논문

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Environment, Drivers and Dynamics of Socio-technical System Transition and STI Policy for the Transition Management

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이 글은 과학기술학의 맥락에서 사회기술시스템 전이에 관한 여러 이론적 측면을 다루고 있다. 사회기술시스템 전이 관점은 특히 지속가능한 개발을 위한 과학기술 혁신정책 연구 분야에서 각광받고 있는데, 그것의 규범적 성격은 연구자 뿐 아니라 과학기술 자체의 실천적 역할을 강조하는 STS 전통으로부터 큰 영향을 받았다. 이 글에서는 사회기술시스템 관점의 이론적 발전과정을 추적하고, 주요한 이론적 요소들인 시스템 전이의 환경, 동인, 그리고 동학에 대해 이전의 여러 이론들과 연결하여 논한다. 결언부에서는 전략적 니치관리론(SNM)으로 대표되는, 전이 관리를 위한 과학기술 혁신정책의 역할을 강조하였다.

【주제어】 사회기술적 전이, 과학기술 혁신정책, 전략적 니치관리

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1. Introduction

1) Locus of this research

Not only in Korea, but also in other developed countries, the STS academic community and STI policy community had stood somewhat apart from each other until 1980. However, since 1980s, the two academic communities have been sharing a number of perspectives on the interactions between society and S&T, for example network and system. The innovation system perspective has emphasized the importance of social aspects in analysing and preparing STI policies. Relatively recently, this strand has strengthen due that the Climate Change became a global issue and political agenda. STI policy has been given a new task of guiding socio-technical transition to sustainable future. Since a majority of sustainable technologies still remain at the niche level, hardly competing with traditional mainstream technological systems, the role of STI policy for promoting their R&D should be regarded as essential. In addition, social acceptance of new technologies is another matter that demands policy support. Transition management should be carried out in a sophisticated way, with reflections on continuously changing socio-economic environment and technical changes. A new policy toolkit for transition management has been suggested, which is known as strategic niche management(SNM).

In the case of Korea at this time being, the Korean government has set the Green Growth agenda that emphasizes both economic growth by emerging industrial sectors and sustainability, which is in fact subtly different from the original meaning of sustainable development though.

For the so-called Green Growth, sustainable niche technologies should make successful socio-technical transitions to achieve both sustainable society and further economic progress. Thus the multi-level perspective, which has been paied a huge attention from STI policy researchers, is worth being reviewed especially in Korea.

The paper begins its discussion with the review that sheds light on STS influences on the development of the multi-level perspective, followed by discussions on the environment, drivers, management, and dynamics of socio-technical transition. In short, this paper is trying to present the context of socio-technical transition theory, which provides us with the reason why both STS academics and STI policy researchers need to pay more attention on it.

2) How STS tradition influenced the development of the socio-technical system perspective

The two widely used and highly developed systemic perspectives, innovation systems and the social construction of technological systems have been interacting with each other less noticeably, although there have been few researchers who dealt with the two perspectives before Rip and his Dutch colleagues. A former chemistry researcher, Rip introduced the Nelson-Winter-Dosi model of technological change to SCOT researchers at the end of 1980s(Belt and Rip, 1989).[1)]

1) Belt and RIp provided empirical evidence of the technological paradigm operating over the history of synthetic dye chemistry. The Netherlands has been very proactive towards technology assessment, which is used to give a public warning – i.e. to ensure ‘precaution’- with regard to a large emerging technology. Dutch scientists and policy researchers have long been interested in the social aspects of technologies.

The concept of a 'transition' was apparently introduced by another Dutch researcher, Kemp, who was at the time studying innovation and thinking about the way to achieve sustainability(Kemp and Soete, 1992). He was inspired by an Edinburgh scholar, MacKenzie, who had considered 'economic and sociological explanations of technical change'(MacKenzie, 1992). It was the issue of the barriers against desirable 'good' technological systems that made Kemp think that not just economic but also social aspects are important in order to bring about a radical technological change, which he denoted as a 'transition'(Kemp, 1994). He had worked with Rip on a theoretical research project and developed the first insight into a multi-level perspective on technological transitions. In addition, he had the opportunity to develop his concept of a 'technological regime', which he used to explain how a 'transition' could also involve a 'regime shift'(Kemp, Schot and Hoogma, 1998; Rip and Kemp, 1998).

