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24 Environmental regulation, globalization and innovation[1]

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Introduction

This chapter explores the complex relationship between environmental regulation, innovation and sustainable development within the context of an increasingly globalizing economy. It will be argued that industrial policy, environmental policy and trade initiatives must be integrated, with a deliberate focus on stimulating technological innovation if trade and globalization are not to undercut progress in sustainable development.

Health, safety and environmental regulation – herein collectively referred to as 'environmental regulation' – addresses failures of the free market to internalize many of the social costs of an industrialized or industrializing economy by requiring the adoption of measures to protect the environment, workers, consumers and citizens. Regulation is criticized and resisted by many industrial firms,[2] who argue that such measures force sometimes unnecessary 'non-productive' investment that could be better directed to developing better goods and services and to expanding markets. Further, one of the complaints made by trading firms in industrialized nations is that such measures are not required in industrializing countries that enjoy the competitive advantage of free-riding on the environment and conditions of work.[3] A more modern view of the effects of regulation on the economy that results in competitive advantage resulting from regulation-induced innovation derives from the work of Michael Porter and Class van den Linde (1995a; 1995b), Martin Jaenicke and Klaus Jacob (2004), Jens Hemmelskamp et al. (2000), and Ashford (1979; 1985; 2000), among others, who argue that there are 'first-mover' advantages to firms that comply innovatively with regulation, become pioneers in lead markets, and displace suboptimal products, processes and firms.

Globalization has indeed changed the economic landscape. It connects the national economies in new ways and denationalizes access to information, technology, knowledge, markets and financial capital. It has also opened up two distinct pathways by which a national sector or economy can compete in international markets: (1) by producing more innovative and superior technology that may or may not be first deployed in niche markets (Kemp, 1994; 1997) and (2) by adopting cost-cutting measures that involve increased economies of scale, by shedding labor, and by ignoring health, safety and environmental hazards. While some have argued that globalization also increases the demand for more protective measures worldwide (Vogel, 1995; Bhagwati, 1997), others have cautioned about a 'race to the bottom' and an ever-increasing tendency to trade on environmental (and labor) externalities (Ekins et al., 1994).

Thus we see that there are not only two drivers of economic growth, technology and trade, but that trade itself can take two diametrically opposed directions, innovation-driven competition and traditional cost-cutting competition.

Health, safety and environmental regulation is the means by which industrial development is forced to become more sustainable, but the absence of strong international regulatory regimes changes the balance between industrialization and environment. This chapter argues that strong national regulation can spur technological, organizational, institutional and social innovation resulting in trade advantages that exceed shorter-term gains from cost-cutting and trade expansion that would otherwise weaken environmental protection, and it can result in better environmental quality than that kind of trade as well. However, more than the 'greening' of industry is needed. Creative destruction in the Schumpeterian sense is required (Schumpeter, 1939; 1962).

Innovation's key role in competitiveness and environment

Technological change is a general – and imprecise – term that encompasses invention, innovation, diffusion and technology transfer. Technological innovation is the first commercially successful application of a new technical idea. It should be distinguished from invention, which is the development of a new technical idea, and from diffusion, which is the subsequent widespread adoption of an innovation beyond those who developed it. [4]

As industrial societies mature, the nature and patterns of innovation change (Abernathy and Clark, 1985; Utterback, 1987). New technologies become old technologies. Many product lines (e.g. washing machines or lead batteries) become standardized or increasingly 'rigid', and innovation, if there is any, becomes more difficult and incremental rather than radical.

Using language that is familiar to traditional innovation scholars, an incremental innovation involves a step-by-step co-evolutionary process of change, whereas radical innovations are discontinuous and possibly involve the displacement of dominant firms and institutions, rather than evolutionary transformation (Moors, 2000; Luiten, 2001; Ashford et al; 2002; Partidario, 2003). Christensen (1997) distinguishes the former as sustaining innovation and the latter as disrupting innovation, rather than 'radical'. He argues that both sustaining and disrupting innovation can be incremental, moderate, or radical. Unfortunately, the term 'radical' in the literature is used in these two different ways and is a source of confusion.

