Technological change as a trade-off between social construction and technological paradigms

Odd Einar Olsen*, Ole Andreas Engen

Abstract

The theory of social construction of technology (SCOT) and the theory of technological paradigms (TTP) are normally regarded as competing or even incompatible perspectives on technological change. In this paper, we show how and when the perspectives are complementary by comparing how the theories conceptualise technology development, understand stakeholders, and determine driving forces for technological change. When stakeholders have different relations to the innovation process, and when the outcome of the innovation process is open, we argue that the two theories could be complementary tools for analysing the process. When using SCOT and TTP as complementary analytical tools, it becomes easier to understand and design innovation processes in which different stakeholders are attached to roles where they are able to contribute in the most productive ways.

Keywords: Social construction of technology; Technological paradigms; Theoretical compatibility; Empirical applicability; SCOT; TTP

1. Introduction

The theory of the social construction of technology (SCOT) and the theory of technological paradigms (TTP) are generally regarded as competing or even incompatible perspectives on technological change [1–5]. The purpose of this paper is to discuss how and under what conditions SCOT and TTP can be used as complementary tools for analysing technological development. We will present some basic assumptions found in most social theories about technological development. Based on these, we will discuss complementarities between SCOT and TTP. Two extensive case studies will illustrate how a complementary application could be accomplished. Finally, we will suggest how a complementary angle may improve practical innovation projects. Advocates for SCOT and TTP benefit from the argument that the other theory is an opposite theoretical pole. It becomes easier to explain their own positions when it is possible to contrast them with something diametrically different. Certain scholars emphasise that SCOT were developed as a sociological alternative to neo-Schumpeterian economic theory [6]. And the neo-Schumpeterian advocates take a theoretical perspective that seems to deal with the same topics but from a totally different angle. The difference between the theories is to a large extent expressed in behavioural assumptions about the actor. While TTP is based on the concept of bounded rationality [7,8], SCOT theorists consider the actors as socially shaped as a result of interactions, negotiations, and conflicts [9–12].

The main objections to a complementary use of the theories are that different behavioural assumptions involve different epistemological perspectives [9,11,13,14]. Therefore, it becomes meaningless to use the theories as complementary tools. Even though scholars have discussed and criticised SCOT and TTP from different theoretical angles [5,15,16], it is hard to find a systematic comparison of the two traditions. Furthermore, it is very rare to see the two perspectives used together in empirical studies, even though complementary use may actually improve the analysis and enhance the explanations of technology development [17,18].

2. The nature of technology

The term "technology" is a slippery one. The common perception is that technology is machines, devices, and tools used for some purpose. Technology is also understood as artefacts. However, both SCOT and TTP expand these definitions by including what we normally consider as "social" elements of technology. The *Concise Oxford Dictionary* defines technology as the "science of practical or industrial arts; ethnological studies of the development of such arts; application of science." Here, technology is understood as knowledge. However, this definition misses the hardware aspect that is the commonly held perception of technology in everyday language. Maybe the most common way of defining technology is to integrate artefacts and knowledge, for example "artefacts and knowledge about their operations."

But these definitions are missing the context in which all technologies exist. Galtung [19] describes the artefact and knowledge elements as the visible tip of a huge iceberg. Galtung includes structures as part of technology. Structures are the modes of production or the social relations within which tools become operational, and the cognitive structures within which knowledge becomes meaningful. This approach emphasises how social relations surrounding the application of technical knowledge determine the nature of the resulting technology [14,20–22].

Bijker identify three layers of technology [6]: (1) a layer of physical objects and artefacts, (2) a layer of activities and processes, and (3) a layer that refers to what people know as well as what they do. Those who write about industrial development based on incremental perspectives avoid the dilemmas of technology semantics by defining technology as appropriate to their analysis or they do not define it at all. These authors are more concerned about the nature of innovations, technological accumulation through social learning processes, and the institutions affecting these processes [23–25]. Analysis at the firm level normally focuses on the "development, imitation and adoption of new products, new production processes and new organisational set-ups" [3] which goes straight to the point of Dosi's analysis and is fairly representative of most studies about industrial development and technological change [26,27]. The recognition that technology also has some social aspects and determinants has led to the conclusion that it is difficult to separate the social and the technical elements of technology [2,28–30]. The borders between society and technology form a seamless web that constitutes a diligent development of technologies [31].

Regardless of their theoretical position, almost all authors agree that technological changes do not arise out of nowhere. Some of the main starting points for technological development are existing technologies, knowledge, and practices shared by groups or embedded in ongoing production. The *Oxford Dictionary* definition referred to above is based on these assumptions. Studies in different traditions establish their analytical frameworks within a context of existing technologies. The so-called autonomous technology approaches consider these frameworks to be the main imperative for change, and thus they diverge from other approaches [9,12]. Authors close to these schools of thought have developed the concept of "techno-economic paradigms" [32], and in the TTP tradition this observation is labelled "technological trajectories" [2,3]. The system-oriented schools of thought refer to "technological style" [29,33]. Others are aware of "technological traditions" [34]. In the diffusion approaches, analytical perspectives exist based on "technological regimes" [4,35]. In the social constructivist approach, the concepts of "technological frames" are developed [6]. In some way, they are all inspired by what Kuhn called "paradigms" [36], or even more precise, what Lakatos called "research programmes" [37].

This similar starting point for almost all social theories about technological development indicates that some common epistemological grounds exist in assumptions about knowledge valuation and knowledge generation. They all understand that the main sources of knowledge for technological development are found in existing scientific communities, technologies, or practices.