The multi-level perspective on transitions was adopted by Geels, a colleague of Rip's who had a strong background in the history of technology and an understanding of the large technological system(LTS) concept. After this, the perspective has become more complex and theoretical, supported by a few historical case studies[2] of technological transition largely carried out by Geels himself(Geels and Kemp, 2000)[3]. At first glance, Geels' approach seemed to be an interesting application of the multi-level transition concept, combined with various concepts such as LTS, actor-network theory,[4] evolutionary economics and technological

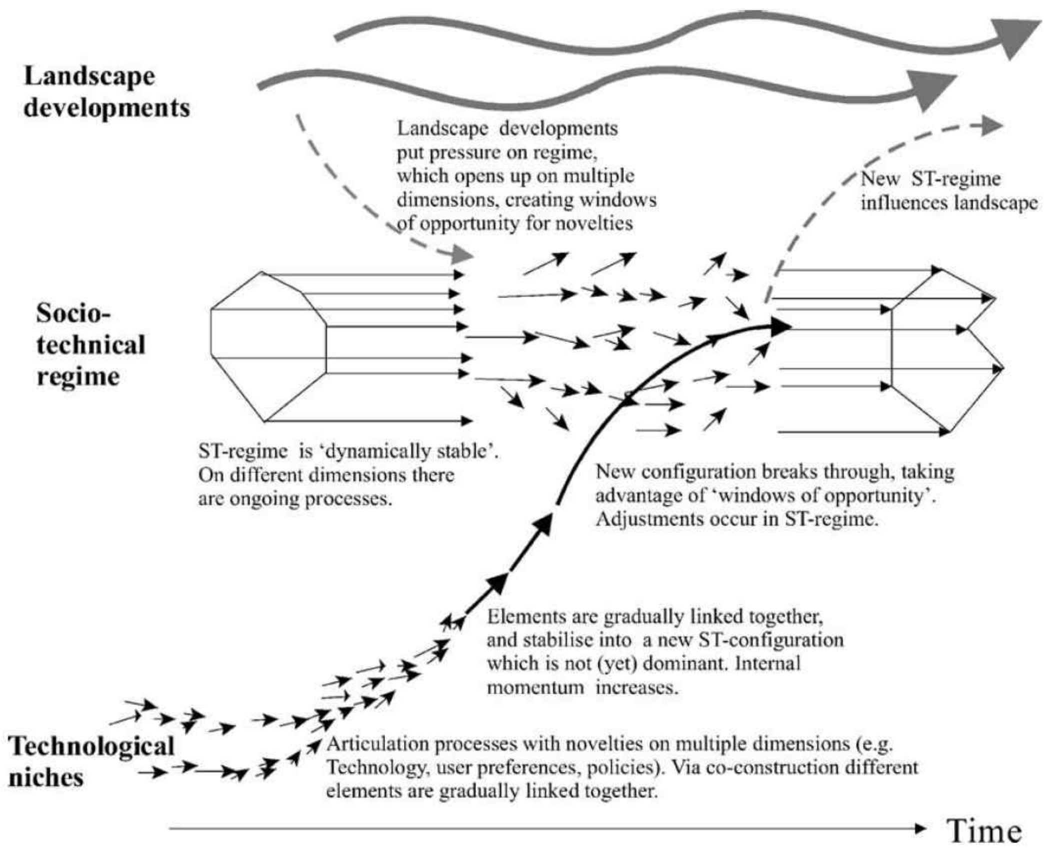
2) Those case studies have been published separately, after the socio-technical system perspective was successfully introduced. They are about 'from sailing ships to steamship'(Geels, 2002), 'transition in water supply and personal hygiene'(ibid., 2005), 'from cesspools to sewer systems'(ibid., 2006a), and 'the shift from propeller to turbojet'(ibid., 2006b).

3) This Dutch-written project paper was edited and published later in Research Policy(Geels, 2002).

paradigms.

The socio-technical systems perspective was ambitiously suggested by Geels, who claimed to merge three previous theoretical developments into one emerging theoretical framework. He brought together large technological systems developed by Hughes(Hughes, 1989), sectoral systems of innovation developed by Malerba(Malerba, 2004), and technological systems developed by Carlsson(Carlsson and Stankiewicz, 1991). He claimed to be putting forward a more advanced, unified theory that could provide a better understanding of technological changes and transitions, in terms of both the techno-economic aspects and the social aspects.

<Figure 1> Multi-level perspective on transitions



Source: Geels(2004).

4) Geels cited Latour(1991) and Callon(1998).

