internal niches: racing, touring, promenading and taxies. Additional niches were bicycles and electric trams. Similar cases in terms of system interactions are the transformation of American factory production (Geels, 2006b), and the transition from sailing ships to steamships (Geels, 2002).

4.3 The transition of aviation systems from propeller to turbojet (1930-1970) (Geels, 2006c)

In the 1930s, the civil aviation regime (focal regime R_1) had stabilised around a dominant design exemplified by Douglas DC3. However, there were two limitations to propeller aircraft in general. The first was the engine's maximum flying altitude limit. The second was the propeller tips approaching speeds close to the speed of sound. Solutions to these problems were fervently sought before and during World War II.

Turbojets were a technology that emerged independently in Britain from the work of Frank Whittle and in Germany from Hans von Ohain and Herbert Wagner. Whittle tried to draw the attention of Air Ministry officials and aero-engine firms to no avail. So, he set up a small company to develop jet engines on his own. In Germany, Von Ohain also self-financed the construction of a demonstration engine. The approach of WWII created a window of opportunity in both countries for jet engine development, as R&D military budgets soared. The British government assigned most development projects to existing aero-engine companies, while in Germany Wagner and Von Ohain collaborated with Junkers and Heinkel. Early jet engines produced considerable thrust, but had high fuel consumption which limited their range. Thus, a first niche for the jet engine was interceptor fighters where range was not a problem since they were guided by radars (internal N_2).

Following the Lyttleton Agreement, Britain focused on bomber and fighter development during the war and the US on heavy bombers and transport aircraft. After the war, Britain utilised its leading edge jet technology in commercial jetliners and developed the Comet which became an immediate success. This prompted American manufacturers to diversify and develop their own civilian jets, the Boeing 707 and Douglas DC8, which were powered by bomber aircraft jet engines. These civilian jets were first introduced in the long distance transatlantic market niche (internal N_1). They gradually diffused to other markets and routes following changes in the civilian aviation regime and diminishing operating costs due to economies of scale.

This case corresponds to the transformation transition pathway (Geels, 2006c). The corresponding system interaction type is niche autonomy, as there is a single aviation system with two distinct regimes: the military and the civilian aviation. Development of jet technology in the niche of military fighters (internal N_1) led to the adoption of civilian jet planes through two routes. The diffusion of jets within the military regime and the development of jet bombers (internal R_2), led to the Boeing 707 in the US, and the de Havilland Comet in Britain. Both trajectories led to the development of long-distance travel niche (internal niche N_1) and the eventual adoption of jet passenger planes in the civilian aviation regime (focal regime R_1) during the 1970s. Similar cases in terms of system interactions include: the breakthrough of rock 'n' roll (Geels, 2007b), the ongoing energy transition of the Dutch electricity system (Verbong and Geels, 2007), the multi regime interactions of combined heat and power technologies in the Netherlands (Raven and Verbong, 2007), and the transition in water supply and personal hygiene in the Netherlands (Geels, 2005c).

4.4 The emergence of functional foods (Papachristos et al., 2010)

Landscape pressures and trends

The shift in individual life styles in the developed world and the demographic shift, have brought into attention two issues related to individual health: healthy nutrition and health care costs. The importance of nutrition to health has been firmly established (De Lorgeril et al., 1998; Potter and Steinmetz, 1996). Awareness of this link has increased with issues of food quality that received wide media attention during the late 1990s and changed public attitudes to nutrition from that of just being necessary for maintaining physiological functions to one directly related to individual health.

Public health care costs are related to demographic developments which stem form the increase in average life expectancy and population growth. The result is that aging people are an ever increasing percentage of the population in developed countries. This increases the demand for pharmaceuticals and health care services and consequently the cost of national health care systems (Denton et al., 2002; EFPIA, 2009). One of the plausible courses of action in the short term, is to induce people by public campaigns, to be proactive about their health by actively modifying their nutritional habits (Coveney, 2003).

The Food System: Pressures and Developments (external system S_1)

During the late 1990s and early 2000s, highly publicised cases of substandard food products made food quality and safety a concern and lead consumers to explore alternatives for their nutrition. These developments along with governmental reports that emphasized the role of diet on health, created a shift in social norms towards having a balanced diet and an increased public interest for nutrition and health issues (Heasman and Mellentin, 2001). Consumers have come to believe that appropriate nutrition contributes directly to health (Mollet and Rowland, 2002). Along with intense competition, this made evident the need for diversification in the food industry (Rohr et al., 2005). These developments created the context in which the emergence of functional foods took place.