3. The social construction of technology (SCOT)

Most studies concerned about the SCOT focus on shaping new artefacts. Whereas economic theories of technology consider the technology itself as a black box, the social constructivists are accused of going into the black box and not coming out again [12]. Research has produced many intensive case studies and lengthy descriptions of specific development processes [1,6,20,28,38–44]. Some, like Latour [41,42], Callon [38], and Law [22] have developed a systematic actor-network perspective; others like Bijker [1] are more structurally oriented [16,17]. However, the SCOT perspective has great potential for analysing technology development because it pays attention to factors rarely examined in techno-economic theories of technology change.

SCOT perceives technological development as the outcome of social interactions between relevant social groups and not necessarily as a response to market demands, external shocks, or technological opportunities. A relevant social group is comprised of those actors who act and re-act in relation to a given artefact or technology and thereby influence the innovation process. A relevant social group could be defined as a group having the same perception of problems related to innovations within a given technology [1,45]. Different actors interpret the potential of the technology differently because they have various interests and views on the problems and solutions. Each social group/actor is defined according to its inclusion in a common technological frame, which is a combination of current theories, tacit knowledge, engineering practice, procedures, goals, and actions shared by this group.

Technology development takes place as a negotiation process between the actors, where the outcome of the innovation process is directed by the distribution of interests, strategies, and knowledge among the participating actors. The results are not necessarily founded on existing objective knowledge. Rather, a technology is developed when the influential actors accept it as developed. After that, controversies, arising from different interests and interpretations of problems and solutions, are closed. Closing a controversy means that one dominant design or solution is accepted and/or supported by the most influential actors. New or changed technologies are stabilised when the main actors define the problems solved even though the problem does not need to be solved in the common sense of the word. The new technology, or design, is stabilised. After closure, it has been proven to be very difficult to re-start the technology development from scratch [6]. This is also referred to as entrenchment [46].

Technological frames are not fixed entities; they emerge during the innovation process. Technological frames shared by a relevant social group are heterogeneous and consist of artefacts and values, objectives and scientific theories, test protocols and tacit knowledge [1]. New structural environments, new knowledge, and changed values give rise to new technological frames and the formation of new relevant social groups. However, this depends on the heterogeneity of the stakeholders in a development process.[1] If no dominant social group controls the innovation process, and resources are distributed among different relevant social groups, many innovations occur. Moreover, these innovations can be quite radical if the purpose for the new technology is not clear. If few social groups are involved in the controversy, criteria external to the technological frames could influence the outcome of the innovation process, such as power, ability to mobilise resources, or networks [16,46].

The dynamic element in SCOT reveals a cumulative perspective on technological change. If one social group is able to insist on the type of problems and the definition of solutions, then the innovations tend to be quite conventional. They often emerge as an answer to functional failures. They are process-oriented and incremental. Inside the SCOT framework, the theory opens for many different factors shaping technology under development and many potential outcomes of the innovation process. Due to its open-ended concept

[1]"Stakeholder" can be defined as institutions, groups, or individuals involved in or affected by a project or programme. "Stakeholder" is used in this paper as a context-free term covering involved or affected actors regardless of the theory discussed or actors discussed in accordance with TTP. "Relevant social group" is a defined term within SCOT and is used as a specific SCOT definition.

and loosely defined variables, SCOT has been accused of being a guideline for investigating technological development rather than a theory [12,17].

4. Theory of technological paradigms (TTP)

In several works, Giovanni Dosi developed a theoretical perspective on technological change in firms operating in a market economy [2,26,27,47]. Dosi's perspective is derived from other works on the economics of innovation and the abundant literature of neo-Schumpeterian scholars [32,35,48–55]. Together they have developed theories about technological change within firms, their nature, causes, and directions occurring when "firms seek to improve and diversify their technology by searching in zones that enable them to build upon their existing technological base" [56].

This does not necessarily mean that technology itself is the main or only imperative for change. The post-Schumpeterian schools also emphasise the role of the entrepreneur in technical change. However, the TTP pays much more attention to the technological determinants that direct technical change rather than to entrepreneurial behaviour. The theory of "path dependence" focuses on how early technology choices have created important paths for development that has great impact in later stages. It also focuses how path dependence has led to a "technological lock in" in firms and sectors [57–60]. Dosi regards this school of thought as complementary to the evolutionary schools [26,61,62].

Most companies operate within a technological paradigm, which is defined as "contextually the needs that are meant to be fulfilled, the scientific principles utilised for the task, the material technology to be used" [3]. According to Dosi's use of the term, a technological paradigm is a pattern for solutions to techno-economic problems based on highly selective principles. It is comprised of both artefacts and a set of heuristics expressed in questions like "where to go from here," "what should we search for," and "where should we search." In other words, technological paradigms "define the technological opportunities for further innovations and some basic procedures on how to exploit them" [3].

Firms follow a technological trajectory in their development and change. Dosi defines a technological trajectory as "the activity of technological progress along the economic and technological trade-offs defined by a paradigm" [3]. A technological trajectory is the pathway to changes that emerge in industries, countries, even firms. Within each technological paradigm there could exist several technological trajectories, which are the materialised pathways of solutions [2].

