Sustainability **2011**, *3*, 270-292; doi:10.3390/su3010270

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

The Importance of Regulation-Induced Innovation for Sustainable Development

Nicholas A. Ashford [1,*] and Ralph P. Hall [2]

[1] MIT Technology and Law Program, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

[2] Urban Affairs and Planning, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA; E-Mail: rphall@vt.edu

* Author to whom correspondence should be addressed; E-Mail: nashford@mit.edu; Tel.: +1-617-253-1664; Fax: +1-617-452-2265.

Received: 10 December 2010 / Accepted: 2 January 2011 / Published: 19 January 2011

Abstract: This article explores the complex relationship between environmental regulation, innovation, and sustainable development within the context of an increasingly globalizing economy. The economic development, environment, and employment aspects of sustainable development are emphasized. We contend that the most crucial problem in achieving sustainability is lock-in or path dependency due to (1) the failure to envision, design, and implement policies that achieve co-optimization, or the mutually reinforcing, of social goals, and (2) entrenched economic and political interests that gain from the present system and advancement of its current trends. The article argues that industrial policy, environmental law and policy, and trade initiatives must be 'opened up' by expanding the practice of multi-purpose policy design, and that these policies must be integrated as well. Sustainable development requires stimulating revolutionary technological innovation through environmental, health, safety, economic, and labor market regulation. Greater support for these changes must also be reinforced by 'opening up the participatory and political space' to enable new voices to contribute to integrated thinking and solutions.

Keywords: co-optimization; economic development; employment; environment; innovation; health and safety; lock-in; path dependency; policy integration; regulation; system changes; sustainability; sustainable development; trade

---

1. Introduction

The senior author and his colleagues have long argued, from the empirical evidence of regulation-induced innovation in a national context, that significant, rather than marginal, environmental advancements may require the displacement of incumbent firms and their technologies [1,2]. This article takes that argument further into the realm of sustainable development where nations operate in a globalized economy which challenges not only the achievement of environmental improvements, but also satisfaction of demands for economic growth and employment [3].

Globalization has changed the economic landscape. It connects 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 [4,5] and (2) by adopting cost-cutting measures that involve increased economies-of-scale, shedding of labor, and often ignoring health, safety, and environmental hazards [6]. While some have argued that globalization also increases the demand for more protective environmental and labor measures worldwide [7,8], others have cautioned about a 'race to the bottom' and an ever-increasing tendency to trade on environmental [and labor] externalities [9]. Thus, trade can take two diametrically-opposed pathways, innovation-driven competition and traditional cost-cutting competition. These two pathways, in turn, have different implications for economic development, environmental quality, and employment.

Rigid industries whose processes have remained stagnant 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 and attitudes. 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 a reliance on more neo-liberal policies, such as reducing the corporate income tax or providing tax credits for adopting green technology which leverage firms' short-term economic self-interests without leading to deeper organizational or societal changes.

Sustainable development requires ten-fold improvements in material, resource, and energy efficiency [10]; adequate reductions in exposure to toxic substances; significant opportunities for stable, rewarding, and meaningful employment with adequate purchasing power; and an adequate level and distribution of essential goods necessary for economic welfare. This article argues that major technological, organizational, institutional, and social changes, not just incremental advances, are necessary to achieve sustainability; these changes need to be more systemic, multidimensional, and disruptive.

This article focuses on the willingness, opportunity/motivation, and capacity of incumbent producers and providers of products and services to change. Capacity can be one of the key limiting factors in a transition to sustainability, and it is often missed in optimistic planning scenarios. This article argues that the capacity to change toward greater sustainability can be enhanced by appropriate legal and policy interventions.

Perhaps the most crucial problem in achieving sustainability is lock-in or path dependency. A basic source of this lock-in or path dependence is the failure to envision, design, and implement policies that achieve co-optimization, or mutually reinforcing, of social goals. Addressing these concerns requires (mostly) legal interventions not only to enhance capacity but also to encourage willingness, opportunity, and motivation to change on the part of incumbents and new entrants. These interventions are necessary to transform the industrial state into a more sustainable one.

