Ecological Economics 152 (2018) 246–259

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Achieving Global Climate and Environmental Goals by Governmental Regulatory Targeting☆

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ARTICLE INFO

Keywords:
Sustainable development
Strategic niche management
Transition management
Regulation-induced innovation
Disrupting innovation
Radical innovation
Incremental innovation
Diffusion

ABSTRACT

Strategic niche management and transition management have been promoted as useful avenues to pursue in order to achieve both specific product or process changes and system transformation by focusing on technology development through evolutionary and co-evolutionary processes, guided by government and relevant stakeholders. However, these processes are acknowledged to require decades to achieve their intended changes, a timeframe that is too long to adequately address many of the environmental and social issues many industrialized and industrializing nations are facing. An approach that involves incumbents and does not consider targets that look beyond reasonably foreseeable technology is likely to advance a model where incumbents *evolve* rather than being *replaced* or *displaced*. On the other hand, approaches that focus on creating new entrants could nurture niche development or deployment of disruptive technologies, but those technologies may only be marginally better than the technologies they replace. Either approach may take a long time to achieve their goals. Sustainable development requires both radical disruptive technological and institutional changes, the latter including stringent regulation, the integration of disparate goals, and changes in incentives to enable new voices to contribute to new systems and solutions. This paper outlines options for a strong governmental role in setting future sustainability goals and the pathways for achieving them.

1. Introduction

This paper traces the strengths and weaknesses of the evolutionary/co-evolutionary processes of transition management (TM) and strategic niche management (SNM) in achieving sustainable development. These approaches mirror ecological modernization (EM) in their focus on learning processes within the firm and among firms in an evolving technological regime that hope to change and accelerate innovation processes in order to achieve more sustainable technologies (Ashford, 2002a). Their early proponents rejected revolutionary and disruptive changes brought on by government fiat, i.e., by regulation (Rotmans et al., 2001), although, curiously, in still earlier work some of them acknowledged the potential of regulation to change technological trajectories dramatically (Schot et al., 1994). Later proponents do argue that a dual policy approach focused on the destabilization of incumbents (echoing a belief in Schumpeterian waves of creative destruction) and the creation and development of new niches are required (Kivimaa and Kern (2016); Grin et al. (2010). However advances in achieving sustainable development may be slow and marginal in nature.

This paper argues that regulation-induced technological innovation has a much greater potential in making the significant changes required to achieving sustainable development by encouraging *radical* rather than *incremental disrupting innovation*, especially from new entrants displacing incumbents (Ashford and Hall, 2011). The new entrants who develop radical disrupting innovations are not niches waiting “in the wings” to develop/evolve further their technologies and eventually displace potentially competitive incumbents, but are more likely to be entirely new firms (such as TESLA) or firms not previously doing business in the area (such as DowSilicone fluid replacing Monsanto's PCBs in transformers and capacitors). TM and SNM processes are argued to be “too little, too late.” Nowhere is this more evident than in the area of global climate disruption. Progress that is too little and too late has been made internationally through evolutionary processes. It is time to embark on a different pathway. Stringent regulation has the potential to encourage discontinuous and radical, rather than incremental evolutionary change (Ashford et al., 1985; Ashford and Hall, 2011). Even with stringent regulation, regulatory capture in theory can be as serious a problem as the capture of TM by the incumbents as

☆ Updated from an earlier paper: Ashford and Hall (2015), presented in August 2015 at 6th International Sustainability Transitions (IST) Conference. Sustainability Transitions and Wider Transformative Change, Historical Roots, and Future Pathways, at Brighton, University of Sussex Campus (Falmer), UK.

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https://doi.org/10.1016/j.ecolecon.2018.06.002
Received 6 September 2017; Received in revised form 20 April 2018; Accepted 8 June 2018
Available online 21 June 2018
0921-8009/

occurred in the energy sector in the Netherlands (Smith, 2003; Smith and Kern, 2007), but the literature reveals that regulation-induced innovation is likely to result in more siginficant change than advances made through TM and SNM.

Unsustainable systems, such as energy production and use, agriculture, and transportation consist of inter-connected components and economic actors characterized by technical (and political) "lock-in" which is difficult to change. We are convinced that strategic stringent regulation of those components, if conceived in an integrated fashion, would be a more successful pathway to sustainability, even if greeted by political resistance.

In this paper, we address the theories of system innovation (Section 2), the strengths and weaknesses of the TM and SNM approaches (Section 3), the argument in favor of a stronger role for government than mere guidance (Section 4), regulation-induced technological innovation as a more viable alternative than TM and SNM for achieving more sustainable development (Section 5), and finally conclude with a discussion of the importance of diffusion (as opposed to innovation) in achieving sustainable development (Section 6).

2. The Innovation Process: Distinguishing Singular Product and Process Changes From Systemic Innovation

Much faith and hope in transforming industrial systems has been placed on the concept of innovation. After all, the root of the word implies change. The innovation process is acknowledged to encompass three related and interactively-connected activities: invention, innovation, and diffusion. Invention is the first working prototype of a technology; it can involve a product, a process, or a manufacturing/service system. Innovation is the first or new market application, while diffusion refers to proliferation of the innovation throughout an industry. When the innovation is then used in other industries, applications, or national contexts, we often also use the term technology transfer to describe diffusion. Finally, if significant adaptation is required in a new context, it is sometimes referred to as a separate innovation (for a full discussion of innovation see Ashford and Hall, 2018, Chapter 6).

While governments, as well as the private sector, generally devote significant resources to create innovations, especially in saleable products although process innovations also receive attention, it is important for our purposes to distinguish what motivates a particular innovation and who provides the financial capital to spur both innovation and diffusion (Ashford and Renda, 2016, p. 36).

Innovation may be driven by technology-push or market-pull forces (see Fig. 1) (Ashford and Renda, 2016, p. 36). Industrial sectors routinely engage in the R&D necessary to develop saleable technologies with the hope that the market will absorb them, even in the absence of nascent market demand. This occurs naturally (as an evolutionary process) and can take decades. Traditional industrial policy that provides government assistance is often said to "grease the wheels of innovation" in hopes of the nation enjoying financial rewards (see the discussion below).

The role of the government in promoting innovation is presented in Fig. 2, indicating all the traditional ways in which innovation might be stimulated (Ashford and Hall, 2011).

The interventions depicted in the figure are of course familiar to those involved with traditional industrial (or perhaps more accurately, innovation) policy that focuses on singular product or process changes. System innovations, discussed below, such as the transportation system or the agricultural system necessarily involve multiple economic actors interacting in larger venues and this model does not adequately represent the complexity involved in system transformations. Technology-push innovations are pursued by profit-seeking firms and by countries seeking to enhance domestic and trade revenues.

In contrast, there are often nascent or express market needs demanding to be satisfied. Market-pull innovations can also be pioneered (Jänicke and Jacob, 2005) by firms recognizing an unmet societal or market need and direct their innovative efforts towards that end. Often the demand is difficult to assess and can wane over time. An example is the need for a better chemotherapeutic approach to cancer, or increased concern for finding a cure for Alzheimer's disease. Often, the R&D need is cutting-edge and financially risky. Government often supports the initial forays into research that is considered too risky by the private sector as exemplified by the development of computers, aircraft, and the Internet (Mazzucato et al., 2015).

When it comes to stimulating innovation (and diffusion) of system transformations – and as we argue in this article – there seems little doubt that government setting of specific medium- to long-term mandatory targets, plus economic support, are essential for achieving transformations within a reasonable period of time (Ashford et al., 1985; Pelkmans and Renda, 2014). For a discussion of targets in the context of evolutionary and co-evolutionary pathways, see Section 4 of this paper. Regulation and mandated targets essentially collectivize public demand or needs through the setting of standards and requirements (Ashford et al., 1985). Costs are imposed on the private sector with cost-sharing achieved through business and R&D deductions. Sometimes direct subsidies are provided. Governments need to understand the different forces giving rise to innovation and diffusion, and not succumb to traditional industrial policy if serious transformations – especially involving the displacement of incumbents or system changes involving many different economic actors – is what is needed. For a further discussion of industrial policies, see Andreoni (2017), Norman and Stiglitz (2017), and Stiglitz et al. (2013). For a discussion of targets in the context of evolutionary and co-evolutionary pathways, see Section 4 of this paper.