The Pharmaceuticals System: Pressures and developments (external System S_2)

Several developments influenced the pharmaceuticals system. First, the onset of molecular biology and genomics introduced a new paradigm in drug discovery from the 1970s onwards based on new recombinant DNA techniques and advances in nanotechnology and supercomputing (Allarakhia and Steven, 2011). Second, the market share of generic drugs grew from 22% in 1985 to 67% in 2000 (Grabowski and Kyle, 2007). Third, drug development got lengthier, and the average time and cost of the clinical test phases increased between 1970 and 1990 (DiMasi et al., 1991; DiMasi, 2001). The need to generate savings in the industry stimulated further interest in generic drugs. Fourth, stringent regulations resulted in declining productivity and increased R&D costs for pharmaceuticals (Jensen, 1987).

There is some overlap between the ensuing needs in the two systems: (i) supplying population nutritional needs and (ii) maintaining or improving human physiological functions in order to reduce demand for pharmaceuticals and health care services, (iii) easing the competitive tensions in the pharmaceuticals system (Brannback et al., 2002). The development of functional food is a response to these needs and has been enabled by advances in life sciences. The fact that they cover both nutritional and physiological individual needs has been a factor to their diffusion (Doyon and Labrecque, 2008).

The niche of functional foods

Modifying the chemical composition of food in order to make it have additional health related properties started in the 1950s, where products introduced were fortified with vitamins and minerals. Later in the 1970s and 1980s, products contained low fat and sugar, and high fibre products. From the 1970s onwards, molecular biology, genomics and more broadly life sciences, introduced a new paradigm in drug discovery (Allarakhia and Steven, 2011). This played a role in the onset of functional foods that initially gained a market share in Japan in the 1980s. Throughout the 1990s numerous product launches followed worldwide, with varying success. The diffusion of functional foods continued in the 2000s and their global market share has been estimated close to 1% (Siro et al., 2008).

Both the food (S_1) and pharmaceuticals systems (S_2), contributed to the emergence of the new niche (external N_3). The external niche emerged because pharmaceutical companies had no experience in the food market and no access to food distribution networks (Bech-Larsen and Scholderer, 2007). Due to this they initially failed to create a market (Menrad, 2003). An illustrative case is the Aviva product line of the pharmaceuticals firm Novartis which was launched in 1999 and was eventually withdrawn (Heasman and Mellentin, 2001). The distribution of functional foods via pharmacies created an unfavourable consumer perception of the product, as going to a pharmacy to buy nutritional products was dissonant to the established function of these stores. Inevitably this strong path dependency in the food market proved difficult for pharmaceuticals to overcome as they lacked negotiation power in securing retail distribution for their products. Consequently, market and distribution capabilities were supplied by the food system firms. Similarly the food system required and in turn benefited from the core capability of pharmaceuticals in substantiating specific product health claims through clinical trials as well as their R&D infrastructure (Menrad, 2003, Brannback et al., 2002). The example of Benecol line of products is characteristic (Lehenkari, 2003). Thus the emergence of the functional food system came through this bidirectional capability transfer where each 'parent' system acted as the requisite outsider to the development of the functional food niche (Van de Poel, 2000).

The role of regulation for product adoption

The acceptance of a novel product category such as functional foods, depends on the consumer's perception of benefits and risks (Cardello et al., 2007). These include the safety of the production processes and technology used, and the health risk that the product claims it reduces. Regulation on providing trusted information and proof for the benefits of functional foods is also necessary because there is no way of immediately experiencing their benefits (Bagchi et al., 2004; Bruhn, 2007). Consequently, their adoption is influenced by consumer trust of this information (Urala and Lahteenmaki, 2004; Mark-Herbert, 2004). Another factor, due to their novelty, is the variety of definitions and national regulatory frameworks that holds back the wider diffusion of functional foods (Doyon and Labrecque, 2008; Asp and Bryngelsson, 2008). The lack of stable uniform regulatory framework indicates that the system is still a niche. Further growth will come when this is overcome and widespread information dissemination is made possible (Arvanitoyannis and Van Houwelingen, 2005). However, information provision alone about the benefits of a particular product is ineffective in producing dietary changes. The increasing incidence rate of obesity in North America, Europe and elsewhere provide evidence for this (Muller et al., 2008). Hence, the diffusion of functional foods goes beyond information provision and the possession of a broad set of skills and resources on the part of firms that attempt to enter the market. It requires a concomitant change of consumer attitudes as well.

