The 5th International Conference on Sustainability Transitions
27 – 29 August 2014, Utrecht, the Netherlands

Towards an integrated conceptual framework for understanding transition dynamics

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Abstract: There are several explanations for the dynamics of transition in terms of theories and frameworks. While they describe the same phenomenon, the concepts and processes that they use to explain the dynamics are varied. Some are at different levels of aggregation including dynamics in micro-level actors' behaviours, meso-level emerging systems' formation, and macro-level existing systems' interactions. This theoretical disparity, as advocated in literature, can be a pitfall in understanding the dynamics. This paper reviews the theoretical concepts and processes and explores their strengths and limitations in describing transition dynamics. It also attempts to identify the complementary features that address their individual limitations. For all approaches reviewed in this study, central questions include: what changes occur during the transition, when it happens, why it takes place, and how it appears. The assessment of theoretical approaches is a step towards developing an integrated conceptual framework for the improved understanding of transition dynamics.

Keywords: Transition dynamics, Multi-level perspective, Socio-technical transition, Pillar theory.

1. Introduction

'Transition studies' is an emerging interdisciplinary field that addresses an analytical challenge: the transformation of complex adaptive systems with nested multi-levels of determinants, composite of several subsystems, and with self-organising and co-evolutionary qualities. The concept of transition in this field has been approached from different perspectives, most importantly, from the role of governance in *Transition Management*, the conceptualisation of change process in *Multi-Level Perspective (MLP)*, the formation of new systems in *Technological Innovation Systems (TIS)*, and the role of experiments and infant innovations in *Strategic Niche Management (SNM)*. It has also come under different terms, e.g. technological transitions [1], societal transitions [2], technological revolutions [3] and regime transformation [4]. What is common to these perspectives and terms is that they conceptualised transition in continuous processes of change, in other words, they lean to study 'the dynamics of transition', instead of just a static picture of initial and new system's states.

The understanding of dynamics is used in historical transitions for gaining insights from development in the past and in ongoing transitions for doing exploration and policy analysis for the future. Because of the importance of dynamics in transition studies, several researchers have tried to understand them from different aspects (i.e. institutional, socio-ecological, and socio-technological transitions [5]), at different levels of aggregation (i.e. micro as underlying mechanisms, meso as functional interactions, and macro as patterns of transition), at different scales (i.e. diffusion of innovation in a system and a broader sectoral transition), and based on different social science ontologies [6]. As Holtz [7] identified, there is a clear theoretical disparity in studying the dynamics of transition in terms of what changes during transition, when it happens, why it takes place, how it appears, and the existing theories do not cover them all together. An improved understating of dynamics can be achieved if the relations between the definitions from different aspects, levels, scales, and ontologies, proposed in the literature, are clarified. How are different theories related to each other? To what extend are they complementary in explaining dynamics? To answer these questions, this study aims to review existing theories[1] on dynamics of socio-technical transition and to compare their strengths and limitations. The review will form a ground for an integrated conceptual framework that brings an improved understanding of the dynamics of socio-technical transitions. More specifically, it can be the dynamics in transition from fossil towards renewable power systems which will be assisting in energy policy making.

The paper is structured in five sections. After the introduction, a brief review of concepts and processes of change in different theories is presented (Section 2). Section 3 deals with the comparison of the theories and highlights their strengths and limitations. Based on the acquired insights from this comparison, a tentative integrated framework is presented in Section 4 as the first step for an improved understanding of dynamics. At the end (Section 5), brief discussions on the most promising ways for future research to strengthen the integrated framework are provided.

2. Theories on the dynamics of transition

2.1. Multi-level perspective

Among the theories, MLP is the most well-known one which has been an inspiration and a foundation for many researches. Based on the previous works by Kemp [8], Rip and Kemp [9] and Kemp et al. [10], Geels [1] integrated concepts from evolutionary economics and technological studies to describe

[1] As their aim, scope, and methods of researches are varied, they are named differently including conceptual framework, perspective, approach, and theory. To prevent confusion, they are generally referred with a single term 'theory' in this study.

how transitions appear at the macro level of the dynamics (e.g. patterns and pathways of transition). The study conceptualised socio-technical transitions in three nested and analytical levels of change, including niche, regime, and landscape and named this way of approaching transitions as MLP (see Figure 1). *Regime* is the established system with tangible and intangible configurations that creates stability in the current system and performs the selection function during change process. *Niches* are places protected from the pressure of regime, for radical novelties and variety creations, and mainly run by small network of outsiders. *Landscape* contains slow changing external factors, or 'deep structural trends', rooted in exogenous environment such as macro-economic, political decisions, or environmental problems. Landscape forces impact the regime and niches while forces are not easily affected by them.

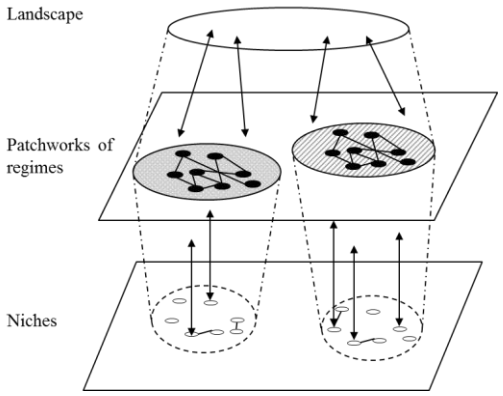

Figure 1. Landscape, regime, and niches in MLP (adapted from [1])