In the last decade, the concept of co-evolutionary innovation has been introduced by Dutch researchers injecting government and stakeholder guidance in the selection process entailing strategic niche management and transition management (Grin et al., 2010). This co-evolutionary process is advocated for system innovation, but its promoters admit the transformations can also take decades to achieve.

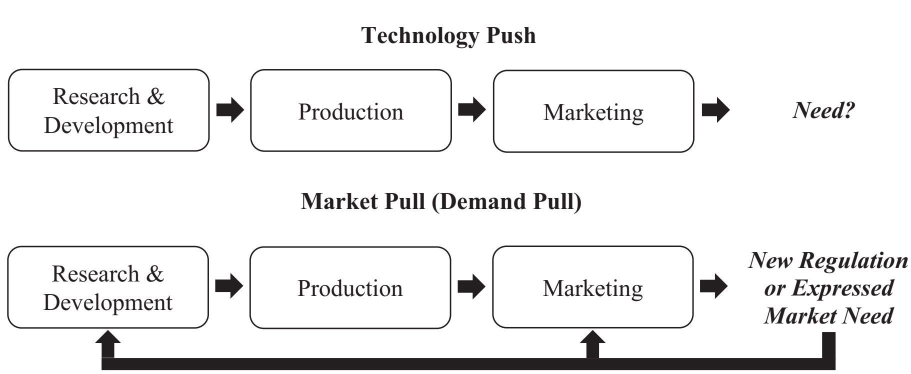

Fig. 1. Technology push vs. market pull innovation.

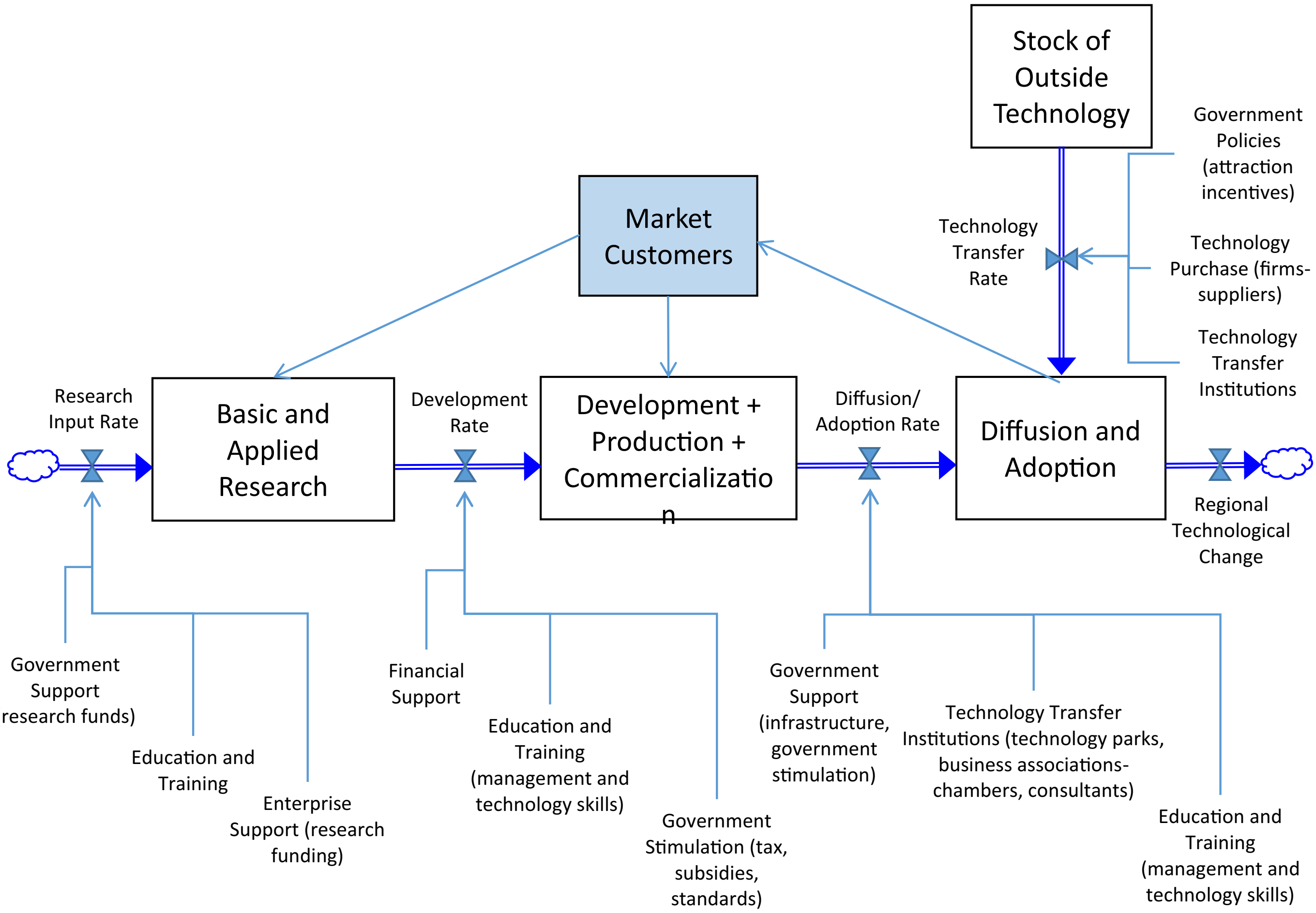

Fig. 2. Traditional industrial policy interventions.
Source: Ashford and Hall (2011).

We certainly believe that system transformations are key to achieving systemic change involving technological, organizational, institutional, and societal innovations among a disparate collection of economic actors, but a much more directive role for government to meet the challenges is needed through an integrated approach utilizing a policy mix of regulations, mandatory targets, and appropriate economic signals (see for example, Rogge et al., 2017; Grubb et al., 2017; and Kivimaa and Kern, 2016). The government must take on the role of trustee for the needed transformations – and trustee of the technologies and firms of the future, often not yet represented at the negotiation table – not of referee, teacher, or generator of consensus.

Finally, one of the bottlenecks in commercialization of useful technologies may come late in the innovation cycle. The innovation literature emphasizes the importance of *deployment* – the step in which a technology moves from bench-top or lab to actual commercial use in practice. Semantic preferences differ as to whether this is described as the last step in the innovation activity or the first step in diffusion. Semantics aside, what is important is that the R&D to accomplish this transition is not basic research, but truly *applied* research, a distinction glossed over in discussions of innovation policy. Barriers to deployment are often influenced by incumbents whose technologies compete with the new technology and seek to delay or prevent its entry. SNM and TM scholars are certainly correct that niches of outsiders could *theoretically* deploy the needed technologies that otherwise cannot penetrate the market to the benefit of society. The strategic question is whether SNM and TM approaches are the best way forward.

2.1. Theories of System Innovation

When we move beyond product and process innovation into system changes, in addition to the wide range of instruments that can be used to guide technological development (in the product and process contexts), there are a number of theories that describe the process of technological innovation. Box 1 shows how the various schools of economic, historical, and sociological thought differ in their approaches to conceptualizing technological development. In each description, the role of government is identified. Whether technologies from these niches go far enough in a particular context is an important question. Ashford and Renda (2016) have argued that rather than an innovation deficit, achieving serious reductions in GHG emissions suffer from a "diffusion" or "deployment deficit". These authors argue that stringent mandatory targets are needed.

The theories of technological innovation shown in Box 1 provide an indication why focusing on government intervention in the process of technological innovation is important, even necessary. In addition, although the policy instruments above have been listed in a general form, we should recognize that the success of a particular instrument in directing or stimulating technological development is context sensitive (Wallace, 1995).

Understanding the role of societal (or cultural) change and how new technology forms can regulate social behavior is essential (Winner, 1977, 1986, 1992). If society is unwilling to accept (or buy) a new technology, then that technology will not be diffused sufficiently to affect the overall system (unless it is imposed by regulation).

Asking whether a new technology form is likely to be diffused

Box 1
Theories of technological innovation and the role of government (Ashford and Hall, 2018, Chapter 8).

Neoclassical economic approach: Technological development is *exogenous*, and technology is treated as a black box. Using this approach, a rational actor will attempt to maximize the production function. Government intervention corrects underinvestment by stimulating fundamental R&D and supporting universities.

Evolutionary economic approach: Technological development is *endogenous* and is a path-dependent process of variation and selection. Technology is described as evolving from a firm's knowledge base. Technological development tends to occur along known directions, favoring path dependency and lock-in. The role of the government is to generate variation within an entrepreneurial climate that enhances innovation.