This case corresponds to the new system emergence transition pathway[2]. The corresponding system interaction type is niche emergence as the niche of functional foods is external to both pharmaceuticals (S_2) and food (S_1) systems. Functional foods have a different use and they don't come under the regulatory framework of either product category, though there is some overlap of system elements, resources and competences which is something to be expected. A similar case in terms of system interactions is the emergence of the computer regime, whose analysis preceded the development of the MLP (Van den Ende and Kemp, 1999).

[2] This is not categorised in the literature, the transition pathway is chosen based on the description in Papachristos et al. (2010)

5. A Typology of System Interactions

The analysis of the cases in the previous section and the identification and description of the inter-system linkages in the transitions discussed, leads to the definition of four types of sociotechnical systems interactions that have been outlined in section 3. They define a typology of interactions which can be used to characterise the interactions of sociotechnical systems in transitions. They are involved in transitions and are related to the criteria of nature and timing of interactions in the Geels and Schot (2007) typology.

In order to illustrate temporally the system interaction types and the new transition pathway, in the rest of the section a description of each type and how change leads to a new focal regime R_1¨ is provided. The first type: *niche transfer* (Figure 2), involves social trends, knowledge, or dominant technologies originating in a regime (R_2) in a different system S_2 that either influence, or contribute to the creation of an internal niche (N_1). Then depending on the nature and timing of interactions with R_1, there are three possible future developments for the niche. First, it can be absorbed by the regime if the interactions are reinforcing irrespective of timing. Illustrative examples of this are: the case of the Dutch highway system (Geels, 2007a), and the transition from mixed farming to intensive pig husbandry (Geels, 2009). Second, it can replace R_1 if the interactions are competitive. In this case because the main influences (social or technological) originate in an established regime, the timing of interactions should coincide with pressures from landscape and internal tensions in the focal regime that create a window of opportunity. Finally, it can dissolve if there are competitive interactions and the focal regime does not face significant pressures.

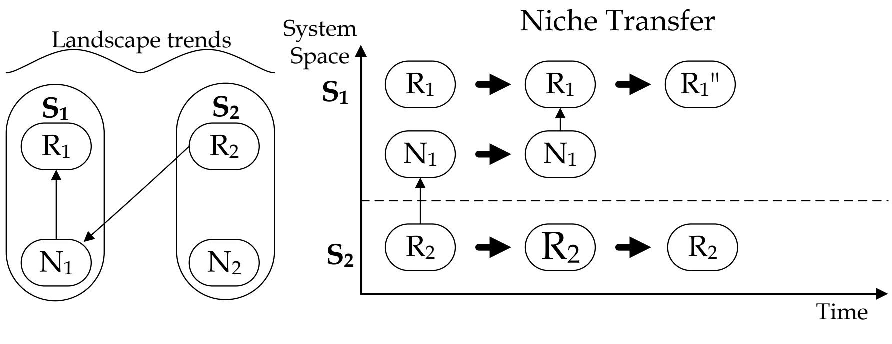

Figure 2 System Interaction type 1: Niche Transfer

In the second type: *niche interference*, an external niche (N_2) influences an already existing niche (N_1) within the focal system S_1 or a new one is created (Figure 3). Depending on the nature and timing of interactions with R_1 the niche can be: (i) absorbed by the regime, if the interactions are reinforcing irrespective of timing. The corresponding illustrative case is the transformation of American factory production Geels, (2006b), (ii) it can replace the regime, if the interactions are competitive and the timing is right i.e. the niche is developed and pressures from landscape and internal tensions in the regime create a window of opportunity. The illustrative case is the transition from sailing ships to steamships (Geels, 2002), or (iii) it can dissolve if there are competitive interactions. The illustrative case is the transition from horse-drawn carriages to automobiles (Geels, 2005b).