MLP defines transition as a change from one socio-technical regime to another, so the focus of transition is mainly on regime. As a result, the dynamics are conceptualised in the interactions of regime with niches and landscape. The alignment of development processes in three levels or as it interprets, the creation of *'window of opportunity'* is the core condition for transition. In other words, timing and the nature (i.e. reinforcing or disruptive) of landscape forces on regime with respect to the maturity and nature (i.e. competitive or symbiotic) of niches' pressure determine the conditions for emergence of transition. Based on an inductive case analysis, Geels and Schot [11] believe the dynamics unfold in five different pathways: *reproduction process* that leaves the system in dynamic equilibrium and happens when no niche innovation is present and landscape is in support of regime (reinforcing); *transformation path* that gradually modifies the functioning of regime when landscape is moderately disruptive while no aggregated and mature niche still exists; *de-alignment re-alignment* that destabilises regime and waits for the dominancy of an alternative when there is a highly disruptive forces from landscape and multiple co-existing niches competing with one another; *technological substitution* that pushes a mature niche and replaces regime when both high landscape forces and developed niche are simultaneously present; and *reconfiguration pathway* that changes regime gradually by symbiotic niches.

2.2. Pillars theory

As it appears from the name, pillars theory bases the understanding of dynamics on three pillars, namely *conditions* that drive transitions, *patterns* that describe their shape of emergence, and *paths* that depict their sequence from initial to new state of a system. Pillars theory has been developed through theoretical deductions by de Haan [12], and it is mainly a macro-level explanation of dynamics (i.e. focusing on patterns and pathways).

According to this theory, transition is a process that profoundly changes the way a societal system fulfils societal needs. The societal system is supposed to be composed of nested subsystems known as *constellations* (see Figure 2) and the way they fulfil societal needs is called *functioning*. During a transition, a constellation, whose functioning is dominant, changes and alternative constellations gain power. The change in functioning is described with building blocks of dynamics known as *patterns*. The main idea of pillars theory is to understand transitions as a concatenation of patterns.

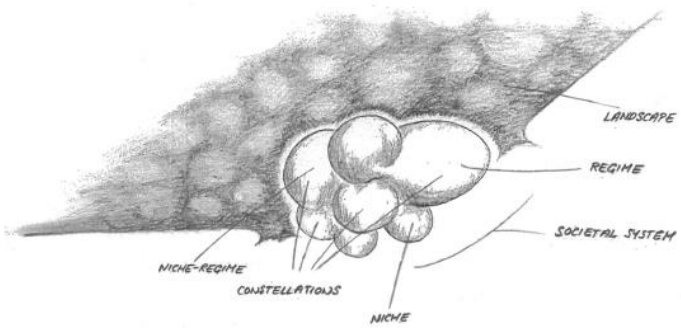

Figure 2. Composition of a societal system [12]

By definition of constellations and the process of transition, de Haan and Rotmans [2] describe conditions, patterns, and pathways as follows:

Generally, transitions begin to take shape when the functioning of systems is compromised. It can be caused by three conditions: the first is the mismatch between inflow and outflow of the dominant constellation and the environment encompassing it, which is called *tension*. The second comes from the interplays of different facets of functioning in the dominant constellation, when they make hindrance to others, which is called *stress*. The third is about the pressure of an alternative functioning to the dominant one, which is called *pressure*.

Three patterns in transition can be identified in terms of change in power of constellations as conditions exist. The first pattern is *reconstellation*, and it is referred to the situation where a constellation emerges or gains power from outside. It can be caused by a tension or stress condition. The second is the situation where a constellation emerges or gains power from inside. This pattern is probable in the condition of pressure and stress, and is referred to as *empowerment*. Finally, the dominant constellation may absorb innovation, co-evolve with others, and incorporate alternative functions. This is called *adaptation* pattern and it may develop through the impact of all three conditions.

Having conditions and patterns defined, transitions' paths are described in a sequence of initial system's state (constellations and conditions), patterns of transition, and new system's state. Based on the dominance of pattern and the role of current established constellation, 11 transition's paths can be postulated. First, when the dominant pattern is reconstellation, regime may be reformed according to an outside constellation which is called *radical reform*, constellation outside the regime may replace the incumbent regime which is called *revolution*, or transition may fail and leave the system in chaos which is a *collapse*. Second, when the path is empowerment-dominated, niches can be gradually adapted in regime which is a *reconfiguration* pathway, niches can turn to empowered niches and overthrown regime which is a *substitution*, or an early hype in niches' expectation vanishes and leads to a *backlash*. Third, there may be also some squeezed paths with both empowerment and reconstellation dominancy. In such situations, regime may take advantage of bottom-up niche

pressure to handle top-down outside tension and to modify itself which is called *teleological* path, if incumbent regime does not have a role in future system, it will be turned to an *emergent* path, and if niche innovations at the bottom cannot satisfy the top-down tension and change regime, it will be *lock-in* path. Fourth, if transition is adoption-dominated pattern, the regime may gradually face *transformation* or in the failed situation, a *system breakdown* may take place.

2.3. Technological innovation systems

Contrary to approaches that discuss the dynamics of interactions among the established system, emerging systems, and external environment, other approaches exist with attention on the meso-level dynamics in systems' formation. These approaches are known as *innovation systems* [13], and the one that is more relevant for explaining the dynamics in socio-technical transitions is *TIS* [14, 15]).

The main part of researches in TIS locates the dynamics from functional perspective, narrows it down to just what drives the formation of a new system, and does not discuss the interactions with the established system and external effects. TIS, as a meso-level description of dynamics, proposes a set of internal processes required for system formation, known as *functions*. Pursuing the innovation process or, in other words, generation, diffusion and utilization of innovations are thought to be as main functions of TIS [15]. Hekkert et al. [16] expanded the concept of functional perspective in dynamics and introduced seven functions, including entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilization and creation of legitimacy. Functional fulfilments are required for system's formation.