Systems-of-innovation approach: Technological development is a process of interactive learning and includes not only R&D and knowledge production but also the transfer, exchange, and use of knowledge and the demand for knowledge. The aim of technological development is to optimize the use of knowledge generated by a system of related and linked actors. The role of the government is to maintain the institutional knowledge infrastructure of universities and research institutes.

Industrial-networks approach: Technological development takes place in a process of interactions between actors who perform activities and have access to different resources. Thus, technology (innovation) is the result of interactions between firms. No explicit attention is given to directing technological development. The role of the government is to build and renew local knowledge-intensive networks and to stimulate cooperation.

Social constructivism approaches: Technological development is led by a process of social interaction that is directed by the values and beliefs of interest groups and actors (including government). The role of the government is to understand and articulate specific positions during negotiations and to develop networks that support social interaction.

Quasi-evolutionary approach: Technological development is a process of co-evolution at different levels of analysis (micro, meso, and macro). Hence, technology is an object in a co-evolutionary learning process. The *technological regime*[a] guides, but does not fix, R&D activities. The role of the government is to influence the rules of a technological regime to facilitate learning processes among the various actors, and to establish *niches* of protected learning.

Large-technical-systems approach: Technological development is the process of solving critical problems of a technical (or engineering) system. Technology is seen as part of an expanding technical system. Critical problems – or *reverse salients* – of the technical system have to be solved before the system can expand. The role of the government is to avoid causing or strengthening reverse salients and to reinforce the capacities or possibilities of system builders.

Sources: Luiten (2001), Moors (2000), and Partidario (2003).

[a]Rip and Kemp (1998, p. 340) define a technological regime as "the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems – all of them embedded in institutions and infrastructures."

sufficiently to affect the overall system is critical for sustainable development. In Europe, and more specifically in the Netherlands, there is a growing body of research that looks into how society can transition (that is, transform) to sustainable forms of development through system innovation (Elzen, 2002; Elzen et al., 2004; Grin et al., 2010; Kemp and Rotmans, 2005; van Mierlo et al., 2010).

A "transition" (or transformation) is described as "a long-term change process in an important sub-system encompassing various functional systems (for example, food production and consumption, mobility, energy supply and use, etc.) in which both the technical and the social/cultural dimensions of such systems change drastically" (Elzen, 2002, p. 1). A "system innovation" is described as "a set of innovations combined in order to provide a service in a novel way or offering new services. System innovations involve a new logic (guiding principle) and new types of practices" (Rennings et al., 2003, p. 14). Geels (2004, pp. 19–20) describes a system innovation as consisting of three important aspects: (1) technological substitution, which includes the emergence and diffusion of new technology that replaces existing technology; (2) the co-evolution of technological and social systems, where both types of systems are continually interacting and changing; and (3) the emergence of new functionalities, where a new product or service provides a new functional characteristic. It follows that a "sustainable" system innovation would provide economic, environmental, and social benefits with the offering of new products, processes, or services.

An important characteristic of research focusing on system innovation is the recognition that the relationships among sets of technologies are dynamic, complex, and nonlinear, and that these technologies are socially embedded. This focus supports the idea of dynamic, as opposed to static, efficiency and the importance of considering the fourfold co-evolution of technology, institutions, organizations, and society. Because the evolutionary economic and quasi-evolutionary approaches to technological innovation (Box 1) make technology and innovation explicit and adopt a systems approach, the frameworks developed to assess system innovation are built on these theories. Because neoclassical economic theory treats technology as exogenous, it does not provide fertile ground for considerations of system innovation.

Briefly, evolutionary economics focuses on the process of technological innovation from the perspective of the survival of the fittest – that is, its roots are Darwinian and Schumpeterian (Geels, 2010; Grin et al., 2010, pp. 35-42). Nelson and Winter (1977, 1982) were the first to develop an economic theory in which the evolutionary theory of technological innovation was embedded. Their theory is based on two independent processes: variation and selection. In addition, because technology is treated as being socially embedded, the ideas of path dependency or lock-in and bounded rationality play important roles in the analysis of technological innovation. For a more recent treatment of lock-in in the context of a carbon economy, including technological, infrastructural, institutional, and behavioral lock-in see Geels (2014) and Seto et al. (2016). The evolutionary model of technological innovation was later extended by focusing on the sociological aspects of the evolutionary approach (Rip, 1992; van de Belt and Rip, 1987). The so-called evolutionary approach treats the variation and selection of technology as non-independent events (Moors, 2000). Thus, the focus is on how technological variations are influenced by the selection environment.

The field of evolutionary economics has emerged as one important framework for understanding how modern economies work. Development is conceived as an evolutionary process. In general, evolutionary theory views innovation as a dynamic, interactive process of variation and selection where institutions and actors continually influence and learn from each other.

Within evolutionary theory there are currently two important and related conceptual frameworks that can be used to develop initiatives to stimulate system innovation for sustainable transformations. Kemp (2002), Kemp et al. (2007); Kemp and Rotmans (2005); and Loorbach and Huffenreuter (2013) propose "strategic niche management" and "transition management" – a quasi-evolutionary approach – for achieving system changes necessary for sustainability. Ashford and Hall (2011, 2018) argue for integrating rather than coordinating government interventions in order to bring about the needed technological, organizational, institutional, and social transformations to achieve significant sustainable system change. A role for government is anticipated by each group of commentators, but to different degrees and in different ways.

3. Strategic Niche Management and Transition Management

The concept of strategic niche management (SNM) emerged from the two opposing views of the *technological fix ideology* (or technological optimism) and the *cultural fix paradigm* (Hoogma et al., 2002). The former argues that the benefits associated with technological progress are likely to far outweigh costs, and that a technological solution can be found to all problems. The latter suggests that the technology itself is actually part of the problem and that real solutions will have to come from *social* and *cultural* change. Therefore, SNM was created to "allow for working on both the technical and the social side in a simultaneous and coherent manner" (Hoogma et al., 2002, p. 3). The related concept of transition management (TM) is discussed later in this section. SNM and TM are only two of several possible theories of sustainable transitions/transformations we have chosen to discuss – see Feola (2015) – because they have captured the attention of Dutch and EU industrial policy, especially regarding energy, and because they heavily envision the involvement of incumbents and would (in our view as explained more fully later) require too long a time to yield the necessary radical technological and social changes to be useful. A useful and thorough treatment of the history of SNM and TM is provided by Loorbach et al. (2017).

Kemp (2002, p. 10) describes SNM as the "creation and management of a niche for an innovation with the aim of promoting processes of co-evolution." The idea is that a new product will be used by *real* users (by society, industry, or government), and its use will promote interactive learning and build a product constituency. The underlying notion is that new technologies will be introduced in a socially embedded manner. It is important to realize that SNM is primarily focused on product innovation, not process innovation. However, its proponents argue that process innovation will be part of technological regime transformations (see the discussion of regime change below). SNM also enables institutions and organizations to adjust the technological development and deployment process to stimulate the adoption and diffusion of a new product.

A key element of the SNM concept is that technological change occurs in a co-evolutionary manner – that is, technologies evolve within institutional networks. Saviotti (2005) suggests that two important general points can be made about the co-evolution of technologies and institutions: "First, the emergence of new technologies increases the division of labor in the economy, but in the meantime creates new coordination problems. One of the roles of co-evolving institutions is to provide coordination. Second, although the firms producing and using the new technologies compete, other co-evolving institutions are in a complementary relationship with the main technology" (Saviotti, 2005, p. 30). Saviotti's comments highlight the complexity that surrounds the introduction of a new technology and provide weight to Kemp's arguments for the creation of protective niches in which promising technology can be tested and developed. The ability to experiment with new technology through demonstration projects that help users and suppliers learn about new possibilities is a vital component of SNM.

The process of experimentation is likely to achieve one of two outcomes: regime optimization or regime shifts. These two outcomes can be described as sustaining or disrupting changes, respectively. A technological regime is defined as "the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures" (Hoogma et al., 2002, p. 19). In general, the type of technologies that are suitable for experimentation should be ones that hold the potential to bridge the gap between existing and new (sustainable) technological regimes (Kemp, 2002). This type of technology is referred to as "pathway technology." In essence, SNM is a bottom-up, initially nondisruptive process where once the niche for experimentation has been established by government policy, the new technology form evolves from interactions among society, government, nongovernmental organizations, and industry. The emphasis is on multistakeholder governance rather than on government as the dominant actor.