According to TTP, patterns of technological change cannot be described or analysed as simple but flexible reactions to changes in market conditions. In fact, the directions of technological changes are often defined by the "state of the art" of the technologies in use within the firm. According to Rosenberg [63], most mechanical productive processes throw off signals that are both compelling and fairly obvious. These processes involve an almost compulsive formation of problems. However, these signals and compulsory formations only make sense in the context of knowledge where they arise. The trajectories evolve as a result of the learning processes and sources of information available for changes in the firm.

Thus, it is the nature of the technologies themselves that determines the potential for adjustment to broader economic and market conditions, not the other way around. Consequently, the probabilities of making technological changes in organisations appear as a cumulative activity. The innovation process becomes highly selective where the problems, directions of search, potential solutions, and final implementations are built on the technologies already achieved by the firms. It is not only the technologies that change through the cumulative processes; the search procedures and routines for change are cumulative processes as well. This means that the set of technologies a firm can use effectively is far smaller than the set of technologies that is open for it. What an enterprise can expect to achieve technologically or organisationally in the future is heavily dependent upon, and constrained by, what it has been able to achieve in the past.

Dosi identifies three main forces driving technological change. First, the opportunities for technological change stem partly from exogenous sources of information and knowledge. Second, they also stem partly from endogenous knowledge and routines accumulated by the firms. Third, environmental factors related to markets, institutional arrangements, and policies play a role. However, Dosi suggests "that environmental factors are going to succeed in radically changing the directions and procedures of technical progress only if and when they are able to foster the emergence of new paradigms" [61].

Although the outcome of the innovative activities is determined by technologies in use and the resources available for changes, this is quite different from the impulses that initiate innovative activities. The driving forces inducing attempts to change production processes or products do not necessarily give any indications about the outcome of innovative activities. Conversely, the outcome depends more on the resources available for implementation. TTP predicts that these resources are, to a large extent, linked to existing technologies either through knowledge and competence, organisational structures, perceptions of market opportunities, or former investments. In other words, the outcome of changes along a technological trajectory is determined by existing technologies and search procedures in the firm, regardless of the causes of change efforts. Therefore, the factors that induce, stimulate, or constrain technological change should be distinguished from the outcomes of innovative activities.

In general, three major resources are vital if an enterprise wants to implement innovations. First, information and knowledge about problems and solutions must be available. Second, the organisational design and existing knowledge in the organisation to a large extent guide the search for solutions. Solutions of ill-structured problems imply the use of knowledge from different sources, although the firm will tend to seek solutions in areas compatible with its existing knowledge. Third, enterprises need resources (i.e., capital and competence). Lack of resources can hamper any attempts to implement innovations. This could emerge partly as barriers embedded within the technologies, and partly as limited potential for acquiring the necessary resources for change.

Compared to SCOT, TTP is based on specific assumptions about the techno-economical rational actor as operating in a market structure, where the aim of the theory is to explain flexible reactions within a given opportunity set.

5. The problem of compatibility

Major critics of TTP have come from the non-uniform group of social constructivists [5,28], while the main critics of SCOT come from the TTP branch of neo-Schumpeterian theories [64]. By concluding that technologies are the products of heterogeneous contingency, SCOT advocates reject that determined pathways and trajectories characterise technological development on an industry level (see, for instance, articles in [28,65]). Advocates of TTP, insisting on rational economic considerations as the bases for enterprise development, reject that social factors overrun economic logic in decisions about technology development.

Although social constructivists admit that it is possible to identify patterns of technological development that could be regarded as trajectories, they claim there is nothing natural or inevitable in such developments [1]. The main argument against TTP is that it does not take sufficiently into consideration the social, cultural, and political environment and forces from which all technologies emerge. A parallel criticism stems from an economic point of view that regards the process of innovation as a result of market selection rather than technology-based trajectories. Evolutionary economists assume that both incentives for innovations and the outcome are determined by market mechanisms [52].

At the same time, SCOT theorists are accused of ignoring important factors that influence the technology development process beyond those revealed by studying researcher-defined relevant social groups [12,16]. The strong influence of resource limitations (i.e., available competence, financial resources, and organisational and institutional structures) is under-estimated as long as the main driving force is defined as individual or group interests.

Although the theories are developed from different traditions and consider technology development from opposite angles, both SCOT and TTP share a common inspiration based on an evolutionary epistemology [2,45]: both accept that one of the main starting points for technological development is existing technologies, knowledge, and practices shared by groups or embedded in ongoing productions.

In Table 1, some of the main characteristics of the two theoretical perspectives are compared. The objective is to deconstruct both perspectives and thus evaluate whether the components are mutually excluding or complementary.

The table highlights three main factors:

1. How the theories conceptualise technology development, how the theories actually perceive the knowledge element in technology, and the influence of knowledge in the innovation process.

Table 1
Comparing main characteristics of SCOT and TTP

	The social construction of technology (SCOT)	Technological change in technological trajectories and paradigms (TTP)
Technological development is understood as:	An evolutionary, step-wise and almost irreversible process	An evolutionary, cumulative and irreversible process
Main outcome of innovative activities	Unpredictable, depending on the dominating relevant social group	Cumulative and predictable changes in existing technologies and practices following the pattern of the trajectory
Main actors	Relevant social groups	The enterprise organisation
Actors understood as:	Individuals seeking self interests and meaning	Techno-economical rational actors limited by lack of knowledge and resources
Main unit of analysis	The artefact or the socio-technological ensemble	Changes in the firm
Driving forces inducing change	Interests of and influence by relevant social groups formed by their technological frames	Existing technologies, technological opportunities and market driven needs
Knowledge understood as:	Tools to achieve own interests	Determining factor constituting the outcome of innovative activities
Main sources of information and knowledge	Resources mobilised by the relevant social groups within their technological frame	R&D, public, general and available information: Private, firm and practice specific within existing paradigm

2. The comprehension of the actors (or stakeholders) draws attention to behavioural assumptions about the actors and how they formulate the innovation problem.
3. The driving forces for changes, which emphasise the importance of knowledge and access to information, are recognised in both theories and bring up issues of knowledge valuation.