The socio-technical system framework partly built upon Hughes' theory. However, large technological system theory and socio-technical system theory can be distinguished from each other, although they do share a few similarities. To validate the use of the socio-technical perspective instead of the well-established large technology system theory, it is first worth examining those similarities and differences.

The two theories are based on the belief that society influences, and indeed shapes, technological changes. There are various levels of interactions between society and technologies. For several decades, it has looked like a spectrum of diverse viewpoints, which lays from the radical viewpoint of the social construction of technology to the liberal viewpoint of the invisible hand in free market. Although this spectrum reveals various viewpoints on the general public either as 'society' or as 'consumers', it is possible to say that in recent years science and technology studies have been paying significant attention to the demand side, instead of concerning on the supply side only. Hughes' works provided us with a new insight that a technology is not a single element of machines, but rather a constituent agent that has the power to interact with people – as if it were a living organism – and to participate in forming a system, which cannot be separated from society. In addition, Hughes showed that the social shaping of a technological system can vary, depending on the society.

The socio-technical system approach emphasizes the demand and application part of innovation, extending large technical system theory to a new concept of systems that is constructed from an ensemble of technologies and society(Geels, 2002, 2004). This approach also uses key concepts from innovation system work, such as institutions, the concept of interactive learning, and networks of actors. Basically, the socio-technical system perspective represents a combination of previous ideas developed over several decades in this field, with the major components being the innovation system perspective and the LTS(and within it, the SCOT) perspective.

2. Environment and drivers of transition

1) Environment of transition and global landscape

Since we are dealing with the socio-technical system which implies social shaping of the technological transition, society represents the environment of transition, because society provides the system with culture and all the components such as actors, institutions, and knowledge. The geographical boundaries of transition environments can be anything from a laboratory as the smallest to the global community as the largest. However, if we consider how greatly STI policy influences the emergence of a new large technology and the early moves of socio-technical system transition, it is practical and effective to focus on national systems of innovation in a broad way, because most STI policies are made by national governments.

The transition environment analysed in this research is suggested to consist of several sub-environments though they cannot be completely separated from each other. They are the techno-economic environment, the cultural environment, and the socio-political environment, all of which vary from country to country, depending on the national system of innovation.

The techno-economic environment depends on several factors such as the following; what technologies a country specialises in, the level of technological development, the scientific and technological capabilities, what industrial sectors are present and playing a major role in the economy, the natural and geographical environment and how high the national income status is. The techno-economic environment guides the transition of systems by varying the speed and trajectory of transition. For example, there exist huge differences in technological trajectories and the speed of technological developments between technological frontier countries and 'chasers'. The chasers learn from frontier countries and can then imitate and repeat what the frontier countries have done. It is possible that countries that depend on imported fossil fuels for their energy consumption easily tend to do more to promote R&D on new and renewable energy sources.

Transitions can also be affected by cultural factors. Some societies are eager to accept newly developed technologies in a very positive manner, while others may react carefully towards new technologies. In general, developing countries often exaggerate the opportunities in industrial applications of new technologies. In more developed countries, the unknown risks and potential malfunctions of new technologies are often considered. Religious background forms part of the cultural environment, too. For example, certain strands of Christianity may prohibit governments from funding stem cell research that uses human eggs, so that scientists must find another way to establish stem cells without using human eggs. Historical background is another part of the cultural environment. For example, in some East Asian countries such as Korea, China and Taiwan, a number of groups of scientists have been making efforts to apply alternative medicine to modern health science, based on the long-term experiences with traditional Chinese medicine(Science, 2003).

The socio-political environment includes the method of communication among actors and political systems including the policy-making environment, governance and structure of society. Even the direction of policy-making approaches can influence transition phenomena. If the STI policy of a country is focused on a variety of possible technological options and the cultivation of niches, the convergence on an emerging technology will occur when it acquires the momentum of transition. On the contrary, if the STI policy of a country is constructed with a top-down approach and aims to select and promote a specific technology that policy makers think is promising, the government can be quite influential in the design of the technological trajectory.

Besides the roles of the transition environment noted above, the influences are not uni-directional. The transition environment and technology interact with each other and induce changes in one another. This fits in with the concept of co-evolution. The socio-technical regime is the space where the co-evolution of technological trajectories and the transition environment, which is based on the national system of innovation, takes place.

Beyond the socio-technical regime, there is the global landscape. The landscape is a bigger environment that provides various socio-technical systems with common conditions, being independent from national systems. Some examples of outer-regime factors are environmental changes like global warming, socio-political trends like the pursuit of sustainability, scientific achievements, the diminution of fossil fuel production, and so on. The outer-regime landscape shapes socio-technical regimes, but when a transition reaches the “macro” stage, which means a major socio-technical change happens, the transition can also influence the landscape.