Transition management (TM) is a model of co-evolutionary management of transformative change in societal systems through a process of searching, learning, and experimenting (Rotmans and Kemp, 2008).[1] Managing means adjusting, adapting, and influencing rather than using a command-and-control approach. There are persistent problems for which there are no immediate solutions. By transforming a persistent problem into a visionary challenge, TM explores a range of possible options and pathways through carrying out a diversity of small-scale experiments. Based on what is learned from these, the vision, agenda, and pathways are adjusted. Successful experiments are continued and can be scaled up, and failed experiments are abandoned, until convergence is reached. Rather than focusing on a single, available solution, TM explores various options and is aimed at guiding variation-selection processes into more sustainable directions, with the long-term aim of selecting the most sustainable option(s) and paths based on learning experiences. TM is meant to be a mutually supportive vehicle for both sociotechnical and policy changes.

It is debatable whether Kemp's description of the latter strategy will result in disrupting innovation. Kemp (2008, p. 374) acknowledges that "faced with sustainability problems, [incumbent] regime actors will opt for change that is non-disruptive from the industry point of view, which leads them to focus their attention on system improvement instead of system innovation." Whether the concept could hold particular merit for system innovation in a specific context remains to be seen. If revolutionary change – or a technological regime shift – can occur via a stepwise system innovation process, SNM can be a useful tool that can be applied to large-scale engineering systems, such as the transportation system (Hoogma et al., 2002; Hoogma et al., 2001), but that is a big "if." It depends on, among other things, the extent to which incumbents dominate the process. A more optimistic set of scenarios incorporating disrupting changes for energy transformations is discussed by Wilson and Tyfield (2018).

[1] Kemp (2008, p. 375) comments: "The management of institutions can be done through the […] use of three coordinating mechanisms: markets, hierarchy, and structure." "The basic steering mechanism is modulation, not dictatorship or planning and control" (Kemp, 2008, p. 377), and "The long-term goals for functional systems are chosen by society either through the political process or in a more direct way through a consultative process" (Kemp, 2008). Kemp endorses market-based instruments, and although he does not explicitly mention regulation, it is clear that he rejects regulation as the main steering approach; this is in line with his commitment to evolutionary approaches and strong commitment to markets. This parallels the recent contribution of ecological economists Beddoe et al. (2009, p. 2488), who also ignore regulation as a mechanism to achieve sustainable transformations and instead rely on cultural evolution to "push our society towards the adoption of institutions that best fit the new circumstances." "Creating a sustainable future will require an integrated, systems level redesign of our socio-ecological regime focused explicitly and directly on the goal of sustainable quality of life rather than the proxy of unlimited material growth" (Beddoe et al., 2009, p. 2483).

Critics of SNM argue that one of the shortcomings of the technique is that at some point the "probe and learn" ideology needs to become action and transformation, and Kemp's theory is unclear on how transformation will occur (Smith, 2003). Further, if niches grow within or alongside existing regimes, they are unlikely to have radically different practices and rules, which raises the question whether the new products, processes, or services will offer significant benefits. A final point raised by Smith (2003) is the fact that the localization of niches may run against the nationalization or globalization ideology of mainstream government and business institutions. Thus, an important question is whether the "transformative potential" of SNM will be inhibited by these powerful forces (Smith, 2003).

Vergragt (2005) raises a slightly different concern from that of Smith (2003). He argues that if the role of government is to legitimize the transition process – including its own reform and the abolition of existing institutional and economic barriers to sustainable development – then a quandary exists because the national government may in fact be part of the problem rather than part of the solution. Therefore, an important question is who will manage the transition process. Quist and Vergragt (2004) also question whether an emerging niche market will survive once its protection mechanisms are removed. On the other hand, Grin et al. (2010, p. 83), in stating that "[m]uch of the cited research focuses on explaining the limited success of the [SNM] experiments studied," references Hommels et al. (2007, p. 85) who are described as arguing that "part of the problem might be that SNM focuses too much on providing protection."

In critiquing the TM approach, Tukker et al. (2008) comment that transition management of innovation neglects the role of the consumer and the importance of demand-side policies influencing consumption. It should be noted that regulation is both a supply-side and demand-side policy intervention; it defines the allowable characteristics and places constraints on the nature of products and on their manufacturing, use, and disposal (Ashford and Hall, 2011, p. 280).

Dewulf et al. (2009), in analyzing transition management in the context of other theories of change management – especially intervention by government – question whether transition management is the "only model in town." Dewulf et al. (2009, p. 12) observe that "a distinctive trait of transition management appears to be the assumption of an overarching position of (governmental) transition managers who can apply management tools, niche-building machinery, and engineering devices from a privileged, knowledgeable and external position […] towards a clear and one-dimensional target." The government participates along with other stakeholders, rather than taking a more directive role reminiscent of command-and-control regulatory involvement. The process is characteristically Dutch, using the so-called "polder consensus-seeking model." Dewulf et al. (2009, p. 4) argue that transition management can take a relatively long time – twenty-five to fifty years – whereas collaboration theory in practice focuses on reaching an agreement and effectuating change in a few years' time. Given the existence of relatively short-term "tipping points" in sustainability challenges, e.g., global climate disruption, endocrine disruption, and rapidly changing financial landscapes, the benefits of transition management may come far too late. Collaborative processes, of course, have their own drawbacks.

Recent transition scholarship has directly addressed the acknowledgement that evolutionary or co-evolutionary developments may take far too long given the challenges presented, particularly in energy and climate change (Sovacool, 2016; Sovacool and Geels, 2016; Kern and Rogge, 2016). Kern and Rogge (2016, p. 13) argue "that quicker transitions have happened in the past and may therefore also be possible in the future globally." They offer three main reasons "for the possibility of low-carbon transitions of the energy system occurring faster than was the case for historical transitions" (Kern and Rogge, 2016, p. 13). First, historic energy transitions have not been consciously governed, whereas today a wide variety of actors is engaged in active attempts to govern the transition towards low carbon energy systems. Second, and in addition to the first point, international innovation dynamics can work in favor of speeding up the global low-carbon transition. Finally, the 2015 Paris agreement demonstrates a global commitment to move towards a low carbon economy for the first time. Of course, the Paris agreement is a quasi-regulatory, though voluntary, set of commitments and Ashford and Renda (2016) have argued that we need to heed the warnings of Jeffrey Sachs that picking the long-hanging fruit to meet those commitments may herald in the wrong kind of technological responses (Sachs et al., 2015).

Although Kemp acknowledges that regulation can be a useful tool to stimulate radical (system) changes, his faith in the formation of strategic niches and stepwise change *within* the original technology regime is not likely to result in disrupting forms of technology that are necessary for sustainable development. The problem is that firms are likely to resist initiatives or regulations that threaten their market position and focus instead on activities that maintain the status quo. Thus, a reliance on evolutionary or even co-evolutionary change rather than revolutionary change is not likely to support the emergence of new market entrants who play an important role in introducing radically different (and potentially more sustainable) forms of technology (Reinhardt, 1999).

Berkhout et al. (2004) make a case similar to that of Ashford and Hall (2011). They argue that the tendency of critical social groups to target the "incumbent regime, rather than its potential successor, […] represents a direct antithesis of the bottom-up niche-based model" (Berkhout et al., 2004, p. 61). They continue, "The lesson appears to be that attempts at normatively-driven sociotechnical transitions (that is those forms most pertinent to the transition management project) do not follow exclusively the pattern described by the niche-based model, but instead imply much greater attention to macro-level processes (public opinion, government policy, and the structure and scope of markets) and their capacity to influence and induce innovation at the micro- and meso-level. Here the landscape is actively seeking to act on and influence the regime, not the other way around" (Berkhout et al., 2004, pp. 61–62).

Jacob (2005), while generally supportive of decoupling economic growth from environmental degradation through ecological modernization, raises questions similar to those of Ashford and Berkhout et al. and asks whether SNM's experimental arena is likely to capture and maintain the necessary political (and financial) support for a real transition. Further, Jacob (2005) argues that although "discourse and persuasion" are useful tools, they are unlikely to resolve any opposing core beliefs held by the actors. Thus, bargaining and making trade-offs are likely to play an inevitable role in any decision-making and transition process.