Advocates for both SCOT and TTP pay attention to the change process and try to offer reasons for the changes and the outcome of change efforts. They regard the nature of technology development as evolutionary and almost an irreversible process, although they differ about the impact of existing technologies on the outcome of innovative activities. TTP represents a more deterministic perspective of technology development and emphasises incremental changes in existing technologies as the expected outcome. SCOT theorists focus on step-wise progression limited by available knowledge. But the outcome is still regarded as unpredictable because it appears as the result of negotiations between different social groups representing different problem definitions, knowledge bases, and interests. The relevant social groups normally have different relationships to the technology under development, and not all groups will be hampered by the same perception constraints during the process. Rather, they will perceive the process and outcome from different perspectives. In TTP, all stakeholders in technology development processes share a common understanding about the purpose of technology development and the rules of the game embedded in a neo-classical economic rationale. The interconnected relationships between actors, organisations, and institutions thus create a strong climate for cumulative technological development.

This is also reflected in behavioural assumptions about the actors. The assumptions rely on who the main actors are, and the unit of analysis. Advocates of TTP regard the enterprise organisation operating in a free market economy as the actor, and thus the unit of analysis has to be changes in the firm. Consequently, in TTP, the basic perspective is derived from economic theory. However, the actor is considered as the "satisfiser" and not the "maximiser". The actors are assumed to be techno-economic rational actors limited by lack of knowledge and resources. SCOT theorists regard the relevant social groups as the main actors. The only thing linking these groups together is the technology under development. Hence, this technology has to be the unit of analysis. SCOT theorists base behavioural assumptions about the actors as creators of meaning. When interacting within technological frames and shaping meaning connected to the actual technical artefact, self-interest is considered an incentive as well. Accordingly, if self-interest is assumed to be an economic benefit, the behavioural assumptions may not be as far from TTP as it may seem at first sight. Most important, SCOT theorists assume that the relevant social groups in development processes have different motives and interpretations, whereas TTP advocates assume that all stakeholders share the same basic values and perspectives on technology development processes.

When it comes to the driving forces (or motives) for technological development, SCOT theorists emphasise that beliefs and self-interests among the relevant social groups are most important. TTP advocates argue for the importance of external, market-driven factors and prevailing technological opportunities as main driving forces. A striking difference between the two is how they view information processing and knowledge. According to SCOT theory, knowledge is synonymous with the resources mobilised or generated within the technological frames by relevant social groups. In TTP, information and knowledge are considered a commodity or resource generated by the scientific community or available through practice. Knowledge is thus an institutional practise of the prevailing technological paradigm. But the assumptions underlying TTP do not necessarily exclude a "relevant social group," as defined in the SCOT perspective, from relying on the same assumptions as the actor in TTP.

6. Complementary use of the theories

So where are the complementarities? One nexus could be defined as "a social institution that carries and shapes the interaction between trajectory and selection environment" [5]. The authors maintain a broad definition of "social institutions," including not only the patent systems, laws, and regulations, but also organisations engaged in technology development. It is a term specifying what Law [66] calls "heterogeneous engineering," i.e., the strategic activity of combining technical, political, and economic resources through network building in order to carry out technological changes.

In heterogeneous engineering, technological trajectories constitute only one framework for the social construction of technologies. Used together SCOT and TTP highlight different processes at different empirical levels, and justify the interlinked relations between technologies in use and steps taken by actors engaged in a development process. The SCOT theory provides a perspective on innovations as multi-centred and complex processes where there exists a large spectrum of technological choices. As they appear in the theory, economic laws or institutional inertia do not necessarily affect these choices. TTP represents one alternative condition under which technologies may be developed. Advocates for the social construction perspectives declare (referring to empirical studies) that there is nothing inevitable about the ways technologies evolve. Technology development does not follow any natural life cycle. Rather, it is the product of heterogeneous contingency [28]. That statement, however, has to be modified. There is something inevitable about technology development in enterprises, but that is socially constructed.

Based on the previous discussions, we argue that the two theories have the same point of departure when explaining the basis for technology development (in existing knowledge and technologies). Furthermore, we argue that the behavioural assumptions in TTP also are one possible set of assumptions about the actor within the SCOT perspective. It all depends on the stakeholder relationship to the technology. One analytical situation, which encourages a complementary use of the theories, is where different stakeholders have different relationships to the technology under development. This is especially true if one relevant social group can be described as techno-economic rational actors limited by lack of knowledge and resources.

If the innovation process appears open-ended, researchers applying TTP will have difficulty explaining radical innovations in an existing technological system because they regard all stakeholders as limited by the same techno-economic paradigm or trajectory. But the complementary use of TTP and SCOT may help explain radical shifts in existing technological systems.

Thus, two dimensions in the theories may encourage use of the theories as complementary analytical tools: (a) the relations stakeholders have to the technology process and (b) the main characteristics of the situation where the innovations take place.