2) Drivers of transition

Over a decade before the concept of a 'system transition' was born, Dosi(1982) claimed that "the role of economic, institutional and social factors must be considered in greater detail" to understand and explain technological trajectories. After Dosi had developed the concept of technological paradigms, Freeman tuned the concept and extended it to techno-economic paradigms(TEP), which took into account not just technologies but also "wider economic, social, organizational and political systems" including technological regimes, product mixes, new forms of organization and management, new infrastructure, changes in education and training, changes in intellectual property regimes and changes in innovation leadership(Freeman and Perez, 1988). Freeman's TEP perspective looks quite like systemic perspectives, which are thought to have been influenced by his original concept of national innovation systems. So, the transition of systems can be regarded as the shift of techno-economic paradigms and the drivers of the transition are not very different from those of techno-economic changes. However, it is worth noting that the socio-technical system transition perspective puts more weight on social aspects than the TEP perspective.

What drives system transitions? First, it is reasonable to mention that technological development itself can drive the transition. Without social interferences, technology would often have its own momentum. This is mostly due to the pioneering nature of scientists and engineers, as they pursue unforeseen things and try to make something previously impossible possible.

Second, as free-market capitalism becomes stronger and more solid, the power of markets increasingly grows. The economic and industrial driver is one of the most powerful drivers of a socio-technical transition. Not only industrial actors but also governments are quite sensitive to the economic value of technologies, especially of emerging technologies, some of which promise to achieve future profits and economic growth. That is the main reason why industrial firms invest, and governments spend, a large amount of money on R&D. Promoting scientific and technological developments, and funding R&D programmes for them, has been one of the major roles of STI policy. When a possible system transition looks viable, there will be a sudden increase in awareness about it that is reflected in a rapid increase of R&D funds in a specific technological field to provide the momentum of transition with a reinforced economic driver. Conversely, even a technologically feasible and socially supported alternative technology can be withdrawn or put on hold if faced by a lack of economic and industrial drivers.

The next driver of change works well with the economic driver. Although they are closely interconnected to the economic driver, socio-political drivers such as the environmental driver have been growing in importance. Global Warming has warned humans – though not all of them – to reduce carbon emissions, in other words, to reduce the use of fossil fuels. The environmental driver has resurfaced and given birth to a number of new and renewable energy technologies, such as biofuels, solar energy and wind, some of which were introduced a few decades ago but had been largely ignored since then. The ongoing system transition shows the pathway from the conventional fossil-fuel energy systems to sustainable, new and renewable energy systems. The socio-political driver plays a key role in this transition. Note that the transition also opens up new economic and industrial possibilities such as job creations and the emergence of a new industrial sector.

3. Management and governance of transition

1) The role of STI policy: strategic niche management

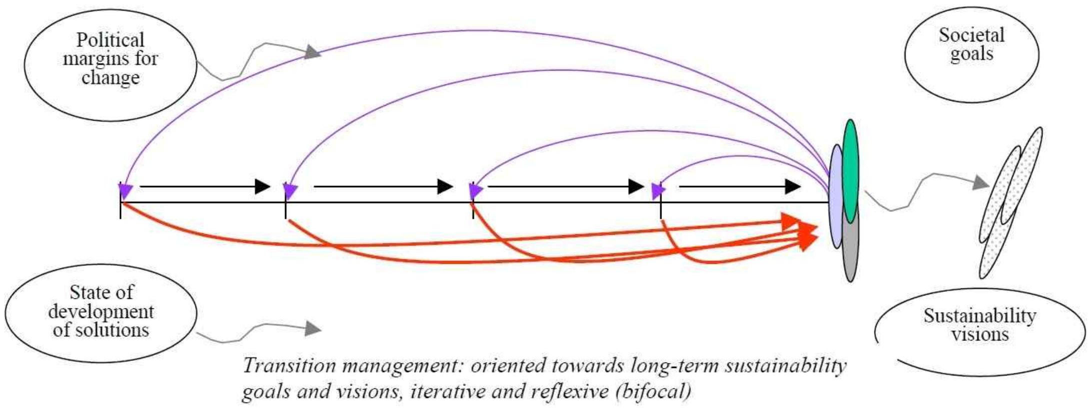
While Geels has been deepening socio-technical system theory by applying it to a few historical cases, Kemp has focused his research interest on the management and governance of transition. The management and governance of transition is important especially when we consider modern democracy, in which policy researchers make efforts to create 'better' STI policies in relation to social and political factors. It is not difficult to see that the concept of strategic niche management is part of an activist's policy-making toolkit rather than an academic analysing device. Kemp wrote: "the strategy of strategic niche management is, of course, valuable for an actor who wants to push new(sustainable) technologies on to the market"(Kemp, Schot and Hoogma, 1998). 'Niche' technologies are radically new(sustainable) technologies in the early phase and Kemp suggests there needs to be strategic management of these because of "the importance of specialized applications in the early phase of technology development" and because "there is usually little or no economic advantage of the technology." In addition, he emphasized the importance of societal views of the new technology.