Finally, continuing from Smith's (2003) earlier reservations about the ability of SNM to bring about the needed transformations, Smith and Kern (2007) comment on its limited success in energy policy in the Netherlands. They describe how Kemp and Rotmans persuaded the Dutch government to adopt SNM as a central strategy in its Fourth National Environmental Policy Plan (NMP4) in 2001. It should be noted, however, that the environmental successes of earlier Dutch National Environmental Policy Plans (NEPPs) were premised on the government setting clear future targets but negotiating ways of achieving those targets with stakeholders. The approach later adopted in its NEPP was to negotiate both targets and pathways with stakeholders. Existing industrial stakeholders may not represent the interests or capacity of future technology providers who are likely to displace them.

The NMP4 focuses on restructuring production and consumption systems over a thirty-year period to achieve a reduction of one-twentieth in both resource and energy use. Some challenged whether such a change can be achieved through SNM (Smith and Kern, 2007) and TM (Shove and Walker, 2007). The latter critique stimulated a response by Rotmans and Kemp (2008) and a counter-response by Shove and Walker (2008), illustrating just how important the issue of transition management is becoming in the sustainability debate.

In spite of initial reservations about the success of TM-inspired re-incarnation of long-term policy design, some of its critics are cautiously optimistic about its future use (Shove, 2010; Voss et al., 2009). We, however, remain skeptical because (1) the time framework for success is far too long given the challenges of sustainable development, (2) there is too much potential for capture of future agendas by incumbents, even if they change somewhat, and (3) without clear and certain long-term targets characteristic of backcasting, long-term investments by new entrants leading to discontinuous change necessary for radical technological change are unlikely to be made. Backcasting in incremental steps is not long-term backcasting, and while it introduces flexibility and mid-term corrections, it does not provide certain targets towards which to innovate. Again, we find it difficult to be optimistic that step-wise changes made towards uncertain futures involving incumbents will lead to radical, disrupting changes. Ecological modernization or reflexive governance arose historically because governments were not willing to exercise courage at setting long-term goals that challenge incumbent forces and agendas. Second generation policy design, represented by SNM and TM, operating under the soft euphemism of accommodation and learning has similar serious weaknesses.

In an earlier critique of the policy implications of SNM, Grin et al. (2010, p. 91) offer:

> The research discussed indicates that SNM is not a silver-bullet solution that will bring about transitions towards sustainable development, if only because experimenting will not be sufficient. SNM should be seen as a useful addition to existing policy instruments that have neglected the value of experiments. Other more traditional instruments for inducing sustainable innovation, such as market incentives, various forms of regulation and technology forcing also have to play a role.

Grin et al. (2010, p. 84) distinguish the potential effectiveness of TM and SNM:

> we acknowledge that TM addresses some factors that SNM underplays. While SNM develops an evolutionary approach that builds on and leverages the dynamic forces of market competition, aimed at overcoming lock-in and promoting socio-technical diversity, TM suggests a more ambitious approach of goal-oriented modulation that places more emphasis on the role of strategic envisioning. In that respect, TM introduces the notion of "transition experiment" which is supposed to be different from regular innovation experiments (van den Bosch and Taanman (2006)).

In more recent work, Smith and Raven (2012) offer an extensive analysis of niches as protected spaces for which the important dynamics are shielding, nurturing, and empowerment. They distinguish incumbents (perhaps dominant incumbents) seeking to continue innovating on proven technology development (mainstream pathways) from others seeking more innovative changes, but a distinction is not made between those "others" who are incumbents and non-incumbents. While a distinction is made between insiders and outsiders, the implication is that both seem to be within the incumbent category, and not the distinction that van de Poel (2000) has made in his work on "outsiders."

Further, while mainstream selection environments hinder path-breaking innovations, the fact that some incumbents seek the protection offered by strategic niche management does not mean the innovations that come forth are significant or sufficiently disruptive. For a contrary view, see Wilson and Tyfield (2018). New innovations nurtured by SNM/TM may take decades to penetrate markets, which may be too long to meet many of the significant challenges to sustainability. Smith (2017) comments that "strategic dilemmas confront more radical, path-breaking innovators [… N]iche spaces […] to develop alternatives and to explore what kinds of new institutions are needed for the innovation to flourish are an important ingredient, and have the potential to link with other forms of transformational agency, such as social movements or progressive business and investment."

Addressing the possibility that innovation in the context of energy might be stimulated by the "grassroots" in the UK, Smith et al. (2016, p. 412) observe that "all grassroots developments soon encounter impediments arising from social structures inherent to regimes" and "[i]t is the spread of critical insight, and transformative politics, that becomes the indicator of success." These observations are in line with our own which are circumspect about the sufficiency of "bottom-up" approaches to chart adequate pathways to sustainable development, except perhaps in the local or regional context – see Hansen and Coenen (2015) on this point.

A potentially significant barrier to transformative change is political. Transition processes tend to be "inherently political, and as encompassing, long-term processes of multiple changes in socio-technical systems, they require broad understandings of the political" including the notion of intended capture in system transition, the role of disruptors, path dependency, and incumbents (Avelino et al., 2016 p. 563). For a further discussion of regime resistance, disruption by outsiders, and the political challenge of governance, see Geels (2014), Kungl (2015), Markard et al. (2016), Meadowcroft (2009, 2011), Stirling (2014), and Voss et al. (2009). See also, Avelino (2017) who analyzes power and empowerment in the context of sustainability transitions and transition governance.

Many scholars acknowledge the importance and difficulties of incumbents in fostering transitions towards sustainability (for a comprehensive treatment see Johnstone and Newell, 2018 and Turnheim et al., 2015). Relying on a deep review of the literature, Smink (2015) in particular explores the many ways in which incumbents guide and influence government policies and put new entrants at a disadvantage, including what amounts to regulatory capture. There is precious little discussion of the role that stringent regulation can play to "make a market for innovation" (Ashford et al., 1985), where what is being demanded cannot easily be satisfied or developed by the incumbents' technology and requires radical (i.e., disrupting) innovation which is less likely to come from the incumbents than outsiders or new entrants. This omission demonstrates a blind spot on the part of scholars who see change as coming not from government technology-forcing, but via predominantly evolutionary or co-evolutionary pathways. Stringent regulation can turn the tide towards the advantage of outsiders (Ashford et al., 1985; Ashford and Hall, 2011). Modest regulation gives incumbents the advantage.

Johnstone and Newell (2018, p. 1) comment that the role of the state (government) is underdeveloped in the transition management literature and "the range and depth of powers that only the state can call upon will be required if radical and rapid transitions are to be achieved" in order that economic systems operate within planetary boundaries. Referencing, among others Mazzucato (2015), Aiginger (2014), and Stiglitz et al. (2013), the authors emphasize the importance of government beyond nurturing niches in influencing industrial policy. They observe that "it has been recognized for some time that there has been an overemphasis on niche development, and that accelerated transitions will have to tackle the dynamics which sustain the stability of unsustainable social-technical systems" and that "regime stability […] slows the pace of [the needed] transitions […] through the strategies of incumbents" (Johnstone and Newell, 2018, p. 3). They conclude "the state in varying ways plays a variety of roles in sustainability transitions, both acting as an enabler and a barrier to transformations to sustainability" (Johnstone and Newell, 2018, p. 9), depending on whose interests the state serves.

4. A Stronger Role for Government

Government has an important role to play in creating winning forces and visions for sustainable transformations. Depending on the type of transformation required, the roles of government should encompass the following (Ashford, 2002b, pp. 18–19):

- The direct support of R&D and incentives for innovation through appropriate tax treatment of investment;
- the creation and dissemination of knowledge through experimentation and demonstration projects;
- the creation of markets through government purchasing;
- the removal of perverse incentives of regulations in some instances and the deliberate design and use of regulation to stimulate change in others;
- the training of owners, workers, and entrepreneurs, and educating consumers; and
- the direct creation of meaningful, rewarding, and satisfying jobs.

It should be clear how these roles relate to the ideas embedded in SNM and TM approaches, but we envision a much stronger role for government in stimulating technological innovation.

Much has been written about "policy mixes" addressing both technology-push and market/demand-pull strategies. They involve research and development undertaken by the government itself (Mazzucato et al., 2015), government funding of research and development at universities and research institutions, economic or market instruments, and regulatory standards to harmonize industrial practices. They are generally focused on greasing the industrial development process, rather than stimulating radical technology that falls under the rubric of "technology-forcing."

A review of papers on policy mixes is provided by Rogge et al. (2017), who draw conclusions from analyzing fifteen papers with different analytical perspectives based on a range of social science disciplines, such as environmental economics, innovation studies, and policy sciences. These papers present a different understanding of policy mixes, and offer a list of key definitions of policy mix components: policy instruments, policy design features, instrument interactions, policy strategy, policy process, and consistency, coherence, or credibility.