6.1. Differing stakeholder relations and complementary explanations

In a study of technology transfer, Olsen [17] concluded that if stakeholders have different relationships to the technology under development, that relationship will offer the stakeholders differing degrees of freedom in the development process. Furthermore, they will probably have different interpretations of aims and obstacles in the development process. Olsen analysed a technology transfer process between Sweden and Tanzania, which lasted from 1978 to 1992, and involved about 40 small enterprises. The project was designed and funded by the Swedish aid agency SIDA and Tanzanian authorities. Bureaucrats in both SIDA and Tanzania had distant connections to what was going on in the small enterprises. They were focused on visions of social and economic development in Tanzania and regarded technological innovations in the small enterprises as a means to achieve some general development goals. In that respect, they developed technological frames about successful enterprise performing very similar to the basic assumptions and predictions found in the TTP. But they wrongly assumed there were free markets in Tanzania, and they wrongly assumed the small enterprises would adapt technologies and products to the existing environment through an incremental innovation process. Furthermore, they wrongly assumed that enterprise development in the Tanzanian context meant gradual improvements in products, processes, and organisations. However, the bureaucrats were not hampered by practical problems in the companies or the problems of selling Swedish-designed products with a Swedish price to poor people in Tanzania. They administered the financial resources allocated by the Swedish government and used the allocations to influence enterprise development on the basis of their own perceptions of gradual enterprise development (their technological frames).

On the other hand, the entrepreneurs in the enterprises had to struggle with daily operating problems. They faced a shrinking or non-existent market for their products, and they did not have access to relevant competence, raw materials, spare parts, or maintenance due to the prevailing import substitution policy in Tanzania. In short, they had no incentives or opportunities to follow the expected development path based on assumptions about free markets and transparency. They were trapped in a technological trajectory that was impossible to follow. After 4–6 years, the entrepreneurs embarked on radical innovations (e.g., from fishnet production to footballs), diversifications (e.g., nail production added to basket production), and investments in totally different activities (from industrial production to restaurants and fixed property) in order to survive. This illustrates that enterprise development along a technological trajectory can be based on socially constructed expectations for technological development. And enterprise development can be regarded as a response to such expectations rather than a development forced by an internal technological logic predicted in the TTP.

In this case, the theories of SCOT and TTP proved to be complementary perspectives more than competing. They explain different processes on different empirical levels. The SCOT perspective can most fruitfully explain how bureaucrats in Sweden and Tanzania influenced the evolution of project design, concepts, and strategies for technology development in the small enterprises far from economic realities. It was possible to show how agents for the Swedish and Tanzanian government designed the project (and technologies) to meet their own visions about enterprise development, and how the bureaucrats as one important relevant social group developed a mutual understanding and interpretation of problems and solutions. Furthermore, it became clear how the technological frames among the bureaucrats to a large extent determined not just strategies and action but also captured the facilitators and tied them to former decisions.

According to Table 1, TTP is better suited to explain the dynamics of enterprise development perceived from the entrepreneur's point of view. This also included the entrepreneur's perceptions about driving forces triggering changes, and resources producing opportunities for implementation of innovations. But TTP also acts as the null hypothesis in the analysis by defining the expected route to success that the relevant social groups in the Swedish and Tanzanian government tried to encourage. It explained the problems of acquiring technological capabilities within each enterprise. A perspective of technological trajectories helped to identify problems within each enterprise, the directions of changes aimed for, and resources available for changes.

A SCOT perspective could hardly have highlighted these issues as adequately. The double perspective applied by using both SCOT and TTP helped explain how different stakeholders operate within quite different logical and epistemological frames. In complex processes of technological development, different agents have different relations to the development process. The SCOT perspective can be used to illuminate how the relevant social groups (or stakeholders) develop different technological frames. TTP can be used to analyse how the enterprise—as the most important stakeholder in commercial projects—is hampered or supported in efforts to improve production processes, products, and results. Applied together, SCOT and TTP contribute to a better understanding of how technologies create trajectories because they are socially constructed.

6.2. Open-ended innovation processes and complementary explanations

When the SCOT perspective is used to analyse technology development, the context is normally the development of new technologies. The relevant social groups have not been restricted by technologies already in use [1]. TTP is normally used to analyse technology development within enterprises where existing technologies are assumed to influence the innovation process [67].

Engen [18] analyses how a long-lasting incremental development process in Norwegian offshore technologies from 1970 to 1990 suddenly changed directions and entered an unfreezing period where new and radical innovations were introduced. The objective of Engen's study was to analyse the unlocking of an existing technological paradigm and the inducement of a technological transformation that finally became a new technological paradigm.

The old paradigm had two main characteristics. The production of oil and gas was carried out by large and complex gravity platforms placed on the seabed, and construction was handled by numerous subcontractors. To manage the complicated setup for construction work and technological changes, oil companies, suppliers, subcontractors, and authorities had to build huge bureaucracies to control each other. Production costs became extremely high, but were somehow legitimised by high oil prices that extended for a long period from 1973 to 1986.