However, another issue is in need of clarification: sustaining or disrupting of what? Christensen uses the term disrupting in the context of a customer base that values certain product attributes, and whose changing desires can change the markets for technological variants in products. The context in which we shall use the term pertains to the product – and also other technological or system changes – from a technological, as well as a customer-based desirability-of-attribute perspective. In this regard, our use of the term disrupting is more in line with Chris Freeman's (1982) use of the term 'radical' or Nelson and Winter's (1977) idea of shifting 'technological regimes' (see below). Since we take Christensen's point that the term 'radical' should be reserved to describe the rate of change rather its type, we shall generally avoid the term as a synonym for disrupting. But more is needed. From a technological perspective, disrupting innovations can be intrinsic or they can be architectural. The former is a dramatically different way of achieving functionality, such as the transistor replacing the vacuum tube; the latter may combine technological ideas in a new artifact, such as the hybrid electric-internal combustion engine. Christensen et al. (1998) stress the latter and focus on product technology. Utterback and Acee (2005, pp. 15–16) observe that '[i]nnovations that broaden the market create new room for firms to start' and '[t]he true importance of disruptive technology . . . is not that it may displace established products. Rather, it is a powerful means for enlarging and broadening markets and providing new functionality'. The problem with restricting one's analysis to the market determinants of technological change is that it neglects the fact that markets may not respond adequately to sustainability concerns. For example, consumers may well be concerned with product safety but are likely to be unconcerned by the safety of the manufacturing process affecting those who made the product. More is needed than matching the technological capacities of firms with current societal demands. Our inquiry will distinguish between sustaining innovation and disrupting innovation in a broader technological and societal context.

Product lines/sectors that are well developed, and that have become standardized, experience incremental innovation for the most part. Changes are focused on cost-reducing production methods – including increasing the scale of production, displacing labor with technology, and exercising more control over workers – rather than on significant changes in products. Gradually, process innovation also declines as manufacturing or production processes are standardized. A useful concept related to individual product lines is that of 'technological regimes', which are defined by certain boundaries for technological progress and by directions or trajectories in which progress is possible and worth doing (Nelson and Winter, 1977).

Sometimes, however, the dominant technologies (such as the vacuum tube and mechanical calculator) are challenged and rather abruptly displaced by significant disrupting innovations (such as the transistor and electronic calculator), but this is relatively rare, although very important (Kemp, 1994; Christensen, 1997). We shall argue that disrupting innovations may be what is needed to achieve sustainability. As industrial economies mature, innovation in many sectors may become more and more difficult and incremental, regulatory and governmental policies are increasingly influenced, if not captured, by the purveyors of the dominant technology (regime) which becomes more resistant to change. However, occasionally, traditional sectors can revitalize themselves, such as in the case of cotton textiles. [5]

Other sectors, notably those based on emerging technologies, may experience increased innovation. The overall economic health and employment potential of a nation as a whole is the sum of these diverging trends, and is increasingly dependent on international trade. Whether nations seek to increase revenues based on competition in technological performance or alternatively rely on cost-cutting strategies can have an enormous impact on both employment and the environment. As will be discussed below, health, safety and environmental regulation, structured appropriately, as well as new societal demands, can also stimulate significant technological changes that might not otherwise have occurred at the time (Ashford et al., 1985).

A technological innovation can be characterized by its motivating force, by its type, and by its nature. The motivating force behind technological change can be the result of an industry's main business activities or it can evolve from the industry's efforts to comply with or respond to health, safety, or environmental regulations and pressures (Ashford et al., 1979). Regulation, market signals and anticipated worker or consumer demand can affect any of the characteristics of innovation. There is ample evidence that the most significant driving force for technological change identified by business managers is environmental legislation and enforcement (Ashford and Hall, 2009).