National governments must integrate their environmental, social, and economic policies, and this integration needs to be of a particular kind. Major, non-incremental advances can be achieved deliberatively, even if piecemeal, by connecting key interventions, policies, and agency missions relevant to a specific policy domain. For example, advancing both energy technologies and green jobs requires co-visioning and implementation of industrial innovation, energy demand-side interventions, and labor market policy integration. The current approach of working on energy technology alone will (co-)optimize neither consumption patterns nor energy-related employment. Wishful thinking that energy technology advances will lead to positive changes in demand and employment might be characterized as 'trickle-down thinking.' In a globalized world, nations must also integrate such policies among themselves.

This kind of strong national regulation can spur technological, organizational, institutional, and social innovation, resulting in economic and trade advantages which exceed shorter term gains from cost-cutting and trade expansion that would otherwise weaken environmental and labor protection. Strong regulation can result in better environmental quality and employment as well; and it can prevent trade and globalization from undercutting progress in achieving more sustainable development. Still, the transition to sustainability will involve creative destruction in the Schumpeterian sense [11,12]. The expectation that a greener economy will yield a 'double dividend' by creating significantly more jobs may or may not be realized.

This article focuses on 'opening up the problem space of the engineer/designer' [13] so that sustainability's multiple goals (social, economic, environmental) are achieved. In the sections that follow, the article explores more deeply the importance of innovation (particularly technological innovation) for both competitiveness and environment protection. It explains how environmental, health, and safety regulation can be used to benefit economic development and the environment. The article also shows the diverse effects trade can have on the environment and employment, depending on what policies are chosen. Finally, the article shows the importance of integrating policies concerning technological innovation, environmental and labor-market regulation, and trade. This kind of integration includes integration of governmental decision-making processes to foster breakthrough technological innovation that furthers social, environmental, and economic goals. It also includes the choice of specific legal and policy instruments to achieve those goals. Lock-in and path dependency caused by the exercise of raw economic and political power also need to be addressed by legal and institutional means, but those interventions are different from interventions focused on opening up the problem space for envisioning, designing, and implementing changes that achieve co-optimization, or the achieving of mutually reinforcing, of social goals.

2. Innovation's Key Role in Competitiveness and Environment

Technological innovation provides numerous ways for manufacturers to distinguish their products from those of their competitors, improve the quality and safety of those products, and reduce their costs. Similarly, technological innovation can reduce pollution, waste, and energy use in the extraction of resources for manufacturing and the manufacturing process. Moreover, it can reduce or eliminate the toxic materials contained in those products, and make those products more recyclable or reusable. Because technological innovation can work for or against sustainability, it is useful to understand how it occurs.

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 [14].

As industrial societies mature, the nature and patterns of innovation change [15,16]. New technologies become old technologies. Many product lines (e.g., washing machines or lead batteries) become standardized or increasingly 'rigid,' and innovation 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 [17-20]. Christensen [21] 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.

Another issue is also in need of clarification: *sustaining or disrupting of what?* Christensen uses the term disrupting in the context of a *customer base* which values certain product attributes, and whose changing desires can change the markets for technological variants in products. The context in which we will use the term pertains to the product—and also other technological or system changes—from a *technological standpoint*, as well as from a customer-based desirability-of-attribute perspective. In this regard, our use of the term disrupting is more in line with Freeman's [22] use of the term 'radical' or Nelson and Winter's [23] 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 than its type, we will generally avoid the term as a synonym for disrupting. But an additional distinction is needed. From a technological perspective, disrupting innovations can be either *intrinsic* or *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.* [24] stress the latter and focus on product technology. Utterback and Acee [25] 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 less concerned by the safety of the manufacturing process affecting the workers 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. Here, 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. The term 'technological regime' refers to an individual product line that is defined by certain boundaries for technological progress and by directions or trajectories in which progress is possible and worthwhile [23].

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). This is relatively rare, although very important [4,21]. Disrupting innovations may be what are needed to achieve sustainability. As industrial economies mature, innovation in many sectors may become more and more difficult and incremental, and regulatory and governmental policies are increasingly influenced, if not captured, by the purveyors of the dominant technology [regime] who become more resistant to change. However, occasionally, traditional sectors can revitalize themselves, such as in the case of cotton textiles.

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 occur [2].

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 [1]. 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 [3].