Table 1 ascertained that TTP considers technological development as an evolutionary process where innovations follow cumulative and predictable pathways. Technological development on the Norwegian shelves between 1970 and 1990 is a good example of the concept of technological trajectory. The decision makers were guided by knowledge embedded in existing technologies and R&D institutions, supplier industries, safety inspection authorities, and strong communities of practise in the oil companies. The influential stakeholders in the Norwegian oil industry were politicians, government institutions, oil companies, suppliers, and labour unions. They constituted a complex network of interests and objectives in which common technological frames gradually emerged [68]. The huge and extremely expensive technological solutions provided a high safety standard and regular production in a harsh environment. These aspects were important for all stakeholders. The government, the Norwegian national oil companies, suppliers, and labour unions were all supportive of the concept because the technological solutions utilised core national competence and had a large national impact on employment and industrial spinoffs [69]. The state paid most of the costs through taxes, which offered few incentives for the oil companies to change the concept. In addition, strong communities of practise within the entire sector had built their futures on incremental improvements in the basic concept. Accordingly, an enormous amount of resources were channelled into incremental technology development projects that involved choices that omitted more cost-efficient alternatives. All stakeholders regarded themselves as economically rational actors, and their move along the defined technological trajectory was the only reasonable pathway to technological development.[2]

The decline of world oil prices in 1986 presented a major challenge to the technological paradigm in the Norwegian offshore industry and revealed the inefficiency of technologies and organisations. Oil production at the Norwegian shelf was seemingly no longer profitable. But stakeholders were locked in by former decisions, sunk costs, and dependence on the old paradigm even though they realised the need for more cost-efficient and flexible solutions. Someone had to make the first move to redirect the technological paradigm. The only stakeholder with a non-technical relationship to the existing paradigm was the state. At the same time, the state was the only stakeholder with the authority to mobilise all the other stakeholders toward a radical shift in technological solutions. After initiatives from the government, a deconstruction of the old paradigm and a period of radical innovations started in 1990.

As Table 1 shows, SCOT advocates to consider the outcome of technological development as unpredictable because the relevant groups are those seeking self-interest and meaning. Even though all the project stakeholders realised the need for change, all had their own interests and preferences when it came to new directions for technology development. Initially, there were large differences between the oil companies, the supplier industry, and the labour unions concerning means and ends of the industrial transformation. The oil

[2] Representatives from the oil companies Shell and Statoil were proud and had no criticisms when construction of the "biggest and most expensive construction in the world that will ever be moved" started around 1990 (the Troll platform).

price decline forced them to change their perceptions. A common interest in maintaining the activity level within the Norwegian petroleum industry gradually created new technological frames that focused on efficiency and international competition. The original frames focusing on national competence building, creation of a maximum number of jobs, and protection of national companies were left. This process of radical shifts lasted from about 1990 to 1998. During this period, most stakeholders changed their positions and alliances several times and influenced the main direction of technological change based on their own interests. The process was open-ended in the first years and gradually formed a new paradigm that allowed only incremental changes in the latter part of the period. During the 1990s, this resulted in formalised cooperation between representatives from the government, the oil companies, the suppliers, and the main unions (denoted NORSOK). This cooperation appeared as a technological frame that aimed to break down the old paradigm and restructure interactions between the stakeholders.

A combination of SCOT and TTP offers a better opportunity to analyse inter-organisational behaviour in technological development. It also demonstrates how organising relevant stakeholders within an industrial sector can maintain, break down, and re-build technological paradigms. TTP is best suited to analyse how the old paradigm was able to develop and resist changes for a long period. The old paradigm was based on existing technologies and organisational structures, available competence within the companies, and ample resources for innovative activities. At the same time, all stakeholders shared the same techno-economic perception about the situation, and the accepted strategy for incremental technology development [70].

The study illustrates how SCOT may be more relevant for explaining the significance of external shocks on technological development. An external shock initiated a redirection in stakeholder interests. In the open-ended innovation process that broke down the old paradigm, stakeholders contributed to the overall development by advocating for their own interests. They appeared as different relevant social groups with very different views of new technologies. TTP advocates merely regard external shocks as changes in the technological and economical opportunity sets. TTP is therefore best for explaining stability, but it has limited capacity to explain why certain technological paradigms disappear and are replaced by others. Used together, SCOT and TTP represent an opportunity to analyse both stability and change in existing technological systems.

7. Conclusion

A SCOT perspective tends to regard change processes as a question of motives, interests, and resources possessed by the actors involved, and the outcome of innovative activities as the result of negotiation processes among relevant social groups. A technology trajectory perspective pays attention to how technologies in use constitute the framework for changes taking place in enterprises, and how the learning process and feasible solutions are determined by technologies the firm already possesses. SCOT theorists regard technological progress as unpredictable; TTP theorists predict the outcome of innovative processes as incremental changes in existing technologies. Even so, they both have the same point of departure in the assumption that technology development is based on existing knowledge and technology. Two analytical dimensions in the theories show the potential for complementary use in empirical analysis: (a) the relationships stakeholders have to the development process and (b) the main characteristics of the situation in which the innovations take place.

When using SCOT and TTP as complementary tools, the analysis becomes richer and reveals explanatory factors that had remained hidden if only one of the theoretical perspectives was applied. Thus, studies concerning technological change should focus more on the social institutions and organisations shaping the interaction between enterprise trajectory and selection environment.

Theoretical approaches to the study of technological development also have policy implications. When designing innovation processes, policy makers should pay more attention to the different relationships that stakeholders have to the innovation process. It makes it easier to see that bureaucrats, politicians, industrialists, and scientists regard technological development as tools for quite different purposes. It makes it easier to avoid counterproductive processes based on assumptions about shared perceptions about the purpose and outcome of innovative processes. It makes it easier to design innovation processes when stakeholders are attached to roles where they can contribute in productive ways.