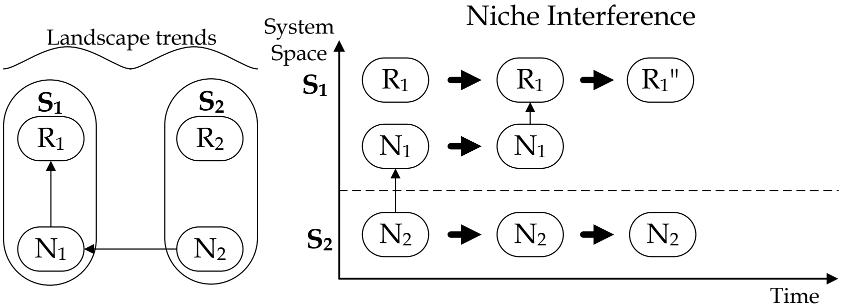

Figure 3 System Interaction type 2: Niche Interference

In the third type: *niche autonomy*, developments in S_1 are independent from any external system S_2 (Figure 4). Depending on the state of internal niche(s) (N_1): (i) some technologies may develop and eventually be absorbed by the established regime. The illustrative case is the breakthrough of rock 'n' roll (Geels, 2007b), (ii) if the technology is competitive then the established regime can be substituted if the timing is right i.e. if the niche is sufficiently developed and if a window of opportunity arises. The illustrative case is the transition of aviation systems from propeller to turbojet (Geels, 2006c), (iii) if the technology is superseded by others then it may dissolve. The illustrative case is the ongoing energy transition of the Dutch electricity system (Verbong and Geels, 2007).

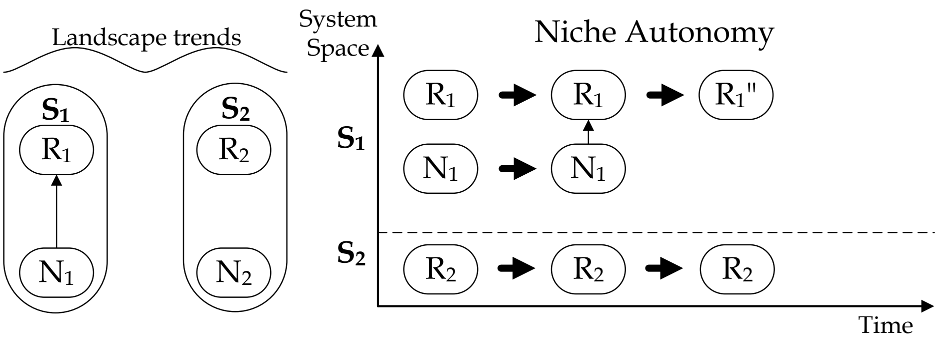

Figure 4 System Interaction type 3: Niche Autonomy

Finally, in the fourth type: *niche emergence*, a new system emerges initially as a niche (N_3) from the contribution of two or more systems (Figure 5). For this to happen interactions have to be reinforcing. Their timing is also important as the systems have to be under pressure and possess sufficiently developed and complementary capabilities in order to contribute successfully to the emergence of the niche. Illustrative case studies of this type are: the emergence of functional foods (Papachristos et al., 2010) and the emergence of the computer regime (Van den Ende and Kemp, 1999).

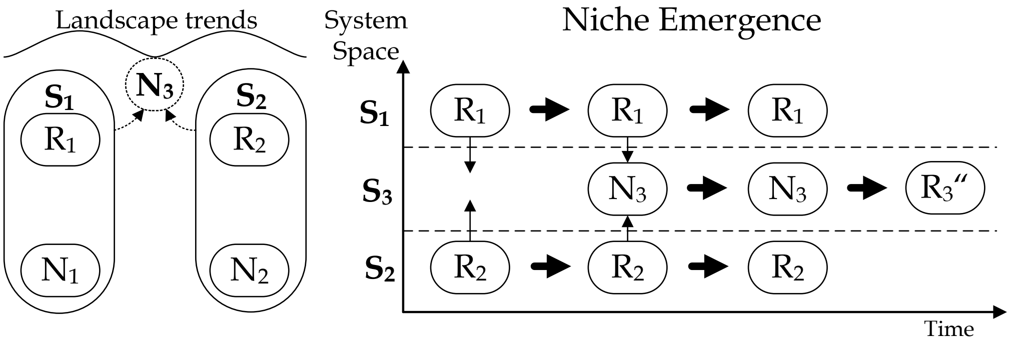

Figure 5 System Interaction type 4: Niche Emergence

Three remarks need to be made with respect to these types of system interaction. First, the fourth interaction type allows for a change in the number of systems with time. Depending on the nature of system interactions, there can be a simple transfer of technology or social influence from one system to the other (as shown in Figures 2 – 5), or if the nature of reinforcing interactions is such, one can be absorbed by the other. This allows for an increase or decrease in the total number of systems in a particular area of consideration. This is a realistic possibility that the current MLP transition typology does not consider.