Concerning the type of innovation, four different levels of technological change need to be considered: (1) product changes, (2) process changes, (3) shifts from products to product-services, and (4) more far-reaching system changes that not only include technological innovation, but also effects on employment, the organization of the firm, and societal demands. Innovation can be of a product-oriented type, meaning that it involves changes in the design of the final product or service. It can extend further to include shifts to product services, in which the firm envisions delivering a desired service or benefit to the customer in creative new ways, with a goal of minimizing resources, energy use and pollution. An example is selling copier services to customers – in which the copier company owns the machine and performs all maintenance and service on it while in use – instead of selling copy machines. This kind of change is described subsequently in more detail. Technological innovation can also be of a process-oriented type, meaning that it can occur as part of the production process of a product or the delivery of a service.

System changes are the deepest and broadest in scope. They extend outside the boundaries of the firm to include many actors, including suppliers, competitor and collaborator firms, government authorities and civil society. They involve the reconceptualization and reordering of entire production chains and stakeholder networks, for example, shifting from non-local industrial agriculture to locally grown organic food systems, or simultaneously altering production, employment, distribution and transportation regimes to move people and deliver goods more efficiently, with less energy use and pollution.

In the context of product change, the nature of a technological innovation can be evaluated according to whether it serves either to sustain or disrupt established product lines and value networks of customers with well-defined demands (Christensen, 1997). Christensen's concept of a 'value network' is 'the context within which a firm identifies and responds to customers' needs, solves problems, procures input, reacts to competitors, and strives for profit'. In Christensen's formulation, sustaining innovations occur when established firms push the envelope to continue to satisfy existing consumers with improved products within the prior but expanded technological trajectory. Disrupting innovations cater to different, perhaps not yet well-defined, customers with product attributes different from those in the established producer–consumer networks.[6] Alternatively, the distinction between sustaining and disrupting innovation might be focused on the technological nature of the change, a distinction that invites incentives focused not only on product changes (which may be the main driver in market-pull innovation), but also changes involving process changes, shifts to product services, and wider system changes. This is not to downplay the importance of consumer demand, but to put it in a proper context, since many desirable technological changes will need to come from more interventionist and regulatory approaches if sustainable development is to be achieved in a timely fashion. We explore these ideas further in the next section.

Another way of comparing sustaining and disrupting innovation is to depict three different pathways that innovation could take. In Figure 24.1, the various performance levels of an existing technology regime (for example, various internal combustion automobile engines with different fuel efficiencies) are shown as a function of cost. The most efficient existing engine is represented by point 'A' at cost C_1. New improvements (sustaining innovations) to internal combustion engines can be developed within the same technological regime in two different ways. First, improvements could be made, extending the capacity of existing technology, but at higher cost, as depicted by the dashed line. Second, a significant innovation could occur within the same technological regime, giving