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. The last level of change includes not only technological innovation, but also effects on employment, the organization of the firm, and societal demands. Innovation can be product-oriented, meaning that it involves changes in the design of the final product

or service. It can also 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 the goal of minimizing resources, energy use, and pollution. An example is providing copier services to customers—an arrangement in which the copier company owns the copy machine and performs all maintenance and service on it—instead of selling copy machines. Technological innovation can also be a process-oriented type, meaning that it can occur as part of the *production process* of a product or the delivery of a service.

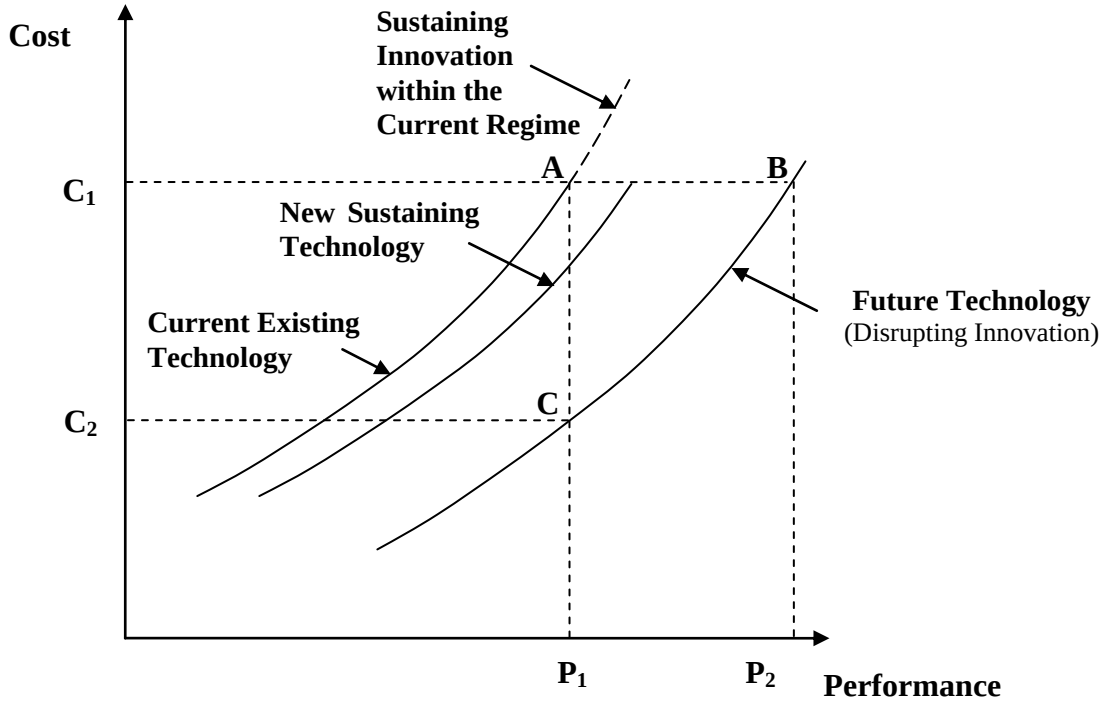
System changes are the deepest and broadest form of technological changes. They extend outside the boundaries of the firm to include many actors, including suppliers, competitor and collaborator firms, new firms to the economic activity, government authorities, and civil society. They involve the re-conceptualization and reordering of entire production chains and stakeholder networks, for example, shifting from non-local industrial agriculture to locally-grown organic food systems (with a change in customer demand towards regionally-appropriate produce), or simultaneously altering production, employment, distribution, and transportation regimes to move people and deliver goods more efficiently, with less energy use and pollution. Another interesting example of a system change is the merger of on-site housing construction with factory-made modular housing units, which results in less waste, safer practices, higher wages, and faster, less expensive construction [20].