Notable articles (all focusing on energy) provide the following insights on the role policy and regulation can play in inducing innovation[2]:

- Cantner et al. (2016, p. 1165): "policies and environmental regulations are important drivers [for both development and diffusion] in environmental technologies especially, in renewable energies;"
- Costantini et al. (2017, p. 799): "a variety of factors drive eco-innovation, but also highlight the primary role played by public policies (environmental regulation, energy and technology policies) that are increasingly used to foster the rate of introduction and diffusion of new environmental technologies to meet sustainable development goals" and "strict regulations on vehicle emissions in the US spurred innovation in foreign countries such as Germany and Japan" (Costantini et al., 2017, p. 801);
- Grubb et al. (2017, p. 25): "many big energy sector investments are in sectors (like electricity), which if not directly conducted by state entities, are nevertheless strongly influenced by the rules and regulations that shape the market structure and related terms of investment;" and
- Jacobsson et al. (2017, p. 18): "the Commission's focus on market failures, static efficiency and technology neutrality does not cover all possible obstacles and leads it to neglect the centrality of dynamic efficiency and the structural build-up of innovation systems around new technologies." The paper scrutinizes "the analytical base of the EU Commission, contrast[s] it with the work of classical economists and recent innovation scholars, and draw[s] lessons for how effective mixes of policy instruments may be identified."

Government should go beyond simply creating a favorable investment climate. "Without deliberate design, significant changes – even system changes – are unlikely to improve competitiveness, environment, and employment at the same time" (Ashford, 2002b, p. 18). As discussed in the next section, *stringent regulation* (focusing on environmental, health, and safety issues) is essential to stimulate significant technological changes, and such regulation may in fact be necessary to create niches that facilitate the entry of new firms and organizations into a new market.

Others who support the view that stringent regulation is necessary for environmental innovation include Foxon et al. (2004); Huber (2004b); Jänicke (1990); Pelkmans and Renda (2014); Botta and Koźluk (2014); and Ghisetti and Pontoni (2015). For instance, Huber (2004a, p. 447) comments that "strict environmental performance standards [… remain] by far the most effective controls instrument for environment and innovation alike (which is not astonishing given the fact that environmental standards are, or immediately translate into, technical standards)." Perhaps what is astonishing is the largely absent mention of government regulation in the early SNM and TM literature. See Pelkmans and Renda (2014) for a recent review of the stimulating effects of regulation on innovation. In later scholarship, regulation appears to be increasingly addressed – see Geels et al. (2016), Hoppmann et al. (2014), Markard et al. (2012), Normann (2017), Quitzow (2015), Smith et al. (2005), and Smith and Raven (2012). It is mentioned as one of four interventions in later literature focused on a dual policy focus on destabilizing incumbents and creating new niches in Kivimaa and Kern (2016, p. 215).

Ashford et al. (1985) have long argued that an *evolutionary* (or incremental) pathway is insufficient to achieve factor ten or greater improvement in a system's performance. Further, because changes in sociotechnical systems (such as the transportation or energy system) are difficult, the "creative use of government intervention is a more promising strategic approach" for achieving sustainable industrial transformations than the reliance on the more neo-liberal policies relying on firms' more short-term economic self-interest" (Ashford, 2002b, p. 10). Hence, relying on Christensen's (1997) approach to radical disrupting innovation is seen as being unlikely to result in "system" transitions towards sustainable development; however, disrupting forms of technological change are likely to continue.

In addition, Ashford (2002b, p. 19) states that governments should work with stakeholders to define future targets – while ensuring that their agendas are not captured by incumbent firms – and then use their position as trustee to "represent the future generations and the future technologies to 'backcast' what specific policies are necessary to produce the required technical, organizational, and social transformations." (Ashford, 2002b)[3] More recent work on the importance of targets includes: Johnstone et al. (2010) on Kyoto targets; Schmidt et al. (2012) on 2020 climate targets; Reichardt et al. (2016) on technology-specific renewables targets; and Nemet et al. (2014) on the credibility of energy policy targets. See also Loorbach et al. (2017).

Sixteen years after Ashford's (2002b) assertion, we contiue to believe that it is likely that an evolutionary pathway is insufficient to achieve factor ten or greater improvements in eco- and energy efficiency and reductions in the production and use of, and exposure to, toxic substances. Such improvements require more systemic, multidimensional, and disruptive changes. We have already asserted that the capacity to change can be the limiting factor, and that this is often a crucial missing factor in optimistic scenarios.

Successful management of disruptive product innovation requires initiatives and input from outsiders to produce the expansion of the design space that limits the dominant technology firms. Especially in

[2] See also Johnstone et al. (2017), Kern et al. (2017), Kivimaa et al. (2017), and Kivimaa and Kern (2016).

[3] The backcasting approach enables policy makers to look back from a desirable future to create strategies that they hope will enable the future visions to materialize. This approach is in contrast to current planning processes that develop strategies based on forecasts.

sectors with an important public or collective involvement, like transportation, construction, and agriculture, this means that new government-led approaches are required to bring about necessary change.

Rigid industries whose processes have remained stagnant also face considerable difficulties in becoming significantly more sustainable. Shifts from products to product-services rely on changes in the use, location, and ownership of products in which mature product manufacturers may participate, but this requires significant changes involving both managerial and social (customer) innovations. Changes in sociotechnical systems, such as transportation or agriculture, are even more difficult. This is why the creative use of government intervention to stimulate the needed changes may be critical.

This is not to say that enhanced analytic and technical capabilities on the part of firms and cooperative efforts and improved communication with suppliers, customers, workers, other industries, and environmental/consumer/community groups are not valuable adjuncts in the transformation process. But in most cases, these means and strategies are unlikely to be sufficient by themselves for significant transformations, and they will not work without clear mandated targets to enhance the triple goals of competitiveness, environmental quality, and enhancement of employment/labor concerns.

Government has a significant role to play, but the government cannot simply serve as a referee or arbiter of existing competing interests, because neither future generations nor future technologies are adequately represented by the existing stakeholders. And new stakeholders are only marginally likely to be brought into development by incumbents, notwithstanding the wishful thinking of SNM and TM advocates.

Government should work with stakeholders to define far-future targets, but without allowing the incumbents to capture the agenda. It has to go beyond its historical focus on coordinating public- and private-sector policies. It must be multidimensional and directly address the present fragmentation of governmental functions. This means that the various policies must be mutually reinforcing and the targets must be clear.

In a recent report intended for the EU Commission by Ashford and Renda (2016), the authors address the likelihood of the EU achieving deep de-carbonization by pursuing traditional industrial policy. They argue that the key is in properly designed and executed regulation.

Beyond energy and climate change challenges, Loorbach and Huffenreuter (2013) address the economic crisis and explore whether TM might contribute to mitigating or overcoming its effects. They provide a lucid analysis of the origin of the crises, the contribution of incumbents to perpetuating an economic development model that is "broken" and focused on GDP-led growth (resulting in systemic lock-in), and question whether "going green" is sufficient to address the needed development reforms because being dependent on GDP is not a "fundamental systemic solution." The authors focus on currencies, resources, and governance, and they argue for a combined "bottom-up" and "top-down" approach, which they term 'glocal governance' that aims to avoid economic growth that results in unequal distribution of resources and increased levels of ecological damage. Also see Loorbach et al. (2017) on the importance of setting targets to escape lock-in in the context of incumbent transformations through transition management in order to stimulate radical innovation. Here, although lock-in is explicitly recognized as a problem, specific policies are lacking. The authors state that "although technologies might play an important role in understanding transitional change, the emphasis is rather on how incumbent routines, powers, interests, discourses, and regulations create path dependencies and how these are challenged by (transformative) social innovations" (Loorbach et al., 2017, p. 610). In other words, regulations are mentioned in the context of their creating lock-in, but not their use in breaking lock-in. Yet the authors comment (Loorbach et al., 2017, p. 600):

> It has been only over the past decade or so that real progress is being made with the diffusion of renewable technologies. It coincides with increasing disruptions in markets for oil and gas, sharp declines in the use of coal, and struggling fossil energy companies. The current dynamics are only partly driven by incumbent actors and are heavily influenced by "outsiders" to the fossil energy system such as co-operatives and cities; companies such as Tesla, Siemens, Ikea, and Google; and social movements such as the divestment movement and the LINGO ("Leave It in the Ground") campaign. The energy transition is thus much more than merely a technological shift; it is a power strugogle and a socio-cultural change having a deep effect on incumbent institutions, routines, and beliefs.