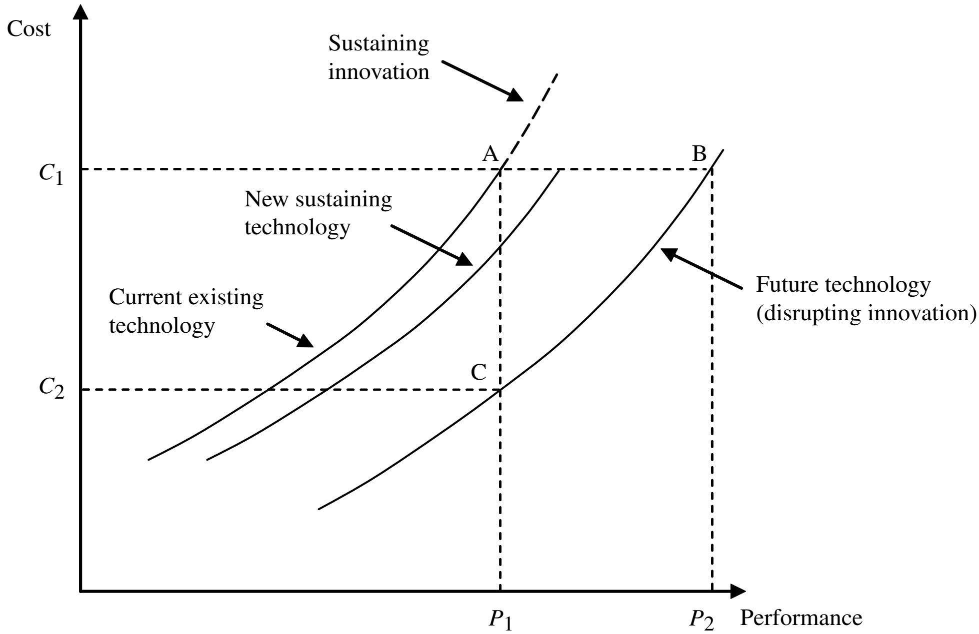

Figure 24.1 The efficient frontier for current and future technology contrasting sustaining and disrupting innovation

rise to new performance–cost relationships as depicted in the second curve, shifted to the right in Figure 24. 1. Third, a power system based on a different concept of innovation (a disrupting innovation) could be developed, represented by the 'future technology' curve, depicted by the right-most curve. At some point, fuel-efficient engines can be developed that provide the best old-engine efficiency, but at a lower cost C_2 represented by point 'C' – or better efficiency can be achieved at the same cost C_1, represented by point 'B'. Anywhere in between on the future technology curve represents a 'win–win' situation over the sustaining innovations on the dashed line.

Regulation's role in benefiting the economy and the environment

The ideology of *laissez-faire* suggests that government regulation is mostly unhelpful or inefficient, but there is increasingly persuasive evidence that regulation – properly designed – is not only necessary to achieve sustainable economies; it can actually stimulate innovation leading to improved competitiveness, employment and to an improved environment. Early MIT research stimulated more focused research into the effects of government regulation in the USA. It was found in a number of MIT studies beginning in 1979 that regulation could stimulate significant fundamental changes in product and process technology which benefited the industrial innovator, as well as improving health, safety and the environment, provided the regulations were stringent, focused and properly structured (Ashford, 1976; 2000; Ashford et al., 1985). This empirical work was conducted 15 years earlier than the emergence of the so-called Porter hypothesis, which argued that firms at the cutting edge of developing and implementing technology to reduce pollution would benefit economically by being first movers to comply with regulation (Porter, 1990; Porter and van den Linde, 1995a; 1995b).

The Porter hypothesis could be described as having both a weak and a strong form. Porter himself discusses only the weak form, essentially that regulation, properly designed, can cause the (regulated) firm to undertake innovations that not only reduce pollution – a hallmark of production inefficiency – but also save on materials, water and energy costs, conferring what Porter calls 'innovation offsets' to the innovating firm. This can occur because the firm, at any point in time, is sub-optimal. If the firm is the first to move by complying 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. Porter argues that in the international context, first-mover firms benefit by being subjected to a national regulatory system slightly ahead of that found in other countries. The strong form of the Porter hypothesis was not put forth by Porter at all. It (and the weak form as well) was first proposed by Ashford and his colleagues at MIT (Jaffe et al. 1995) after years of cross-country and US-based studies that showed that stringent regulation could cause dramatic changes in technology, often by new firms or entrants displacing the dominant technologies. The replacement of dominant technologies by new entrants, rather than incremental change by existing technology providers, has been the source of the most important radical innovations this century.

MIT research found paradoxically that the only government policy that affected innovation was health, safety and environmental regulation, not strategies devised by government as a part of its industrial policy. Moreover, the effects of regulation on innovation turned out to be positive, not negative as expected by the conventional wisdom at that time. Stringent regulation could stimulate entirely new products and processes into the market by new entrants with the displacement of dominant technologies rather than the transformation of technologies by existing firms. 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 'value networks' or 'customer bases' in which demands for improvements in both environmental quality and social cohesion are more sharply defined and articulated. Of course, industries that would fear disrupting 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 (Caldart and Ashford, 1999).

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 and can be an important element in creating favorable conditions for innovation. This enhances environmental sustainability and creates incentives for the development of powerful lead markets which pull innovation towards that sustainability. With regard to regulation, what seems to matter is not only the stringency, mode (specification versus performance), 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 the regulated firms) (Ashford and Heaton, 1983; Ashford et al., 1985). The importance of new entrants is missing in the analysis offered by Porter.