In addition to fulfilment of functions, the interaction between them also creates a momentum for fostering the dynamics. TIS frames the interactions by a concept known as *motors of innovation* [17, 18]. They are actually groups of interacting functions which create reinforcing loops in emerging systems and build them up (see Figure 3). Four motors of innovation have been identified from inductive case study researches: science and technology push (STP) motor for hastening research and development and reducing scientific uncertainties; entrepreneurial motor for transforming the developed knowledge to innovation, system building motor for systemising the formation process; and market motor for turning demand-push development to market-pull one [18-21].

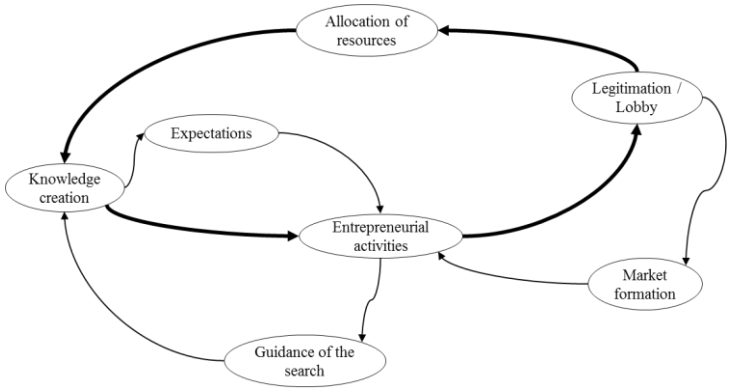

Figure 3. A sample of interactive functions and reinforcing loops (adapted from [16])

2.4. Actor-option framework

The conceptualisation of dynamics in actor-option framework is fundamentally different from the theories discussed till now since it is about the micro-level description of dynamics (i.e. underlying mechanisms). In this framework, actors and their decisions regarding available options to satisfy

societal needs are considered as drivers of change (see Figure 4). Therefore, what bring dynamics in transition process are changes in the behaviour of actors (their choice in supporting or opposing options) as well as changes in the environment of options (the properties of options).

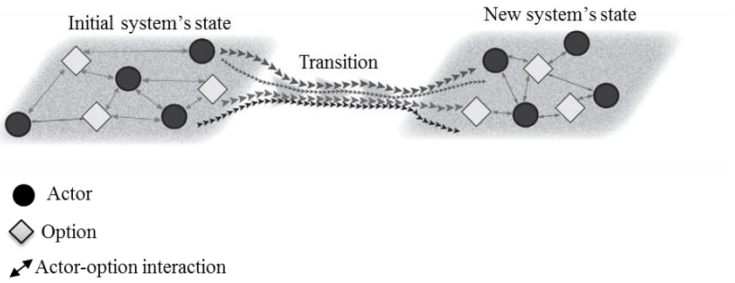

Figure 4. The conceptualisation of transition [22]

Based on this idea and in a process of induction from case studies and deduction from theories, Yucel [22] identifies three main mechanisms of changes bringing dynamics into transitions:

The first mechanism is related to change in options' properties themselves. By option's property, it means techno-physical features of an option referred to as embodied properties as well as practical and provisional features referred to as disembodied properties. This group of mechanisms can be driven externally or internally. External mechanisms are exogenous-driven spillovers of embodied or disembodied properties. On the other hand, internal mechanisms are endogenously driven and they include: experience-driven changes caused by cumulative experience of actors in practical and provisional ways; scale-driven changes caused by up scaling of utilization or provision of options; and resource-driven changes which are purposeful resource allocation to options, methods of provision, and capacity of provisions.

The second mechanism is related to change in actors' perception. Changes in understanding of actors from options and their properties alter the interactions between actors and options, and subsequently the dynamics of transition. This is actually dynamics in perceived information[2]. It can be driven in three ways: by individual learning from direct observation of actors or their experience from properties of options; by social learning from diffusion of information or learning of other actors' knowledge; and by external source of learning from media, published reports etc.

The third mechanism is related to change in actors' behavioural identity. These mechanisms bring dynamics into the values and assumptions of actors[3] in decision making, and subsequently change the interactions between actors and options. They can be driven in three ways: the first is by reference formation which refers to the change in ideal (or expected) options' properties and caused by outside regulations or social influences; the second is by commitment formation which refers to the change in their inertia in moving towards new options; and the third is preference change which is the change in the priority of issues and suitability of options' properties. All of them are factors reflected in decision making and change actor-option interactions as the driver of dynamics.

2.5 Methods and Tools for Integrated Sustainability Assessment (MATISSE) model

MATISSE model was developed as an improvement to the tools available for conducting Integrated Sustainability Assessments in EU policies [23-25]. It represents the dynamics of transition by

[2] Known as first-order learning.
[3] Known as second-order learning.

focusing on the path, from one equilibrium to another, and to use agent-based representation for framing this path. In this regard, it supposes actors as individual agents creating support, while niche, empowered niche, and regime as collective agents competing in transition, and landscape as signals affecting them. It defines transition as a sequence of agent transformations driven by support of individuals; a transformation from niche to empowered niche to regime (see Figure 5). MATISSE model therefore presents both micro and macro representations of the dynamics.

These agents are subsystems formed by structures and cultures, and characterised by practices. Structures are physical assets with ability to create resource and institutional capacities with ability to exert influence and attract support. Cultures are collective set of norms, values, and perspectives [26]. Practices are the accumulation of actions defining the characteristics of subsystems.