Niches can either be formed spontaneously or intentionally. However, the survival and growth of niche technologies are a different matter. If a government of a certain country thought it needed to realize a niche technology to pursue sustainability, it would manage the niche technology by supporting R&D activities and promoting the industry formation. Selection of technologies involves complex processes, being made under various societal and political pressures. In addition, policies for niche management aim at not only at R&D funding but also at influencing the relationship between society and the new technology.

Even if niche technologies are being successfully managed, not all niche technologies succeed in gaining the momentum necessary for transition. In addition, it is nearly impossible to intentionally cause a system transition. Consequently, the transition needs to be monitored carefully and to be reflected in government policies. The concept of transition management was introduced by Kemp(2005) as the next stage after niche management. Transition management is the method for maintaining a specifically oriented policy in the long term, and it consists of a number of feedback loops. This ensures that the policy action can be "interactive and reflexive". <Figure 2> shows the conceptual diagram of the policy process corresponding to transition management. During transition management, the policy process is to be governed not only by state actors but also by non-state actors such as interest groups. So, the governance also needs to be reflexive(Voss and Kemp, 2005), changing the distribution of power continuously.

STI policies for strategic niche management and/or transition management may include following aspects, in other words, following missions may be given as specific roles of STI policies; 1) designing socio-technical experiments, 2) inviting public engagement, 3) articulating visions from vague expectations, and 4) scaling-up socio-technical experiments. When a successful socio-technical transition was carried out, consequently there should need appropriate STI policies for institutionalization, for example safety regulations, competition rules, industrial standards, legislations, etc.

<Figure 2> Policy process of transition management



Source: Kemp and Loorbach(2005).

2) Governance of transition

The concept of governance in modern democracy implies a 'public-private partnership in governing', in other words, it is about interactions and relationships between state actors and non-state actors(Rhodes, 1997). In socio-technical transition, i.e. socio-technical regime shift, the governance of transitions is important, firstly because socio-technical transitions influence society considerably. Secondly, transitions are social processes with interactions between a large number of actors and technologies involved. Third, if transitions are driven or supported by government policies aimed at transition management, the policy making process needs to be deliberate and reflexive.

There are several issues relating to the governance of transitions such as the negotiation of interests, the context of the transitions, agents, and the power and membership of socio-technical regimes(Smith, Stirling and Berkhout, 2005). Smith, Stirling and Berkhout(2005) argued that "interventions have to be negotiated through governance processes involving multiple agents, none with decisive power. Governance in therefore carried out through negotiation and bargaining between interested state and non-state actors with interdependent resources relevant to maintenance and change of the regime."

With hindsight, most historical technological changes had been thought to emerge in an autonomous and spontaneous manner. It was perhaps true in the past that none of those historic transitions were caused by intentional management. However, the philosophy of transition management clearly reveals that it aims to achieve sustainability and that policies have to be applied to achieve this. Consequently, managed transitions are purposive, and even path-constructed(Kemp, Rip and Schot, 2001). Although Kemp et al. emphasized the role of non-state actors, Smith et al. claimed that "the coordination of the many diverse and nascent resources involved in a radical change has often required robust intervention by states"(Smith, Stirling and Berkhout, 2005: 1502).