In order for innovation to occur, the firm (or government itself) must have the willingness, opportunity/motivation, and capability or capacity to innovate (Ashford, 2000). 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 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 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 could prompt firms to change their technology, as could the opportunity for cost savings. Regulatory requirements could 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 – whether diffusion, incremental innovation, or major innovation. These are (1) opportunities for cost savings or expansion of sales, (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. All these factors, however, 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 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) could be facilitated through deliberate or serendipitous transfer of knowledge from suppliers, customers, trade associations, unions, workers and other firms, as well from the available literature. The skill base of the firm (4) could 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 (5) could 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 particular product or production lines (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 conceivably they may find it easier to meet environmental demands.

The different dimensions or factors of willingness, opportunity and capability offer a variety of starting points for government policies for stimulating technological and organizational innovation. This represents an opportunity as well as a problem. The opportunity is that government does not depend on a few specific instruments, but may have command of a large variety of instruments. These include removing regulatory barriers to innovation, stimulating innovation by getting the prices for natural resources right, using government regulation to stimulate innovation, procurement and investment to develop new markets, advancing knowledge transfer from universities to small and medium enterprises, implementing proactive programs for the education and training of labor for a knowledge-based economy, and encouraging management and labor to bargain before technological changes are planned and implemented, and last but not least, cultural activities to enhance openness and willingness to engage in change (Ashford, 2000).

The problem is that these instruments must be integrated in a systematic approach or they will create various contradictory and conflicting effects – as is often the case with uncoordinated public policy. The coordination of a variety of policy instruments is often a complex task which exceeds governments' capacities. The real challenge, thus, is to find effective approaches and methods to coordinate a complex variety of instruments with complex impacts in a systematic way. We address this problem and its solution in the final section of this chapter.

Trade strategies, the environment and employment

Charles and Lehner (1998) argue that 'the type of innovation which is the key to new employment is one which develops markets in new directions and creates new markets and thus enhances a strong leading-edge economy'. One could make the same observation for the enhancement of the environment. As Schumpeter has pointed out, companies in the leading-edge economy can exploit a temporary monopoly resulting from their superior products and services (Schumpeter, 1939; 1962). Advanced-industry economies in their innovative sectors have already shifted in the last 10 to 15 years from technocentric to anthropocentric production systems – those that capitalize on human intelligence and are designed for continuous improvement and learning. Instead of a cost-driven strategy that calls for reduced labor costs, Charles and Lehner recommend that industrial economies aim for an innovation-driven strategy, which depends on a large number of human interfaces in the company that are likely to produce organizational learning, creativity, new ideas – and well-paying jobs. An innovation-driven strategy also affords an opportunity to modernize and improve products, processes and services.

Sustainable development should be seen as a broad concept, incorporating concerns for the economy, the environment and employment. All three are driven or affected by both technological innovation (Schumpeter, 1939; 1962) and globalized trade (Diwan and Walton, 1997; Ekins et al., 1994). They are also in a fragile balance, are interrelated, and need to be addressed together in a coherent and mutually reinforcing way. Technological innovation and trade drive national economies in different ways (Charles and Lehner, 1998). The former exploits a nation's innovative potential, the latter its excess production capacity. Innovation-based performance is enhanced by technological innovation and changing product markets, characterized by fluid, competitive production. Cost reduction strategies are enhanced by increased scales of production and/or automation, usually characterized by rigid, mature monopolistic production. Economies seeking to exploit new international markets may enjoy short-term benefits from revenues gained as a result of production using existing excess capacity, but they may ultimately find themselves behind the technological curve. Performance-driven markets may be slower to gain profits, but may outlast markets driven by cost reduction strategies. The consequences for the environment and for workers may differ as well.