Second, the definition of system interactions in Figure 1 is consistent with the MLP framework. Consequently, its transition pathways can be derived from a combination of inter-system interactions, and the nature and timing of intra system interactions. Support for this argument can be found in published literature cases. For example, in the substitution pathway innovations developing in niches break through and substitute the dominant sociotechnical regime. This is accounted for by *niche autonomy* if it concerns an internal niche, or *niche transfer or interference* if it concerns technologies developed outside the focal system. Each time, the particular system interaction type will depend both on the specific context and phase of the transition. Therefore, a transition case may correspond to a single transition pathway and at the same time to one or more system interaction types. A complete listing of all the analysed cases, and their related transition pathways and system interaction types is provided in Table 1.

While it is possible to relate each transition to a single system interaction type (Table 1), it is not possible to establish a one to one correspondence of system interactions with transition pathways in the same way that the nature and timing of interactions relate to them. For example, looking at Table 1, niche interference can be related to cases of reconfiguration

(Geels, 2006b) or substitution (Geels, 2002) depending on the nature and timing of interactions. It is hard to make any general definitive statements about transition pathways as only one case of substitution and one of de-alignment re-alignment were considered, and in both cases the system interaction type is 2: Niche interference. It is plausible that cases with similar transition pathways entail a different system interaction type.

What is possible to infer from Table 1 is that processes of transformation or reconfiguration are possible with some outside influence (niche transfer and niche interference) or without outside influence (niche autonomy). This confirms that the analysis and the concept of system interactions does not deviate from the original definitions of the MLP transition pathways despite the fact that the latter concerned single system transitions. They simply provide an extension to it. It also implies that in future MLP analyses, it might be worth paying more explicit attention to the inside/outside dimension in order to refine and/or complement the descriptions of the MLP transition pathways with an explicit account of the system interactions that take place.

Case Title	**Reference**	**System Interaction**	**Transition pathway**
The hygienic transition from cess pools to sewer systems	Geels, 2006a	Niche Transfer	Transformation
An analysis of the Dutch highway system	Geels, 2007a	Niche Transfer	Transformation
The emergence of the computer regime	Van den Ende and Kemp, 1999	Niche Emergence	Emergence
The transformation of American factory production	Geels, 2006b	Niche Interference	Reconfiguration
The breakthrough of rock 'n' roll	Geels, 2007b	Niche Autonomy	Reconfiguration
The ongoing energy transition of the Dutch electricity system	Verbong and Geels, 2007	Niche Autonomy	Transformation
The transition from horse-drawn carriages to automobiles	Geels, 2005b	Niche Interference	De-alignment re-alignment
Combined heat and power technologies in Netherlands	Raven and Verbong, 2007	Niche Autonomy	Reconfiguration
The transition of aviation systems from propeller to turbojet	Geels, 2006c	Niche Autonomy	Transformation
The transition from sailing ships to steamships	Geels, 2002	Niche Interference	Substitution
The transition in water supply and personal hygiene in the Netherlands	Geels, 2005c	Niche Autonomy	Transformation
The co-evolution of waste and electricity regimes in the Netherlands	Raven, 2007	Niche Transfer	Emergence
The transition from mixed farming to intensive pig husbandry	Geels, 2009	Niche Transfer	Transformation
The emergence of functional foods	Papachristos et al., 2010	Niche Emergence	Emergence
The use of ICT in car sharing	Papachristos, 2011	Niche Transfer	Transformation

Table 1 List of transition cases, pathways and types of system interactions

6. System emergence: A new transition pathway

Drawing on the cases presented, the sociotechnical system interaction types introduced in the paper conceptualise in a consistent manner the inside-outside aspect of regime changes and help to further structure the analysis of transitions by assigning system interaction types to each case (Table 1). In addition, the analysis of the transition cases leads logically to the possibility of niche emergence outside of existing systems and an extension to the MLP. The proposed new transition pathway adheres to the two criteria of nature and timing of interactions and is illustrated in the cases of functional foods (Papachristos et al., 2010) and the emergence of the computing regime (Van den Ende and Kemp, 1999). There are some common patterns in these cases: the importance of old regimes for the development of a new system, the influence of specialised applications on the new technology, and the development and utilisation of complementary technologies and new skills. These cases provide support for the *new system emergence* transition pathway defined below:

When two or more stable regimes face landscape and/or internal pressures, due to limiting returns to development and/or intense competition, it might be impossible to look for solutions in internal niches that will provide for increasing, pending or diversifying societal needs. As long as the regimes serve some societal function, they will not disintegrate (as in the dealignment-realignment transition pathway). Then, contingent on the nature of the technologies that each system harbours, it is possible for them to "vent pressure outwards" and for a new system to grow on the fringes of, and be shaped out of the interactions of existing systems.

The degree to which the new system is compatible with aspects of its 'parent' systems depends on the degree to which it provides solutions to the problems they face. For example, the digital computer system had to maintain some aspects of compatibility with the punch card regime, data handling procedures and with the existing supplier–user relations. There was also pressure from users that wanted digital computers to be as compatible as possible to their practices. Similarly, functional foods had to be compatible with aspects of the food system like food texture, taste and look and utilise its distribution channels. The latter proved to be instrumental for their successful diffusion process.

7. Discussion

Drawing on the cases presented, the interaction typology introduced in the paper conceptualises the inside-outside aspect of regime changes and helps to further structure the analysis of transitions by assigning system interaction types to each case as illustrated in Table 1. This increases the analytic power of the MLP, particularly with regard to sustainability and future oriented case studies. These differ from historical MLP case studies as the current systems of transport, energy and power generation, include a multitude of ‘green’ niche innovations (Geels, 2010). This characteristic multitude of ‘green’ innovations can be addressed with the introduction of system interactions and an additional transition pathway.

These enhance the ability of the MLP to tackle present day issues such as sustainability and ongoing transitions, which requires a shift from single regime, single technology approaches to multi regime, and multi technology interactions (Geels, 2011; Raven, 2007; Konrad et al., 2008; Geels, 2005a). Such examples of present day ongoing processes include: (i) combined heat and power (CHP) applications, in which the co-generation of heat and power links heat and electricity regimes, (ii) the production of biofuels which links the agriculture, energy and transport regimes, (iii) battery-electric or plug in hybrid vehicles which link road transport and electricity supply regimes, and (iv) natural gas and the development of cleaner alternatives.

The grounding of the research in a wide range of transition cases ensures that system interactions are consistent and complementary to all of the transition types already postulated by Geels and Schot, (2007). Therefore, system interactions together with nature and timing of interactions, constitute a more complete framework for analysing transition cases that is consistent with current theory. All of the standard MLP transition pathways plus the one proposed in this paper, can be obtained from a combination of system interaction types, and the nature and timing of intra system interactions.

The use of a wide range of historical cases of completed transitions and contemporary case studies of ongoing transitions, provides the necessary generality to the proposed concepts while retaining the simplicity of the MLP framework. Furthermore, the cases that were analysed include that of Raven and Verbong (2007). Hence, the proposed system interaction types account for the possibilities outlined in their framework, therefore it enhances the explanatory power of the MLP. More importantly the knowledge systematization process revealed the necessity to introduce an additional pathway in the transition discourse which has not been discussed so far.

Clearly, the case of functional foods adheres to this pathway and cannot be analysed in terms of the multi regime interaction framework of Raven and Verbong (2007) where niche emergence as a result of inter system or inter regime interactions is not accounted for. Their framework has been derived from a single case study which differs from functional foods at a fundamental level. It concerns the systems of electricity and natural gas that can in principle fulfil both heating and power generation functions interchangeably. Therefore, interactions between the two regimes seem inevitable as the production of power in any form, releases heat that can be recovered and utilised. It is a case where differences are at the level of regimes and in the form of energy supply, rather than at the level of system and the social need they supply, which is the defining characteristic of sociotechnical systems. The authors acknowledge this fact, and suggest that future research should focus not only on emerging innovations, but also on socio-technical regimes.

The case of functional foods is an example of niche emergence and differs from other cases of multi regime interaction. This case along with the case of Van den Ende and Kemp (1999), provide support for the proposed additional transition type: new system emergence. Consequently, it is not possible to categorize it under any of transition pathways of Geels and Schot (2007) because these concern single system transitions. The functional foods case can be described and analysed only in terms of system interactions and the nature, and timing of inter system interactions.