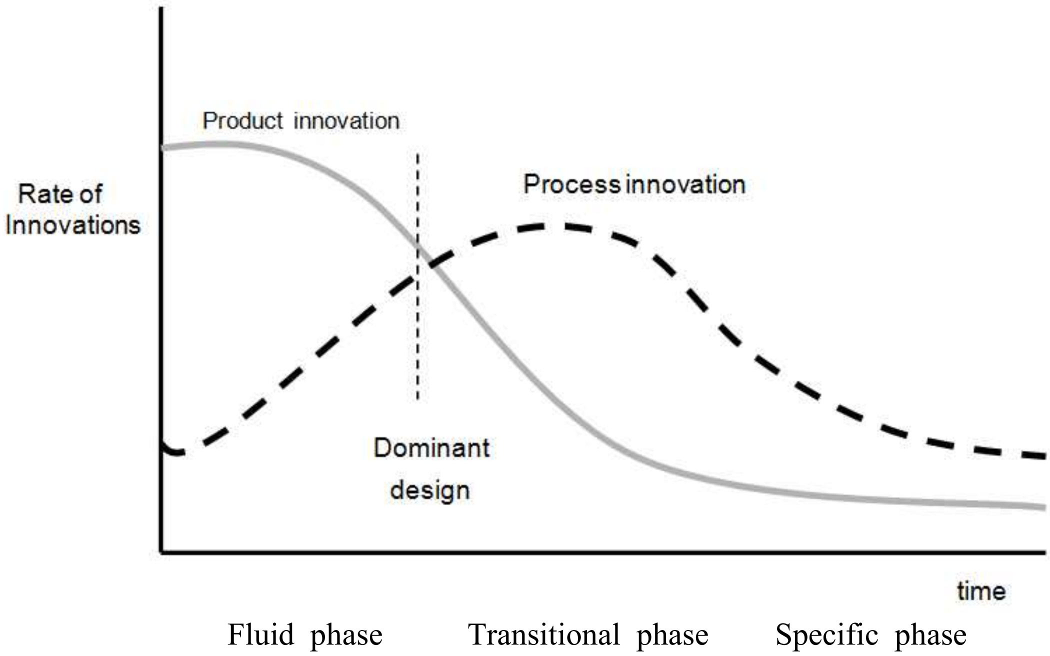
In summary, unlike historical transitions, the ongoing transition to sustainability is being managed with government intervention through explicit policies, the governance of which has to be deliberate and reflexive. If we are dealing with emergent transitions, this kind of statement should be common knowledge to policy researchers. However, note that the transition to sustainability is socio-politically driven, and many policy researchers have participated in the drive.

4. The Dynamics of transition

To describe the dynamics of transition, it is generally considered better to think in terms of sequential stages(or levels) in the evolution of systems, the pattern of innovation over time and the speed of transition. Although the concept of transition was introduced relatively recently compared with the conventional approaches to technological systems and technological change, the explanation of dynamics is reasonably compatible to both.

Utterback has been one of the leading researchers who investigated the dynamics of industrial innovation(Utterback, 1996 - reprinted version of 1976 one). He paid particular attention to radical innovations that had totally changed corresponding industrial sectors. After the radical innovation, the three phases of his dynamic innovation model follow. These are the fluid phase, the transitional phase, and the specific phase(see <Figure 3>). During the fluid phase, the innovations introduced tend to focus on product innovations, these competing with each other to provide market users with better and more advanced functions and performance. When the competition approaches an end where the convergence of function and performance occurs, or when a dominant product appears, the transitional phase begins. Process innovations make up the majority of innovations at this stage, since reducing the cost of mass-production becomes very important with the wide range of innovative products. The final('specific') phase is one where the number of innovations is decreasing due to the fact that the market is becoming mature.

<Figure 3> Abernathy-Utterback three-phase model of the dynamics of innovation



Source: Utterback (1996)

Utterback's dynamic innovation model implied a multi-stage(i.e. multi-level) perspective based on his concept of three phases, which is still applied in the socio-technical system perspective. His notion of a 'transitional phase' implied a transition between the old and the new market environments. The old market environment where products with conventional technology were bought and sold faces a radical rearrangement with the introduction of a radical innovation. This rearrangement can be either an opportunity or threat to firms with different sectors reacting differently. The transition denotes the pattern of innovation, the pathway of technological change and the transformation of the market environments.

Large technological system theory also implied a multi-stage perspective. Hughes explained that the evolution of large technological systems involves seven stages, these being invention, development, innovation, transfer, growth, competition, and consolidation(Hughes, 1989). There are difficulties in compatibility between the terms and notions used here by different innovation scholars and technology historians, but it is possible to understand and translate Hughes’ explanation if we take his notion of invention to mean radical innovation and development while ‘innovation’ denotes product innovations. The three stages of transfer, growth and competition might take place within the transitional phase, where technology transfer and diffusion occur and where more actors become involved. However, there are clear differences between Hughes’ viewpoint and Utterback’s, because Hughes supposed that the competition is embodied in various fixed ways based on alternative technologies or industrial standards so that he skipped process innovations. The final stage of the evolution is one of consolidation, where a dominant technology forms a new large technological system. This resembles Utterback’s 'specific phase'.