Innovation-based performance competitiveness presents opportunities for environmental improvements and for skill enhancement and building optimal human–technology interfaces, while cost reduction strategies focus on lean production (with worker displacement and usually designed without health, safety, or environmental performance in mind), flexible labor markets, and knowledge increasingly embodied in hardware and software rather than in human capital. The consequences for the environment and for workers are different for these two strategies. The former strategy can lead to more environmentally sustainable technologies of production and also reward and encourage skill acquisition for many, with appropriate financial benefits for those workers. The latter may seek to minimize environmental improvement costs and create a division between workers, some of whom are necessarily upskilled and many whose job content is reduced. Different national strategies might be pursued, reflecting different domestic preferences and culture, but there are further implications, depending on the extent to which trade drives the economy.

The changing global economy presents challenges for all nations as concerns for the number of jobs, job security, wages, and occupational health and safety increase and compete for attention with environmental concerns. In the private sector, labor needs a role in choosing and implementing information-based technologies. In the public sector, there is a need for integrating industrial development and trade policies with those of employment, occupational health and safety, and the environment.

The need for integrating industrial, environmental and trade policies

Articulating policy approaches to sustainability requires more than an understanding of the challenges to sustainability posed by the international context. Integrated sustainability policies must utilize, alter or supplant existing policies (and the institutions that administer them) in the areas of economy, trade, environment and employment.

Recalling that a sustainable future requires technological, organizational, institutional and social changes, it is likely that an evolutionary pathway is insufficient for achieving 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 – often crucially missing 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 sectors with an important public or collective involvement, such as transportation, construction and agriculture, this means that intelligent government policies 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 socio-technical 'systems', such as transportation or agriculture, are even more difficult. This suggests that the creative use of government intervention is a more promising strategic approach for achieving sustainable industrial transformations than the reliance of the more neoliberal policies on firms' shorter-term economic self-interest.

This is not to say that enhanced analytic and technical capabilities on the part of firms, 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. Government should work with stakeholders to define far-future targets – but without allowing the agenda to be captured by the incumbents – and then use its 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. As mentioned earlier, this backcasting will have to be of a next-generation variety of backcasting. 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 – not only at the national level, but also at the regional level in closely allied nations such as those in the EU, and at the international level through multilateral environmental and labor agreements and within revised trade regimes such as the WTO and NAFTA.

There is a great deal of serendipity and uncertainty in the industrial transformation process, and the long-term prospects may not be sufficiently definable to suggest obvious pathways or trajectories for the needed transformations. Thus it may be unreasonable to expect that government can play too definitive a 'futures-making' role. What follows from this is that rather than attempting tight management of the pathways for the transformations that are sustainable in the broad sense in which we define it in this chapter, the government role might be better conceived as one of 'enabling' or 'facilitating' change, while at the same time lending visionary leadership for co-optimizing competitiveness, environment and employment. This means that the various policies must be mutually reinforcing. This newly conceptualized leadership role, focused on 'opening up the problem space of the engineer/designer', is likely to require participation of more than one ministry and more than one division of the industrial firm, with the assistance of professionals trained in a more multidisciplinary way (see Ashford, 2004).

Notes

1. Copyright © 2007 Nicholas A. Ashford. This chapter draws heavily from a book in progress: Nicholas A. Ashford and Ralph P. Hall (2009), *Technology, Globalization and Sustainability*.
2. Here the term 'industrial firms' is broadly defined to include those engaged in the extraction of energy and material resources, manufacturing, transportation, agriculture and services.
3. I argue elsewhere that the three pillars of sustainable development include competitiveness, environment and employment, although this chapter is concerned primarily with environment, broadly construed. See Ashford (2000).
4. The distinction between innovation and diffusion is sometimes hard to draw, however, because innovations can rarely be adopted by new users without some modification. When modifications are extensive, i.e. when adoption requires significant adaptation, the result may be a new innovation.
5. Under the economic threat of more stringent worker protection standards for cotton dust exposure, the leading US textile firm decided to redesign and modernize its technology to reduce occupational exposure to both cotton dust and noise, and to improve production efficiency. It stands out as one of the rare instances where an industry reinvented and replaced itself.
6. The creation of new products in this case is not a wave built upon prior waves of technological advance, but rather occurs in an entirely new trajectory, often creating a new market.

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