In the context of product change, the *nature* of a technological innovation may be evaluated according to whether it serves either to *sustain* or *disrupt* established product lines and the value networks of customers with well-defined demands [21]. 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. 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. Alternatively, the distinction between sustaining and disrupting innovation might focus on the technological nature of the change, rather than on a firm's customer base. This distinction invites incentives focused on not only product changes (which may be the main driver in market-pull innovation), but also changes involving process improvements, 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. 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 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 $\mathbf{C_1}$. New improvements (sustaining innovations) to internal combustion engines can be developed within the same technological regime in several different ways. First improvements can be made, extending the performance of existing technology, but at higher cost, as depicted by the dashed

line. Second, a significant innovation can occur within the same technological regime, giving rise to new performance-cost relationships as depicted in the second curve, shifted to the right in Figure 1. Third, a power system based on a different concept of innovation (a disrupting innovation) can 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 at a lower cost $\mathbf{C_2}$ (represented by point 'C') or better efficiency can be achieved at the same cost $\mathbf{C_1}$ (represented by the point 'B'). Anywhere in between on the future technology curve represents a 'win-win' situation over the sustaining innovations on the dashed line.

Figure 1. The efficient frontier for current and future technology contrasting sustaining and disrupting innovation.



Both sustaining (evolutionary) and disrupting (revolutionary) innovation can occur without governmental intervention. However, the time periods over which these changes are expected to occur may be too long to address the environmental and employment crises which are upon us. For this reason, it is important to address the importance of government intervention.

3. Regulation's Role in Benefitting the Economy and the Environment

The senior author and his colleagues have argued previously that regulation—properly fashioned—can transform products and processes which confers both economic and health, safety, and environmental benefits [1,2]. In contrast, classical economic analysis of the relationship between health/safety/environmental regulation and competitiveness maintains that stringent regulation increases production costs, diverting resources from R&D, and consequently hinders innovation [26,27]. This assumption was challenged first in the late 1970s at MIT [1] and made popular in 1991 by the so-called 'Porter hypothesis.'

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. This literature, and the insights gleaned from it, provide 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 [28] 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 continues, "[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" [28]. Porter's hypothesis is that firms which respond to stringent regulation by developing new technologies have a 'first mover' advantage and can capture the market for their products/services. A comparison of national competitiveness with good environmental governance and private sector responsiveness supported the Porter hypothesis [29]. The study found that "good economic management and good environmental management are related" and that "firms which succeed in developing innovative responses to environmental challenges benefit both environmentally and economically" [29].

Earlier empirically based work on this concept, dates back twelve years before Porter's work to research undertaken at MIT [1,2,14,30]. 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 [2]. 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 [31]. Examples include regulation-induced replacement of poly-chlorinated biphenyls used in transformers by a silicone oil, a new polymerization process for polyvinylchloride, and textile weaving innovation eliminating the need for a formaldehyde-containing resin that imparted permanent press properties to cloth [14,31].

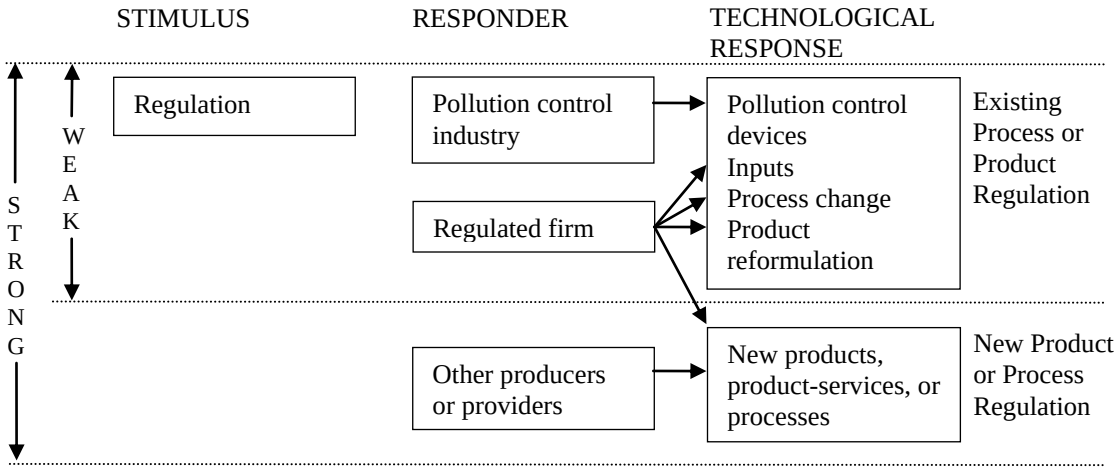
A weakness of Porter's hypothesis is that it focuses on how incumbent firms respond to more stringent regulations, but it ignores the important dynamics of new entrants [32]. Porter and van den Linde [33,34] argue that regulation, properly designed, can cause a regulated firm to undertake innovations 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 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 [33,34]—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 [35]—a distinction that Porter does not make. In its weak form, as Porter observes, firms subject to more stringent regulation respond with incremental (or sustaining) product and process innovations. Thus, while environmental and worker health and safety improvements may be realized, the offending products and processes are only incrementally changed.