While the analysis of Loorbach and Huffenreuter (2013) is insightful, we believe their faith in TM offering a solution is more wishful thinking – by providing opportunities for transition pathways – than backed up by evidence. Examples of community-based economic activity and alternative currencies do not have enough traction on which to base a revolution. In fact, they leave to future research the means to bring this transformation about.

As with so much of the early writing on TM and SNM, the focus was curiously on only influencing and destabilizing incumbents, rather than replacing them, and government regulation was only vaguely discussed in the context of creating an effective and timely stimuli for change. Later writing (for exmaple, see Kivimaa and Kern, 2016) departed from this myopia and recognized the need of creating or propelling niches to replace the incumbents using regulation but without emphasizing the importance of mandatory targets that demand performance beyond current capabilities.

5. Regulation-induced Innovation as an Alternative Pathway to Achieving Sustainable Development

In a longer article the authors have argued that regulation – properly fashioned – can transform products and processes which confers both economic and health, safety, and environmental benefits as well as costs (Ashford and Hall, 2011). In contrast, classical economic analysis of the relationship between health, safety, and environmental regulation and competitiveness maintains that stringent regulation increases production costs, diverts resources from R&D, and consequently hinders innovation. This assumption was challenged first in the late 1970s at MIT and made popular in 1991 by the so-called 'Porter hypothesis' (Porter, 1991; Porter and van den Linde, 1995).

The Porter hypothesis and the relevant literature indicate that environmental, health, and safety regulation can induce dramatic innovations, not only by spurring the development of new products or services by incumbent producers, but also by creating conditions in which new producers can enter the field. Regulation can do this when firms have, or are induced to have, the willingness, opportunity, and capacity to innovate (Ashford and Hall, 2011, 2018). This literature, and the insights gleaned from it, provides an important set of clues for how regulation can be used to foster sustainability.

Based upon his research into the competitive advantage of nations, Porter (1991, p. 168) claimed that "[s]trict environmental regulations do not inevitably hinder competitive advantage against foreign rivals; indeed, they often enhance it. Tough standards trigger innovation and upgrading." He observes, "[p]roperly constructed regulatory standards, which aim at outcomes and not methods, will encourage companies to re-engineer their technology. The result in many cases is a process that not only pollutes less but lowers costs or improves quality. […] Strict product regulations can also prod companies into innovating to produce less polluting or more resource-efficient products that will be highly valued internationally" (Porter, 1991). Porter's hypothesis is that [incumbent] firms which respond to stringent regulation by developing new technologies have a 'first mover' advantage and can capture the market for their products/services. Comparison of national competitiveness with good environmental governance and private sector responsiveness supports the Porter hypothesis. Good economic management and good environmental management are related and firms which succeed in developing innovative responses to environmental challenges benefit both environmentally and economically.

Earlier empirically based work on this concept, dates back twelve years before Porter's work to research undertaken at MIT (Ashford, 1993; Ashford et al., 1985; Ashford and Heaton, 1983; Ashford et al., 1979). This earlier work showed how stringent and focused regulations in the U.S. chemical producing and using industries had the effect of stimulating fundamental product and process innovations. The MIT studies revealed that *environmental and health and safety regulation* – if appropriately designed, implemented, and complemented by economic incentives – can lead to radical technological developments that can significantly reduce exposure to toxic chemicals in the natural and working environments, and in consumer products.

A limitation of Porter's hypothesis is that it focuses on how *incumbent firms* respond to more stringent regulations, but it ignores the important dynamics of *new entrants* (van de Poel, 2000). Porter and van den Linde (1995) argue that regulation, properly designed, can cause a regulated firm to undertake innovations that not only reduce pollution – which is a hallmark of production inefficiency – but also save on materials, water, and energy costs, conferring what Porter calls 'innovation offsets' to the innovating firm (and what Ashford and his MIT colleagues called 'ancillary benefits'). This can occur because the firm, at any point in time, is sub-optimal. If the firm is the first to comply with regulation in an intelligent way, other firms will later have to rush to comply and do so in a less thoughtful and more expensive way. Thus, there are 'learning curve' advantages to being first and early.

Given Porter's focus on 'innovation offsets' – i.e., the cost savings due to induced innovation that could exceed the cost of the regulation (Porter and van den Linde, 1995) – he is mainly concerned with the costs to *incumbent* firms. However, it is possible to differentiate between 'weak' and 'strong' forms of the regulation-induced innovation hypothesis – a distinction that Porter does not make. In its weak form, as Porter observes, firms subject to more stringent regulation respond with product and process innovations. However, while environmental and worker health and safety improvements may be realized, the offending products and processes may only be incrementally changed.

In contrast, in the strong form of the regulation-induced innovation hypothesis, stringent regulation can stimulate the entrance of entirely new products and processes into the market, thereby displacing dominant technologies. In this situation, unless incumbent firms have both the willingness and the capability to produce and compete with the new forms of technology, they too are likely to be displaced from the market (Christensen, 1997). Fig. 3 below provides a simple diagram of the likely technological responses to the strong and weak forms of the regulation-induced innovation hypothesis. Empirically-based examples were researched by Ashford and his colleagues in their work.

While some question whether environmental regulation does generate a positive effect on innovation (Jaffe and Palmer, 1997; Robinson, 1995; Walley and Whitehead, 1994), their analyses tends to miss the essence of the 'strong' form of the regulation-induced innovation hypothesis. Although it is likely that stringent regulation will not stimulate technological innovation in most firms, some firms are likely to rise to the challenge and become technological leaders in the process. Hence, the "evidence is necessarily anecdotal" (Ashford, 1999, p. 3). The Schumpeterian notion of 'waves of creative destruction' leading to succeeding advances in technological development describes the process by which dominant technologies are being continually displaced as new technologies become available.

The design challenge facing government is how existing undesirable technologies can be retired (or displaced) through a combination of regulation and market incentives. These ideas thus challenge the notion that incumbent firms will reinvent themselves in a significant way and should have a major role in setting the targets for future regulation. Incumbents will not set targets they do not expect that they can meet.

With regard to the 'weak' form of the regulation-induced innovation hypothesis, ambitious environmental policies in developed nations can lead to the formation of 'lead markets' for environmental technologies (Jänicke and Jacob, 2005). However, the evidence suggests that "the international diffusion of environmental innovations must be accompanied by international policy diffusion, or the adoption by other countries of the induced innovation must be economically reasonable" (Beise et al., 2003, p. 1). Both of these factors make it difficult to predict with certainty whether an ambitious environmental policy is likely to create a lead market for the international diffusion of innovations. The uncertainty surrounding the likely impacts on national industries of more stringent environmental [and health and safety] regulation is seen as one reason why governments hesitate to implement such policies (Blazejczak and Edler, 2004).

Stringent regulation can stimulate new entrants to introduce *entirely new products and processes* into the market – products and processes that will displace dominant technologies. One of several vivid examples is the displacement of Monsanto's PCBs in transformers and capacitors by an entirely different dielectric fluid pioneered by Dow Silicone. Regulation can thus encourage disrupting innovations by giving more influence to new customer bases, in which demands for improvements in both environmental quality and energy use and efficiency are more sharply defined and articulated. Of course, industries that would fear being displaced by new entrants would not be expected to welcome this regulation. This explains in part their resistance to regulation and their propensity to try to capture regulatory regimes, surreptitiously or through direct negotiation with government (Caldart and Ashford, 1999). For a later discussion of resistance from incumbents see Geels (2014) and Hess (2014).