However, the concept of transition was not at the centre of theoretical discussions in these two dynamic perspectives. Kemp's concern with transition has focused on the management of transition. Kemp suggested the concept of technological niches, which can initiate transition if one accidentally acquires momentum. Kemp’s transition model has three levels, these being niches-micro, patchworks-meso, and system-macro. This three-level perspective looks somewhat similar to Utterback’s, but actually Kemp’s model appears to be a mixture of Utterback’s and Hughes’, since Kemp’s systemic perspective partly inherited the large technological system theory rather than the dynamics of innovation theory.

Technological niches consist of technologies not yet in wide-spread use, many of which may be emerging from relatively new radical innovations.

A driver provides momentum to a niche technology, so that it obtains the opportunity to be introduced to society, to encounter a bigger number of actors and their networks and to interact with various system components such as policy, institutions and culture, at the second level, which Kemp called the meso level. If consolidation happens, the emerging technology becomes a new socio-technical system and reaches the final stage, the macro level.

Geels' model of socio-technical system transition is a complex version of Kemp's. Geels has added detailed explanation on the niche-meso-macro multi-level perspective. However, instead of three levels, he has suggested a two-level model to describe transition phenomena, because he thought the 'macro' level was something bigger than a technological system and it should consist of outer-regime factors and the landscape of the system transition. Other than that, Geels' suggested theory of socio-technical system theory provides us with almost same transition model and theoretical considerations.

Not many researchers have looked specifically at the speed of transition. The reasons are, first, the speed of transition is thought to be less important than other topics related to transition, such as causes, patterns, drivers, environments, effects and governance. Second, the speed of transition varies considerably – for example, from around ten years for the internet transition, to a few decades for electrification or even thousands of years for the energy system transition from wood to fossil fuels. The speed of transition depends on the scale of transition and the extent of its social effects and it can be stalled by technological limitations, waiting for a radical innovation that provides the system with a break-through. There is no adequate explanation of why the speed of transition differs, since technological systems are usually too complex to fully understand, with numerous factors and components interacting. However, it is certain that a combination of strong driving forces and positive environments can accelerate the transition.

Geels adopted and suggested a number of concepts to describe what the socio-technical system is and how it operates, for instance, alignment, cognition, multiple regimes, multi-level structure, co-evolution, transition, and dynamics, not to mention the numerous components of the system. Recently, Harvard scientists reported that they had succeeded in establishing stem cells from human skin tissue cells. The Bush government has been against using human eggs. It is interesting that the Global Warming crisis has even apparently saved nuclear power from diminishing in importance in European countries. For example, developing countries often choose so-called 'strategic future technologies' and support R&D activities in pursuit of them.

In this article, Smith, Stirling and Berkhout(2005) also discussed about the selection pressure, adaptive capacity, and so on, issues that are skipped over here. This statement sounds quite normative. When researchers talk about governance, they presume that the governance has to be 'good' governance. However, in real cases, it is more often than not, that a single agent or actor – especially government actor – has decisive power. Kemp is thought to have become interested in system transitions after he wrote about how we can retard global warming by technological change. Consequently, he might want to suggest that we should make a 'good' transition occur in a quite 'strategic' manner.

5. Conclusion: socio-technical transition and STI policy

The concept of transition was initially applied to transitions of large technological systems, especially when a new system gradually replaces an existing one. Geels claims that his socio-technical system theory had resulted from the experiment of combining three different approaches – Hughes' large technology system theory, Carlsson's technological system perspective and the sectoral innovation system perspective. He also drew on the concept of actor network theory.

One can debate whether Geels' claim to have developed a 'new' theory might be more a mixture of existing concepts rather than a grand theory that unifies all the other theories. When the socio-technical system perspective is applied to historic cases, it becomes harder to distinguish this from when large technological system theory is used to describe technological transitions. In this case, the socio-technical system perspective seems to be a feedback loop for large technological system theory, seasoned with additional 'flavours' of actor network theory and evolutionary approaches.