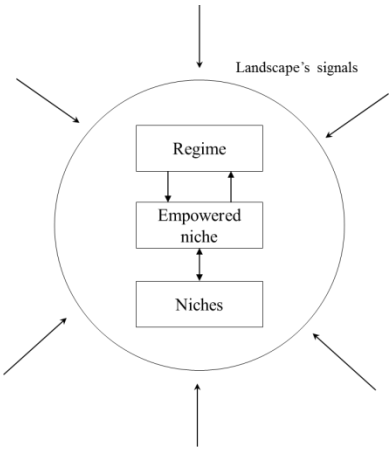

Figure 5.Subsystems interactions in MATISSE model (adapted from [23])

The dynamics that the MATISSE model describes for transition can be driven exogenously and endogenously. Endogenous dynamics are the result of coupling non-linear interactions between niche, empowered niche, and regime which are collective agents, and heterogeneous population of societal actors which are individual agents. On the one hand, individuals, in an analytical level called 'support canvas', make decision and create coalition to support niche, empowered niche, and regime based on their attractiveness. Such devoted supports are turned into the resource, and it builds the structure (physical and institutional) for collective agents. This bottom up process is called support mechanism. On the other hand, collective agents try to adapt their functioning to increase their share of support from individual agents too. The amount of support they gain depends on the institutional capacity of collective agents as well as their strategy (e.g. sticker[4], aggregator[5] etc. [24]). Exogenous dynamics is coming from the effects that landscape forces on agents, such as key policies and regulations. Landscape forces as macro-level signals change the individual agents' preferences, and subsequently influence their decisions on supporting collective agents.

Based on the explained micro-level dynamics, transition from macro-level is constructed using three concepts: *mechanisms*, *patterns*, and *pathways*. Mechanisms are societal processes and building blocks of dynamics which have been extracted by historical case study. They include niche-to-empowered niche, empowered niche-to-regime, emergence of niche, growth of subsystem, clustering of niches, adaptation in resource, adaptation with maintenance of practice, adaptation with change in practice, adaptation with absorption of niche by regime, adaptation with competition with regime [23]. The sequence of these mechanisms forms transition patterns, which are based on what was

[4] Never change functioning.
[5] Moving toward the mean ideal point of all individuals.

identified by Geels and Schot [11]: transformation, de-alignment re-alignment, technological substitution, and reconfiguration. Finally, the description of patterns plus a set of starting and ending point of system's states constitute transitions pathways in this model.

2.6. The multi-stage framework[6]

The multi-stage is a conceptual framework developed by Frantzeskaki [5], in order to understand the dynamics of transition at macro-level and to use it for deriving governance propositions. According to the framework, transition is defined as a cyclic evolution of slow and fast dynamics in a continuous transformation process. The transformation process in long term can appear with different patterns depending on institutional, socio-ecological, and socio-technical contexts of transitions.

Frantzeskaki [5] defined three key concepts for the framework. The first is the structure of the societal system which changes during transition and consists of environment, technology, civil society, and institutions. Second is the stage of transition as evolution cycles of a system and where the system is in a dynamic equilibrium. Stages can be characterised by novelty with an aim to bring a new constellation (genesis), by stability with an aim to settle down competition (stasis), and by rapid changes with an aim to break down the old regime (metastasis). The third is forces as conditions driving transition toward the stages. Forces such as the presence of a new practice, new niches, or new social demand that move the system toward the genesis stage are formative. Those such as standardisation of practices, provision of resources, and exercise of power that push the system toward stasis stage are supportive forces. Forces such as system failure, crises, and exogenous events which make the system uncertain (and shift to metastasis stage) are triggers.

By grounding the concepts in theoretical and empirical researches, the different patterns of dynamics are reconceptualised for institutional, socio-ecological, and socio-technical transitions. The patterns are defined by feedback loops and relations between stages. For example when there is a socio-technical transition, two feedback loops and one relation are expected to form (see Figure 6). The relation is known as 'demand-pull bypass' which refers to a situation that a new demand in stasis stages drives innovation in genesis stage. The first loop is known as 'institutional restraining loop' which hamper innovations opposite to the current institutions. The second loop is 'technology lock-in loop' which is the reluctance of old technology toward appearance of new ones Similar patterns are also defined for different transitions [5]. Similar feedbacks and relations can also be defined for institutional and socio-ecological transitions.

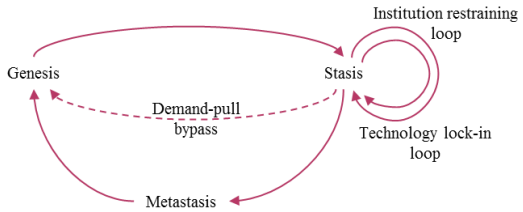

Figure 6. Evolution stages and feedback loops in socio-technical dynamics (adapted from [5])

3. Comparing and contrasting theories

In this section, the theories presented are compared and their strengths and limitations are examined. The theories can be contrasted based on the aggregation level of dynamics that they study [5]. At

[6] It should be noted that the name of multi-stage framework was selected by authors (and not by its developer, Niki Frantzeskaki) based on their stage-oriented definition from transition.

macro-level, the dynamics are discussed by the possible patterns of transition in terms of interactions between new systems' formation, old regime's destabilisation, and external influences. MLP, pillar theory, multi-stage framework and to some degree MATTISE model explain the dynamics at the macro-level. At the meso-level, the intra-system dynamics are discussed by the functional interactions that form an emerging system, no matter how it interacts with the current regime. TIS is an approach which analyses the formation of a system. At micro-level, the functionalistic approach changes, and dynamics in actors' behaviours and system's structures are studied. Actor-option framework and MATISSE model are two examples of this group. The following strengths and limitations can be discussed for the reviewed theories based on their aggregation level.