Finally, a higher consciousness of the characteristics of the situation where the innovations take place could contribute to design innovation processes involving actors with complementary roles and interests. This may avoid conflicts and counterproductive processes based on misconceptions about stakeholder interests in the technology under development.

Acknowledgements

Thanks to Professor Kjell Grønhaug, Norwegian School of Economics and Business Administration for commenting on earlier drafts of this article, and to Professor MSO Anne Lorentzen, Aalborg University, Denmark, for giving us the idea and inspiration to write it. Thanks also to the Norwegian Research Council for funding the project. They are of course not responsible for any errors or misunderstandings.

References

[1] Bijker WE. Of bicycles, bikelites, and bulbs—toward a theory of sociotechnical change. Cambridge, MA: MIT Press; 1995.
[2] Dosi G. Technological paradigm and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res Policy 1982;2(3):147–62.
[3] Dosi G. The nature of the innovative process. In: Dosi G, Freeman C, et al., editors. Technical change and economic theory. London: Pinter; 1988.
[4] Malerba F, Orsenigo L. Technological regimes and firm behaviour. In: Dosi G, Malerba F, editors. Organisations and strategy in the evolution of the enterprise. London: Macmillan Press; 1996.
[5] Van den Belt H, Rip A. The Nelson–Winter–Dosi model and synthetic dye industry. In: Bijker W, Hughes TP, Pinch T, editors. The social construction of large technological systems. Cambridge, MA: MIT Press; 1987.
[6] Bijker WE. The social construction of facts and artefacts. In: Bijker WE, Hughes TP, Pinch T, editors. The social construction of large technological systems. Cambridge, MA: MIT Press; 1987.
[7] Cyert RM, March J. A behavioural theory of the firm. 2nd ed. Cambridge, MA: Blackwell; 1992.
[8] March J, Simon H. Organizations. 2nd ed. Cambridge, MA and Oxford: Blackwell; 1993.
[9] Cronberg T. Social experiments with new technology. Challenging democratic actions by democratic structures. In: Moser I, Sejersted F, editors. TMV-report series no. 3. Humanistic perspectives on technology, development and environment. Oslo: University of Oslo; 1992.
[10] Hacking I. The social construction of what. Cambridge, MA: Harvard University Press; 1999.
[11] Moser I. Technology in theories of social science. Perspectives and movements (in Norwegian only). PhD thesis, University of Oslo, 1993.
[12] Winner L. Open the black box and finding it empty. Social constructivism and the philosophy of technology. TMV-report no. 44. Oslo: University of Oslo; 1992.
[13] Beckman S. System and systemacy in technology. TMV-report no. 20. Oslo: University of Oslo; 1990.
[14] Mitcham C. Thinking through technology. The path between engineering and philosophy. Chicago: University of Chicago Press; 1994.
[15] Fuglsang L. Technology and new institutions. Copenhagen: Academic Press; 1993.
[16] Klein HK, Kleinman DL. The social construction of technology: structural considerations. Sci Technol Hum Values 2002;27(1):28–52.
[17] Olsen OE. Small steps toward great changes: enterprise development in aid supported technology transfer projects. PhD thesis, Norwegian University of Science and Technology, 1995.
[18] Engen OA. Rhetoric and realities. The NORSOK program and technical and organisational change in the Norwegian petroleum industrial complex. PhD thesis, University of Bergen, 2002.
[19] Galtung J. Environment and technology. Toward a technology for self-reliance. New York: United Nations; 1979.
[20] Elliott B. Technology and social process. Edinburg, Scotland: Edinburg University Press; 1988.
[21] Hickman L. Technology as a human affair. New York: McGraw-Hill; 1990.
[22] Law J. A sociology of monsters: essays on power, technology and dominance. London and New York: Routledge; 1991.
[23] Lall S. Learning to industrialise. London: Macmillan; 1987.
[24] Freemann C. Introduction. In: Freemann C, Dosi G, Nelson R, et al., editors. Technical change and economic theory. London: Pinter Frances; 1988.
[25] Marengo L. Structure, competence and learning an adaptive model of the firm. In: Dosi G, Malerba F, editors. Organisation and strategy in the evolution of the enterprise. London: Macmillan; 1996.
[26] Dosi G, Malerba F. Organisational learning and institutional embeddedness. In: Dosi G, Malerba F, editors. Organisation and strategy in the evolution of the enterprise. London: Macmillan; 1997.
[27] Dosi G, Chytry J, Teece DJ. Technology, organisation and competitiveness. Perspectives on industrial and corporate change. Oxford: Oxford University Press; 1998.
[28] Bijker WE, Law J. Shaping technology and building society. Studies in sociotechnical change. Cambridge, MA: MIT Press; 1992.