In the case of functional foods, this involves two ‘parent’ systems, food and pharmaceuticals. A new niche system emerges out of the combination of resources, technologies and competences that each ‘parent’ system possesses and contributes, acting in effect as an outsider to the other one (Van de Poel, 2000). This comes as a response to a new societal need. The example has the following interesting features: neither the new technology nor the market were protected or regulated at their infancy (in fact regulation is still an issue), and the new system does not replace any of the ‘parent’ systems. They coexist without any of them decaying or disappearing in the near future as each one fulfils a distinct societal need. The food regime fulfils the need of human nutrition, the pharmaceutical regime that of medicine discovery and supply, and the functional food niche the emerging need for proactive/health enhancing nutrition.

Therefore it is necessary to add to the MLP pathways the *new system emergence* pathway which has been derived from the fourth system interaction type, niche emergence. This type of transition is also helpful towards framing better the transition to the computer regime which seems difficult to place under any of the existing transition types (Van den Ende and Kemp, 1999). It is not a historical case study and as such it provides further evidence that transitions in the modern era concern multi regime interactions to a greater extent.

The proposed extension to the MLP maintains the same level of complexity with the original framework, as it is firmly based on the same pool of documented historical and contemporary cases. At the same time, it has a broader scope hence it constitutes an improvement with higher explanatory power (Weick, 1979). The proposed interaction types and the additional transition pathway also contribute towards answering some of the criticism that the MLP has received about its focus on single regime transitions (Genus and Coles, 2008; Smith et al., 2005). By emphasising multi regime interactions, the proposed interaction types explicitly allow for transitions that do not originate in internal niches. System interactions thus address this issue by emphasizing the horizontal aspect of interactions in each transition pathway between a system and its wider context.

The integration of an additional transition type to the MLP also places an emphasis on the possibility of parallel developments taking place outside the system of analysis, that influence it or that result in the emergence of new niches. Finally, it prompts for an explicit treatment of internal and external regimes and niches to a system, thus also providing some impetus ground for a more systematic application of the MLP framework. Therefore, in addition to analysing the timing and nature of interactions, transition analysis should clearly identify the focal system and regime of analysis, the regimes and niches that are internal to the system and those that are external and influence the transition it undergoes.

An attempt to integrate system interactions with the original MLP into a more coherent whole was not possible. Despite the numerous reviews and analyses of the transition cases, it was not possible to establish a one to one correspondence of system interactions with transition types in the same way that the nature and timing of interactions relate to them. Thus it is plausible that future cases of similar transition pathways may entail a different system interaction type. In retrospect this outcome provides further evidence for the multitude of ways in which a transition can unfold. It reinforces the notion that transition paths cannot be forecasted or anticipated in any significant way. Had it been otherwise, it would be possible to support the claim that once a system was known to be on a particular pathway and interact with other systems in a particular way, it could be possible to anticipate its trajectory and steer it by modulating interactions with external systems.

8. Conclusions

This paper has proposed and discussed the concept of sociotechnical system interactions and a new transition type based on a review of historical and contemporary transition cases and the addition of a new case that concerns multi regime interactions: functional foods. There were several motivations for this research: the need to broaden the MLP framework, the constructive criticism that it has received and the desire to devise a satisfactory explanation for the emergence of functional foods. These have led to the concept of system interactions and the additional new system emergence pathway. The resultant extension to the MLP is better equipped to explicitly address multi regime and multi system interactions, in a way consistent to the original framework.

The four types of system interactions were inferred through a review of published and unpublished case studies of transitions. Their association with the typology of transition pathways provided support for the introduction of the new transition pathway. They also constitute a response to some of the criticism that the MLP framework has received and an answer to the call for developing further the MLP towards meeting the needs of multi regime analysis and increasing its analytical reach, something necessary for addressing sustainability transitions.

While currently there are few case studies of multi regime interactions, the increasing trend of hybrid technology development and its use beyond its initial intended domain of application, makes boundary definition difficult but necessary. The cases presented in the paper justify the notion that multi system, just as multi regime dynamics, matter in the emergence of innovations within existing regimes and in the emergence of new systems. Hence, multi regime and multi system interactions must be at the forefront of transition research. The introduction of the system interactions concept is a step in this direction. It shifts the emphasis to the inside/outside dimension in future MLP studies and could potentially lead to refinements and/or additions to the descriptions of the MLP transition pathways.

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