Actors and micro-foundations of dynamics

One of the criticisms usually raised in some theories is their functionalistic approach and lack of attention to underlying mechanisms in describing the dynamics. MLP, as Smith et al. [27] discussed, is one of them. MLP has mainly a functionalistic approach and does not provide a clear explanation of the role of agencies, their behaviours and actions in dynamics of transition[7]. Agents' decisions and their actions are underlying reasons for explaining the pathways already described, so ignoring them leaves the micro-foundation explanation of dynamics untouched in MLP. Multi-stage framework and to some extend pillars theory suffer from not fully dealing with micro-foundations as well. A major limitation that is attributed to multi-stage framework is its over-functionalistic and macro-level approach in describing the dynamics. It defines dynamic equilibriums in systems based on their functioning; the functioning of creating variety for genesis stage, bringing stability for stasis stage, and putting into disturbance for metastasis stage. It also explains formative, supportive and triggering forces based on a functional approach on actors' action and their impacts on the system. Similarly in pillars theory, the explanation on the role of agents and their power which drive the patterns and pathways of transitions is still lacking. Although it has been stated that change in the function of the dominant constellation takes place through change in structure, culture, and practice, the mechanisms of change have not been elaborated.

The missing link to micro-foundation dynamics is covered in actor-option framework. It presents a micro-level conceptualisation of dynamics in terms of actor-option's interactions and takes into account the role of agents and their decision in transition[8]. MATISSE model also benefits from this strength and provides a clear portray of micro-foundation mechanisms or as they call 'metabolism' driving transitions. The metabolisms can link the roles of structure, resources, actors, and their support to patterns and pathways of transition. In a system formation (and not with its interaction with other systems), TIS is another approach that investigates the role of actors and their strategies [28], the networks and available resources [29, 30], and formal and informal institutions [31, 32].

Inter-systems and Intra-system dynamics

In addition to micro-level dynamics already discussed, the dynamics can be explained from meso and macro levels; the meso-level includes internal processes of emerging systems' formation (intra-system) and the macro-level deals with the transitional interactions among external environment, regime and emerging systems (inter-systems). There is insufficient discussion at meso-level, on the processes/mechanisms that form and scale up niches to the new regime and those that destabilise and destroy the old regime in existing theories. This is close to the discussion of Markard and Truffer [33] on the weak explanation of the dynamics at the niche level. MLP only talks about the dynamics

[7] However, Geels later discussed this criticism [11] and also rejected the functionalistic label to MLP [6].

[8] However, the framework does not discuss over the patterns and pathways coming out of explained underlying mechanisms and leave a room for more works on functionalistic perspective of dynamics.

coming out of interactions between levels and does not clarify their internal formation of systems. Although the formation process have not been discussed in MLP, internal dynamics for destabilization of regime have been recently addressed by Turnheim and Geels [34]. This limitation is the same for pillars theory, multi-stage framework, and actor-option framework. Pillars theory does not discuss the internal dynamics of constellations, especially how they internally rise or fall in power. Multi-stage framework examines the overall state of the system in slow and fast dynamics and does not specifically talk about formation processes in each system. Actor-option framework also sees actor-options interactions in transition, no matter how their effects contribute to system formation or interactions.

On the other hand, TIS basically captures the formation dynamics of systems through functional interaction, so it can be exploited as a complement to what MLP, pillars theory, and multi-stage framework define as dynamics. MATISSE model also practically discusses the dynamics in subsystems in addition to the dynamics of interactions by the idea of the endogenous dynamics of agent formation. However, this idea is a discussion more about the structural side of dynamics and not the functional side in terms of shapes and patterns of interactions.

Top-down and bottom-up transitions

The direction of transition, in terms of the emergence of new system from niche innovations or from the landscape, is another debate between different theories dealing with inter-systems dynamics[9]. A criticism was raised by Berkhout et al. [35] about the leading role of niche in creating transitions in MLP. Although Geels [11] proposed that transitions take place by the alignment of landscape forces, regime disturbance and niche presence, they are seen as a way to create windows of opportunity where the pivotal role is still with niches and transition originates from the bottom. Overemphasis on niche innovations may distract the analysis from the main source of dynamics and deviate it from causes to effects.

There are some situations, as de Haan and Rotmans [2] explained, where the transition is driven by a mismatch inside the system, or by government-led support and landscape signals at macro-level. In this regard, in addition to niche empowerment, pillars theory also considers reconstellation and adaptation patterns of dynamics that are driven from outside and inside respectively. They are actually explanations for transitions happening in reality but not being led by niche innovations. Actor-option framework discusses the direct influence of external environment in addition to niche innovations when it refers to exogenous-driven spillovers changing options' properties, external sources of learning changing actors' perception, and outside regulations or social influences on reference formation changing actors' behavioural identity. The MATISSE model also takes into account the possibility of a transition driven not only from niches, but also from outside in two points. First, in exogenous dynamics, i.e. the influence of landscape forces on individual agents' preferences and subsequently on collective agents' support; and second in conceptualisation of mechanisms of transition where the possibility of top-down adaptation of regime by internal and external influences are taken into account. In multi-stage model, these are driving forces that define whether the direction of change is top-down, bottom-up or internal. In trigger forces, crises and exogenous events are from external environment and system failure is from internal system's stress. In supportive forces, transition can be led either from external environment by standardisation of practices, exercise of power, and provision of resources or from internal stress by self-regulation. In formative forces, the presence of a niche, new demand or new functions comes from the bottom while the imposition of new practices is from the external environment [36].

[9] So it is not relevant for TIS which only deals with formational dynamics.