[29] Hughes TP. Networks of power. Electrification in Western society, 1880–1930. Baltimore and London: Johns Hopkins University Press; 1993.
[30] Hughes T. Evolution of large technological systems. In: Bijker W, Hughes TP, Pinch T, editors. The social construction of technological systems. Cambridge, MA: MIT Press; 1987.
[31] Hughes TP. The seamless web: technology, science, et cetera, et cetera. In: Elliott B, editor. Technology and social process. Edinburgh, Scotland: Edinburgh University Press; 1988.
[32] Freeman C. The economics of innovations. London: Pinter; 1982.
[33] Hughes TP. Technological momentum. In: Smith MR, Marx L, editors. Does technology drive history? Cambridge, MA: MIT Press; 1994.
[34] Constant EW. Communication and hierarchies: structures in the practise of science and technology. In: Laudan E, editor. The nature of technological knowledge: are models of scientific change relevant? Dordrecht, The Netherlands: Reidel; 1984.
[35] Nelson R, Winter S. An evolutionary theory of economic change. Cambridge: Cambridge University Press; 1982.
[36] Kuhn T. The structure of scientific revolutions. 3rd ed. Chicago: Chicago University Press; 1996.
[37] Lakatos I. Falsification and the methodology of scientific research programmes. In: Gilje N, Grimen H, editors. Compendium in philosophy of science. Bergen, Norway: University of Bergen; 1996.
[38] Callon M. Society in the making: the study of technology as a tool for sociologist analysis. In: Bijker WE, Hughes TP, Pinch T, editors. The social construction of large technological systems. Cambridge, MA: MIT Press; 1987.
[39] Collins HM. Artificial experts. Social knowledge and intelligent machines. Cambridge, MA: MIT Press; 1990.
[40] Dierkes M, Hoffmann U. New technologies at the outset: social forces in the shaping of technological innovation. Frankfurt and New York: Campus Verlag and Westview; 1992.
[41] Latour B. Science in action. Milton Keynes, UK: Open University Press; 1987.
[42] Latour B. The price for machines as well as for machinations. In: Elliott B, editor. Technology and social process. Edinburg, Scotland: Edinburg University Press; 1988.
[43] MacKenzie D, Wajkman J. The social shaping of technology. Milton Keynes, UK: Open University Press; 1985.
[44] MacKenzie D. Inventing accuracy. A historical sociology of nuclear missile guidance. Cambridge, MA: MIT Press; 1993.
[45] Ærøe A. How to comprehend military conversion in a theoretical perspective. Working paper. Copenhagen: Danish Technical University; 1993.
[46] Sørensen K.H. Social shaping on the move. On the policy relevance of the social shaping of technology perspectives. Working paper. Trondheim, Norway: University of Science and Technology; 1997.
[47] Dosi G. Technical change and industrial transformation. The theory and an application to the semiconductor industry. London: Macmillan; 1984.
[48] Andersen ES. Evolutionary economics; post-Schumpeterian contributions. London and New York: Pinter Publishers; 1994.
[49] Freemann C. The economics of technical change. J Econ 1996;18:463–514.
[50] Magnusson L. Evolutionary and neo-Schumpeterian approaches to economics. Boston: Kluwer Academic Publishers; 1994.
[51] Nelson R. National innovations systems. A comparative analysis. New York and Oxford: Oxford University Press; 1993.
[52] Nelson R. The co-evolution of technology, industrial structure, and supporting institutions. In: Dosi G, Teece DJ, Chytry J, editors. Technology, organisation and competitiveness. Oxford and New York: Oxford University Press; 1998.
[53] Rosenberg N. Inside the black box. Technology and economics. Cambridge and New York: Cambridge University Press; 1982.
[54] Sahal D. Patterns of technological innovations. Reading, MA: Addison-Wesley; 1981.
[55] Sahal D. Technology guideposts and innovation avenues. Res Policy 1985;14(2):61–82.
[56] Rosenberg N, Frischtak C. International technology transfer: concepts, measures and comparisons. New York and London: Praeger; 1985.
[57] Arthur WB. Competing technologies, increasing returns and lock-in by historical events. Econ J 1989;99(1):116–31.
[58] Arthur WB, Ermoliev YM, Kaniovski YM. Path-dependent processes and the emergence of macro-structure. Eur J Oper Res 1987;30:294–303.
[59] David PA. Technical choice, innovation, and economic growth. Cambridge: Cambridge University Press; 1975.
[60] David PA. Clio and the economics of QWERTY. Am Econ Rev 1985;75(2):332–7.
[61] Dosi G. Sources, procedures and microeconomic effects of innovation. J Econ Lit 1988;26(3):1120–71.
[62] Ruttan VW. Induced innovation, evolutionary theory and path dependence: sources of technical change. Econ J 1997;107(444).
[63] Rosenberg N. Perspectives on technology. Cambridge: Cambridge University Press; 1976.
[64] Edquist C, Johnsen B. Institutions and organisations. In: Edquist C, editor. Systems of innovations: technologies, institutions and organisations. Science, technology and the international political economy. London: John de la Mothe; 1995.
[65] Bowker G. What is a patent. In: Bijker WE, Law J, editors. Shaping technology and building society. Studies in sociotechnical change. Cambridge, MA: MIT Press; 1992.
[66] Law J. Power, action and belief: a new sociology of knowledge. London: Routledge and Kegan Paul; 1986.
[67] Dosi G, Malerba F. Organisational learning and institutional embeddedness. In: Dosi G, Malerba F, editors. Organisation and strategy in the evolution of the enterprise. London: Macmillan Press; 1997.
[68] Engen OA. An ability to adapt. International oil technology and Norwegian recipient competence. In: Paper presented at the international museum conference ICOM, Stavanger, Norway, 1995.
[69] Engen OA, Olsen OE. Organising the North Sea. Perspectives on technical and organisational change in the Norwegian oil industry 1965–95. In: Paper presented at the KNEXUS conference. Ideas about social, political and economical change. California: Stanford University, 2001.
[70] Engen OA, Olsen OE, Rosenlund L. Stability and change. Technology and knowledge networks in the Norwegian supplier industry. In: Paper presented at the final open conference COST A17. Barcelona, Spain: Knowledge and Regional Development; 2004.