In principle, regulation can be an effective and proper instrument for government to guide the innovation process. Well-designed regulation that sets new rules changes the institutional framework of the market. It can thus be an important element in creating favorable conditions for innovation that will enhance environmental

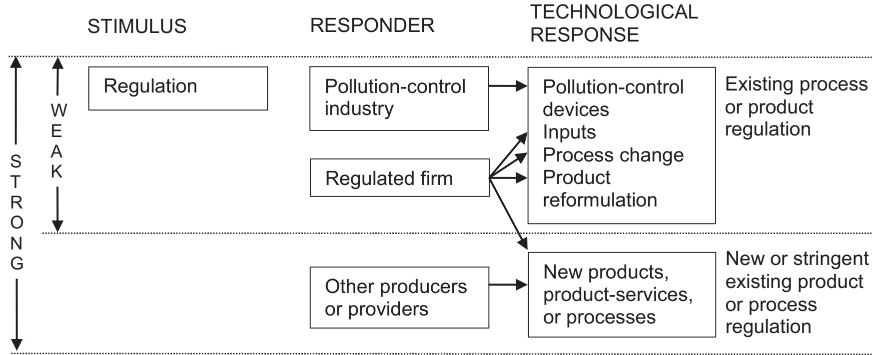

Fig. 3. A model for regulation-induced technological change for 'weak' (Porter) and 'strong' (Ashford/MIT) forms of the regulation-induced innovation hypothesis.

sustainability and create incentives for the development of powerful lead-markets, which pull innovation towards sustainability (Jänicke and Jacob, 2004). With regard to regulation, what seems to matter is not only the stringency, mode (specification versus performance standards), timing, uncertainty, focus (inputs versus product versus process) of the regulation, and the existence of complementary economic incentives, but also the inherent innovativeness (usually in new entrants) or lack of it (usually in the regulated firms) that the regulation engenders.

In order for innovation to occur, the firm (or government itself) must have the *willingness*, *opportunity/motivation*, and *capability/capacity* to innovate (Ashford, 2000; Ashford and Hall, 2018). These three factors affect each other, of course; but each is determined by more fundamental factors.

Willingness is determined by (1) attitudes towards changes in production in general, (2) an understanding of the problem, (3) knowledge of possible options and solutions, and (4) the ability to evaluate alternatives. Improving (3) involves aspects of capacity building through the diffusion of information, through trade associations, government-sponsored education programs, inter-firm contacts, and the like. Changing attitudes towards changes in production (1) often depends on the attitudes of managers and on the larger culture and structure of the organization, which may either stifle or encourage innovation and risk taking. Factors (2) and (4) depend on internal intellectual or knowledge-based capacities. In the context of disrupting innovation by firms representing the dominant technology, willingness is also shaped by the [rare] commitment of management to nurture new approaches that are at odds with its traditional value network or customer base.

Opportunity and motivation involve both supply-side and demand-side factors. On the supply side, technological gaps can exist between the technology currently used in a particular firm and the already-available technology that could be adopted or adapted (known as diffusion or incremental innovation, respectively), or alternatively the technology that could be developed (i.e., significant sustaining or disrupting innovation). Consciousness of these gaps can prompt firms to change their technology, as can the opportunity for cost savings. Regulatory requirements can also define the changes that would be necessary to remain in the market. On the demand side, three factors could push firms towards technological change. These are (1) regulatory requirements, (2) public demand for more environmentally-sound, eco-efficient, and safer industry, products, and services, and (3) worker demands and pressures arising from industrial relations concerns. The first factor could result from changes in the customer value networks. However, all these factors may stimulate change too late in the dominant technology firms, if new entrants have already seized the opportunity to engage in developing disrupting innovations.

Capability or capacity may actually be the most important and limiting factor and can be enhanced by (1) an understanding of the problem, (2) knowledge of possible options and solutions, (3) the ability to evaluate alternatives, (4) resident/available skills and capabilities to innovate, and (5) access to, and interaction with, outsiders. Knowledge enhancement/learning (2) can be facilitated through deliberate or serendipitous transfer of knowledge from suppliers, customers, trade associations, unions, workers, and other firms, and the available literature. The skill base of the firm (4) can be enhanced through educating and training operators, workers, and managers, on both a formal and informal basis, and by deliberate creation of networks and strategic alliances not necessarily confined to a geographical area, nation, or technological regime.

Interaction with outsiders can stimulate more radical and disrupting changes. This last method of enhancing the capacity of firms to undertake technological change involves new 'outsider' firms and stakeholders with which the firm has not traditionally been involved. Capacity to change may also be influenced by the innovativeness (or lack thereof) of the firm as determined by the maturity and technological rigidity of a particular product or production line (Ashford, 2000; Ashford et al., 1985). Some firms find it easier to innovate than others. The heavy, basic industries, which are also sometimes the most polluting, unsafe, and resource-intensive industries, change with great difficulty, especially when it comes to core processes. New industries, such as computer manufacturing, can also be polluting, unsafe (for workers), and resource and energy intensive, although they may find it easier to meet environmental demands. Government should not miss the opportunity to loosen the creative forces that bring about innovative changes that can simultaneously benefit the economy, the environment, and the general welfare.

6. The Importance of Diffusion in Achieving Sustainable Development

Although technological innovation is crucial to achieve long-term sustainable development and fosters adaptive transformations, the preoccupation of scholars with innovation, in contrast with diffusion, may contribute to under-deployment or lack of development of policies that promote diffusion. The diffusion of technology is essential for enhancing sectoral and national revenues, as well as promoting more sustainable industrial, agricultural, transportation, and construction practices. There are many existing technologies that could contribute to the reduction of health, safety, and environmental problems and improve labor productiveness, but they either encroach on vested interests in maintaining current practices or may impose costs on firms, on consumers, or on both. In many cases, "environmental technologies" are process technologies rather than products and may confer proprietary benefits on their designers, who may not want others to have them. Environmental technologies are also difficult to organize into a market.

The slow pace of widespread technology adoption (diffusion) that could contribute significantly to more sustainable industrial systems is not due to the fact that the "discovery" of solutions to health, safety, and environmental challenges is lacking, nor is there a need for slow co-evolutionary approaches. Rather, what is missing is political and private-sector will for technology adoption. This may be as true for cleaner technologies as for so-called end-of-pipe technologies. After all, if the health, safety, and environmental harms that come from a technology are not internalized in the price of a manufacturer's activities, products, or services, why should they care if it is "cleaner"? Technology-diffusion forcing by government supported by significant demand by consumers, citizens, or workers through the tools of regulation, taxes, legislation, and stakeholder participation is likely to speed up the pace of change towards sustainable development. In summary, government needs to play a strong role in stimulating both radical disrupting innovation and the diffusion of technology. Otherwise, SNM and TM by themselves are likely to be too little and too late.

The challenges of market failure and lock-in particularly apply to radical systemic changes, which require changes in the institutional environment and long periods of sustained policy support (Kemp, 1994; Foxon and Pearson, 2007; McDowell and Ekins, 2014). Developing countries face the additional challenges of more limited resources (financial, institutional, skill, etc.) and fewer experiences with state-driven technology development and phase-in. While lock-in effects may be weaker in some cases where hardly any technologies exist yet, market failures may be more pronounced in others due to stronger information asymmetries and cost barriers (Kemp and Never, 2017).

The promotion of a green industrial policy for developing countries was explored by Kemp and Never (2017). The lock-in to unsustainable technologies and resistance to change on the part of incumbents was underscored. The authors observe that "challenges of market failures and lock-in particularly apply to radical system changes, which require changes in the institutional environment and long periods of sustained policy support" (Kemp and Never, 2017, p. 67). What is revealing about this conclusion is that no mention is made of discontinuous, radical change that might be exacted on the application of stringent regulation.

Instead, what the authors are describing is the slow process of evolutionary change that delivers needed change with great difficulty.

Though a recent paper, the authors rely on the older literature on transition management to explain the recommended approaches in the context of developing countries. Since developing countries are not likely to have mature regulatory systems, and certainly are not wedded to technology-forcing that stringent regulation can elicit, the authors may well be correct in investing their faith instead in transition management. This begs the question of whether some developed economies who are reluctant to adopt stringent technology-forcing regulatory approaches will utilize evolutionary or co-evolutionary strategies to achieve more sustainable development in a timely manner. If not, this does not bode well for the needed progress. The Paris Agreement on Global Climate Change, while eliciting voluntary commitments from its many signatories, is premised on the belief that sufficient pressure for rapid enough change has been created and changes will emerge soon enough. This remains to be seen.

Acknowledgements

We would like to express thanks to Adrian Smith for providing valuable input to an earlier version of this paper (Ashford and Hall, 2015) and to Johan Schot and others who provided feedback at an earlier presentation of this work at the 6th International Sustainability Transitions (IST) Conference held in August 2015 in Brighton, UK. We are also grateful for final reviewers of this paper who provided important perspectives and essential updates to the initial submission of paper. Finally, we are indebted to our research assistants Jessica Agnew and Johan Arango-Quiroga who provided valuable analysis and assessment of the extensive literature suggested by the reviewers.

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