However, it is the position of the theory in academic communities that provides the socio-technical system perspective with its strength and advantages. It lies at the mid-point between science and technology studies, and science, technology and innovation policy studies, which have been developed by different groups of researchers, although they have influenced each other to a limited extent. Recently STI policy researchers have demanded better understanding and wider application of the social aspects of innovation, especially in fields where non-technological aspects are more important than technological achievement, such as the environment and energy. This may be one of the many reasons why the socio-technical system perspective has spread so rapidly among STI policy researchers, despite its complexity and abstractness. Its complexity allows other researchers to make versatile use and modifications to the approach.

In my assessment, the latest form of the socio-technical system perspective provides us with a better description and explanation of technological transition and the interactions not only with the market but also – more importantly – with society. Society steers the transition, and technology induces social change – hence the significance of the term, socio-technical system – suggesting we should rather consider one unified system than two separate ones.

STI policy is itself a component of the system. First of all, public policies, including STI policies, represent one of the major building blocks of institutions of innovation systems, especially when we consider a socio-technical transition that is being brought about by an emerging technology. It is clear that STI policies play essential roles in the transition. Before the emerging technology gains its momentum of transition, it is just one competing option among various possible and sometimes substitutable technologies. At this stage, which we call a socio-technical niche, strategic niche management is applied. selection of a technology that achieves the momentum of transition might be made in the market by an ‘invisible hand’, as has been assumed by a majority of economists for decades.

However, unlike natural selection, socio-technical selection can be made in a very artificial or social way such as through policy-making decisions. For example, for countries that are in the process of catching-up in a certain field of technology, one is very likely to observe and learn from what other countries at the technological frontier do and whether their trials are successful or not, and then to follow the trail of frontier blazers. In this case, a strong government drive facilitated by appropriate STI policy to promote technological developments and industrial application will be needed.

Nevertheless, it is not always the case that the selection is made in either a natural or a strategic way. Another selection mechanism that can operate in a more sensitive way is to follow what is, people in society believe is, the right direction of social change for the future. Although the meaning of sustainable development is coming to posses a growing amount of economic and industrial value, the term originated from environmental concerns. Despite the fact that renewable energy sources still lack economic competitiveness against fossil fuels, the installation of production facilities and the use of renewable energy are increasing, accompanied by rather ambitious and ever-expanding future plans. This kind of socio-technical selection can be regarded as a socio-philosophical one. It is notable that along with scientists, STI policy researchers are the people who have been supporting renewable energy technologies. This is presumably because they believe science and technology should contribute to making the world a better place for human beings.

When an emerging technology starts to have an influence on society, people usually try to estimate these influences, instead of leaving the technology to evolve on its own without any social intervention. It is widely accepted that society shapes technological trajectories, but, in many modern societies, stronger intentional mechanism cans interfere with this trajectory. The birth of nuclear weapons was a shock to many people, who came to believe they must intervene in scientific and technological activities to prevent science and technology from misuse. The reason for this was not only socially motivated precaution, but also a desire to estimate the economic value of the technology.

'Telescoping futures' is one of most important fields in STI policy studies, which includes technology forecasting, technology foresight, and technology assessment. The results can influence technological trajectories in various ways, such as public perception, social acceptance, investments and political decisions. If an emerging technology is successful in gaining the momentum of transition, the transition appears automatic and there is nothing to stop the snowballing of momentum. However, it can still be steered. At this stage, the governance of technological transition becomes a major issue in STI policy research.

In short, STI policy is more than just one component of the system in transition. Resulting from communications between various actors in the system, STI policy reflects not only techno-economic but also socio-political contexts. STI policy can be included in institutions, and it can also provide the technological trajectory with a culture, the socio-technical environment. In addition, STI policy can act as a non-human actor, or as a protocol that directs others' actions. To sum up, STI policy influences the technological trajectory, the evolution of the socio-technical system, and the way an actors' network works.

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Environment, Drivers and Dynamics of Socio-technical System Transition and STI Policy for the Transition Management

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ABSTRACT

This paper presents theoretical discussions on socio-techical system transition, by shedding light on the STS context. With a rising attention paid by STI policy researchers, the socio-technical system perspective seems particularly promising in applying to the pursuit for the sustainable development. The normative strand in STI policy research has been strongly influenced by the STS tradition that emphasizes active and participatory roles not only of academian but also of science and technology. Throughout reviewing the development of the socio-technical system perspective, its theoretical components of environment, drivers and dynamics are discussed, often being linked to older perspectives. STI policy involves in socio-technical transition in a manner of transition management and governance, which is the final part of this paper.

Key terms

Socio-Technical Transition, STI Policy, Strategic Niche Management