Quasi-static and dynamic analysis of transition

de Haan and Rotmans [2] discussed the issue of conceptual simplicity that some theories such as multi-level perspective and TIS have in grasping the complexity of transitions. It was discussed that they can just provide a quasi-static picture (a snapshot in time) of dynamics. MLP and TIS see transition as one process with multiple changes and do not take into account the sequence of changes and stabilities in consecutive processes. The authors believe this is the same issue for actor-option theory too. However, in pillars theory, MATISSE model, and multi-stage framework, the dynamics are described through time and in different phases of transition. Pillars theory and MATTISE model are capable of describing and explaining the dynamics in a pathway of system's state, patterns, and the new system's state. Multi-stage framework also considers a circular process between stages of dynamic equilibrium. It discriminates between slow and fast dynamics and their respective mechanisms in a cyclic evolution process. The framework analyses fast dynamics as 'transformative processes' shifting the system and including driving forces as its mechanisms, and slow dynamics as 'metabolic processes' adapting the system with the environmental changes and including evolution stages with their relevant feedback loops.

Configuration of theories

The term 'configuration of theories' means the concepts created to explain the dynamics and the way it present the concepts. Among the theories, pillars theory has some advantages with this regard. First, it has a modular configuration consisting of conditions, patterns, and pathways. The advantage is that some parts of the theory can be easily modified or replaced from future theoretical, modelling, and empirical learnings, without putting an end to the whole theory in case they are found in contrast with parts of reality [2]. Second, pillar theory uses patterns of transition as a unit to explain dynamics. This allows for an in-depth analysis, with more detailed and flexible approach to describe dynamics in shorter timescales. Pillar theory also clarifies subsystems involved in transition by assuming a 'niche-regime', a constellation with ability to attack the regime. MATTISE model does the same clarification with a different name, 'empowered niche' and has commonalities with pillars theory in the agent-based conceptualisation of analytical levels and modular format for constructing transition pathways. Third, pillar theory accommodates the improper interactions and failed transitions in its typology of pathways. This is an important form of dynamics in developing countries where less stable long-term planning exists. MLP is somehow different in configuration: It is less modular than pillar theory in defining its main concepts; it does not define a separate analytical level of analysis between niche and regime and just implicitly refers to that by the accumulation of niches in existing applications (add-on and hybridisation) or in a new market; and it also does not consider situations when failed transitions happen.

Besides several configuration strengths for pillar theory, the way that it was constructed through theoretical deduction is a matter of concern. It leaves the framework of the theory speculative to some extent as their authors acknowledge, and demands to be empowered by some empirical evidence. Other approaches, such as MLP and TIS with induction from several empirical cases and actor-option framework and multi-stage framework with induction from theoretical backgrounds and grounding in empirical cases, do not have this limitation.

4. Bridging the gaps

As it can be concluded from Section 2 & 3, several theories conceptualise the dynamics of transition at different level of aggregations. These seemingly varied conceptualisations however are attempting to explain the same concept. Therefore, they can be linked together and thus provide an improved understanding covering their individual limitations. The inspiration for linking them together is

further strengthened when similar efforts of integration are found in other studies. Among them, Smith et al [27] stated the idea of incorporation of power and agency's role in MLP structure, Genus and Coles [37] brought the possible connections between MLP and constructivist approaches (e.g. social construction of technology), Markard and Truffer [33] argued an encompassing framework of transition by integration of technological innovation systems and MLP, plus several other similar researches (e.g. [38, 39]). Furthermore, Geels [6] also goes to the deeper levels of MLP and talks about the ontologies of social science research and the possible ways for extending MLP. Following the fundamental discussions of Geels [6] and inspired by the idea of an encompassing understanding of transitions, the integration and adaption of theories about the dynamics are sought in this section.

The multi-dimensional character of socio-technical transitions is understood with a multi-ontological perspective. This multi-ontological perspective is realised by a crossover position and bridging between ontologies, most importantly constructivism, functionalism, and evolutionary theory [6]. Moving towards an integrated conceptual framework, the dynamics are described here in a repetitive sequence of slow and fast dynamics; it starts with slow dynamics in initial system's state, continues with fast dynamics in the process of change, and ends with slow dynamics in a new system's state. This sequence is repeated and repeated again and creates transition pathways in long-run. Slow dynamics in system's states discuss about the dynamic equilibrium that constellations have in fulfilling societal needs, the conditions that signal the inability of constellations to properly satisfy societal needs, and the feedback loops that intensify the effects of these conditions. Conditions push the transition toward fast dynamics. In fast dynamics, the underlying mechanisms of change at micro-level, the systems' build-up or breakdown at meso-level, and the patterns of constellations' interactions at macro-level are discussed. The conceptualisation of transition dynamics is represented in Figure 7. The more detailed explanations the concepts and processes are presented below.

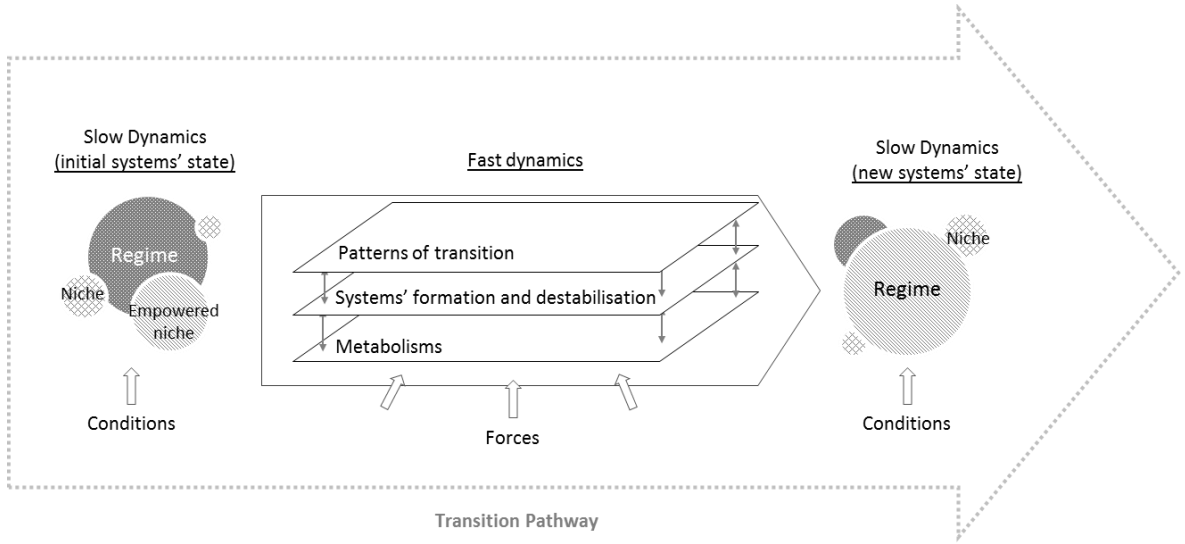

Figure 7. The conceptualisation of transition dynamics

Systems' state: How do systems in transition look like?

System's states, with slow dynamics, describe the object of change in transition. They can be described by the functional conceptualisation of pillars theory [12]. With this respect, a socio-technical system (e.g. electricity system in a country) is part of society attributed a functioning (e.g. fossil electricity generation) in order to fulfil a socio-technical need (e.g. demand for electricity). Each socio-technical system is composed of several constellations. They are actually nested subsystems contributing to the overall system with their own competing or supporting functioning. Based on the

contribution they have as well as their stability and power, they are named differently: regime as stable and high power constellation with dominant functioning (e.g. fossil electricity system); niches as unstable, low power and emerging constellations with unorthodox functioning (e.g. solar electricity); and empowered niches (e.g. wind electricity) as seeking to be stable, with medium power, deviating functioning and with an aim to take over the regime. The global trends (e.g. advances in clean technologies) and external forces (e.g. international climate change regulations) are seen as landscape signals influencing the system but staying out of its control.

Systems' states are further elaborated with the definition of stages in multi-stage framework known as metastasis, genesis, and stasis [5]. They are not actually static positions, but they are dynamic equilibriums with gradual changes. Dynamics equilibriums are attributing with making turbulence at the beginning, in creating variety at the start of take-off phase and in getting settled down at stabilisation phase of transition. Some feedback loops in each system's state, such as technology lock-in which fosters stability, usually strengthen the dynamic equilibriums further.

In addition to functional definition, the system in transition should be defined based on constituting components, i.e. the groups of actors which share practices, cultures and structures [23, 24, 36]. Culture is the component where actions emerge, including people, their shared rules and conventions as well as values and ethics that influence the perception of actors. Practices are the aspects of functioning or different ways to satisfy societal needs. They are represented by the accumulation of actions and behaviours of actors in the use of natural resource from environment, scientific and technological achievements, or even social and lifestyle practices. Finally, structures comprise market and non-market rules and institutions as well as physical infrastructure. The important point is that the components are interrelated: actors by doing actions under the influence of cultures create physical and institutional structures and shape new practices. Structures here are both the outcomes of actions and the means for shaping practices. Established structures are inclined to oppose new practices while modified structures open up a place for new practices. Though structures and practices are created by culture component, they influence culture recursively. The developed structures can support the culture in doing more actions, and new practices influence the perception of actors and change culture component.

This functional and structural conceptualisations of system's states are aligned with the definition of transition as de Haan and Rotmans [2] explained: fundamental changes in structures, cultures, and practices of a socio-technical system, occurring in sequential stages of slow and fast dynamics, and profoundly change the way the system functions by shifting the power between constellations.

Conditions: when does a transition take place?

The shift in power is signalled by conditions. Three conditions have been identified in pillar theory that create stimuli for transitions [2]. The first condition is when landscape imposes destructive forces on regime. These forces, based on their frequency, amplitude, speed and scope, come in forms of regular, hyperturbulence, specific shocks, disruptive, and avalanche [11]. The mismatch of working structures (structural tension[10]) or making sense of working constellation (cultural tension[11]) with a new external situation puts 'tension' on the regime.

[10] An example is the landscape force of commitment to an international program on GHG reduction while the country still has its infrastructures based on fossil fuels.

[11] An example is the necessity of moving toward renewable energies as a global trend while energy policy makers and industry managers have the illusion of unlimited fossil resources (widespread in oil-states countries around Persian Gulf).

The second condition is when the origin of misalignment is within regime, when one aspect of functioning is hindrance for others. This situation is called 'stress' and can be the result of misaligned system's structure and culture (system hypocrisy[12]) or of distracting the goal of the system from its functioning to just keeping structure and culture aligned (system perversity[13]).

The final condition is when an alternative functioning threatens regime. This is called 'pressure', and it is rooted in niche innovations at the bottom. The pressure appears in two forms, when the alternative constellation uses the same resource as regime it is called competing pressure and when it tries to replace the regime it is called obsoleting pressure.

Metabolism: why does a transition happen?

Metabolisms lie in micro-foundation of dynamics and narrate the story of underlying mechanisms that are triggered by conditions. They are explanations for why transitions happen. The main idea of metabolisms in transition is introduced by Haxeltine et al. and Shilperoord et al. [23, 24]. What the metabolisms do is to shift the power between constellations. This is the point which connects the popular functionalistic view of dynamics to the role of actors which has been widely criticised (discussed in Section 3).

The basic drivers for metabolisms can be traced back to transition forces in multi-stage framework [5]. Based on that the initial systems' state and existing conditions, forces appear in different phases of transition (triggering, formative, supportive) and in different direction (top-down, bottom-up, internal) [36]. Forces influence the system in its components, namely practice, culture, and structure. Through making changes in components, they trigger three inter-related mechanisms of power shift. The first mechanism is the orientation of individual actors toward constellations though actors' decisions. According to actor-option framework, actors decide to support a constellation based on the constellations' attributes as well as their own features. As a result, changes in constellations' attributes, change in actors' behavioural identities (i.e. an update in their preference and reference points in selection), and changes in actors' perception (i.e. the gradual increase in their understanding of niche advantages) alter actors' decision function and subsequently, shift their support between constellations. Changes in actors' features and constellations' attributes are induced by change in culture and practice components respectively. The second mechanism is through constellations' adaptive learning, i.e. the modification of their attributes according to the preference of actors. As Schilperoord et al. [24] explain, each constellation based on their power and stability follows a strategy that defines their capability to adapt and influences the attraction of support from individuals. Actors' support brings power to constellations, and the power defines the dominant functioning in socio-technical system, i.e. regime and niches. The third mechanism is through constellations' structure. The relation between constellations' structure and support is recursive. On the one side, support devoted to a constellation creates resources in the form of finances, materials, knowledge etc. and thus subsequently shapes structures. On the other side and reciprocally, available structures affect the creation of resources and the attraction of more support.

Pattern: how does a transition appear?

The functionalistic interpretation of shift in constellations' power through metabolism is described in the literature by patterns [2, 11, 27]. The patterns of transition are discussed here for two types of

[12] An example is the implementation of targeted subsidies plan and the increase in energy prices, while people still see it as the government's responsibility to subsidise energies.

[13] An example is the development and legislation of comprehensive national plans for renewable energies in developing countries which usually takes several years and become "the goal" while at the end they are not fully implemented and do not yield intended results.

dynamics: the one that appears in rise and fall of an emerging system and the other that comes from the interactions between constellations and with landscape. The first one is patterns in system build-up and breakdown and the other is the patterns in transition.

Transition patterns have been discussed for different theories in Section 2, and several classifications have been proposed for them. Based on the typology proposed by de Haan and Rotmans [2], dynamics appear in three main patterns: reconstellation in which the role of landscape in emergence of a constellation is emphasised (top-down changes), empowerment in which the role of niche innovations on emergence of a constellation is stressed (bottom-up changes), and adaptation in which existing constellation modifies itself internally.

Build-up dynamics have been mainly discussed in functional interactions of TIS approach [16, 17]. The dynamics that form a constellation can be described through the seven system functions of the TIS approach and the interactions they may have in reinforcing loops referred to as motors of innovation. These inter-system dynamics appear optimising for regime functioning and broadening for niches functioning. However, in describing breakdown dynamics, few publications have appeared to date in this area. In one report, a similar concept to TIS functional approach is briefly presented, but this time with reinforcing loops that work downward in the system, known as vicious cycles [17]. Similarly but in different analytical level, Turnheim and Geels [40] specifically addressed dynamics that destabilise the regime during the transition.

5. Conclusions

There are various theories and frameworks that provide explanations for dynamics of transition with an ambition to learn from the past, to steer the current path, or to explore the future paths. Since their aims and ontological positions are varied, they conceptualise the dynamics from different levels of aggregation. This study reviewed the concepts and the processes of change in different theories in order to contrast their differences and emphasise their commonalities. The finding in this study revealed that the current theories have some complementary features that their integration can cover the existing limitations in understanding transition dynamics.

This study constitutes the first step toward designing an integrated conceptual framework bridging the gaps between theories, starting with the integration and adaption of existing concepts and processes with no overlap between them and with clear relations and ontological positions. This is actually the study of micro-level process of change which results in emergent behaviours at meso and macro levels. Because the emphasis of this paper was on reviewing various theories, the proposed integration needs to be further investigated if it is going to be a practical conceptual framework. One of the important required steps is to prove the validity and compatibility of the framework with reality. This can be done by grounding the framework in several historical cases and to assess if the framework is capable of explaining dynamics in socio-technical transitions. Another possible future work is to extend the conceptualisation of dynamics by other theories and approaches such as strategic niche management which specifically deals with the formation of niches. However, it should be noted here that while capturing more complexities of reality is helpful, the complexity of the framework itself can become confusing. Hence, the extension to other theories should keep the framework as simple as possible.

An attractive application of the integrated conceptual framework is to use it as a basis for modelling transition dynamics. Since the framework provides an understanding from conditions, mechanisms, and patterns of changes, it can provide the required inputs for computational and mathematical

modelling of large-scale transformations. Those models with the power of computer simulation can reproduce complex behaviours, such as time delays, threshold effects, and multi-causalities, which cannot be analysed with narrative descriptions and can be used for ex-ant policy evaluations of ongoing transitions. Hence, developing a formal computer simulation model based on the integrated framework is another potential extension of this research.

Acknowledgement

Enayat A. Moallemi thanks the University of Melbourne for providing Australian Federal Government scholarships: International Postgraduate Research Scholarship (IPRS) and Australian Postgraduate International Award (APA).

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Title:
Towards an integrated conceptual framework for understanding transition dynamics

Date:
2014

Citation:
Moallemi, E. A., George, B. A., Aye, L. & Webb, J. M. (2014). Towards an integrated conceptual framework for understanding transition dynamics. The 5th International Conference on Sustainability Transitions: Impact and Institurions, Utrecht University.

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