However, 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 the willingness and capability to produce and compete with the new forms of technology, they too are likely to be displaced from the market [21]. Figure 2 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 colleagues in their work.

Figure 2. A model for regulation-induced technological change for 'Weak' (Porter) and 'Strong' (Ashford/MIT) forms of the regulation-induced innovation hypothesis.



Source: Adapted from Ashford [36].

While some question whether environmental regulation does generate a positive effect on innovation [37-39], 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" [35]. 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 [40]. 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" [41]. 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 [42].

In a five-country study of the effectiveness of various government interventions collectively known as 'industrial policy,' MIT research found, paradoxically, that the only government policy that affected innovation was in fact health, safety, and environmental regulation, rather than strategies devised by a government as a part of its industrial policy [13]. 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 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 '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 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 [43].

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 sustainability and create incentives for the development of powerful lead-markets, which pull innovation towards that sustainability [44]. 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 in the regulated firms) that the regulation engenders [2,14].

In order for innovation to occur, the firm (or government itself) must have the *willingness*, *opportunity/motivation*, and *capability/capacity* to innovate [36]. 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

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) 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. 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 [2,36]. 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.

If we were not living and trading in an increasingly globalized world, integrating national industrial, environmental, and employment policies might go a long way towards achieving more sustainable development. However, trade also influences the outcomes of national domestic policy goals, such as improving the environment and creating an economy with meaningful, rewarding jobs with sufficient purchasing power.

4. Trade Can Benefit or Harm the Environment and Employment Depending on the Strategy Chosen

Whether trade itself improves or harms a particular nation's environment has been debated for almost two decades and continues to be an intensely controversial issue [45,46]. On the one hand, the world-wide proliferation of toxic chemicals, pesticides, and other technologies facilitated by global markets raises serious concerns. On the other hand, to the extent that nations improve their economic position, there may be more demand and revenues to implement environmental protection measures. There is evidence of both. But beyond trade in harmful technologies per se, there are more far-reaching effects of trade on the environment and employment, depending on the strategy chosen.

Technological innovation and trade can drive national economies in different ways, depending on whether trade is based on an innovation or cost-cutting approach [6]. Charles and Lehner [6] 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 area in which new markets might be developed is the environment. As Schumpeter has described, companies in the leading-edge economy can exploit a temporary monopoly resulting from their superior products and services [11,12]. Advanced-industrial economies in their innovative sectors have already shifted in the last ten to fifteen 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 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.

Technological innovation exploits a nation's innovative potential, while cost-cutting is often associated with a trade strategy driven by the desire to exploit a nation's 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. Nonetheless, they may ultimately find themselves behind the technological curve. Performance-driven markets may be slower to gain profits. However, they may outlast markets driven by cost-reduction strategies. The consequences for the environment and for workers may differ as well.

Innovation-based competitiveness presents opportunities for environmental improvements and for skill enhancement and building optimal human-technology interfaces. In contrast, 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 workers, with appropriate financial benefits to them. The latter strategy may seek

to minimize environmental improvement costs and create a division between workers, some of whom are unskilled and many for whom the demand for higher-level skills 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 economic growth, jobs, job security, wages, and occupational health and safety increase and compete for attention with environmental and energy concerns. Since trade does influence the outcomes of other national domestic policy goals, there is a need for integrating trade policies with the sort of initiatives focused on industrial development, energy, employment, environment, and worker and public health that are discussed after the next section [9,47].

5. Integrating Industrial, Environmental, and Trade Policies

Government can open up the problem space for more sustainable policies by fostering greater technological innovation. That, in turn, requires integration of environmental, health, and safety regulation with industrial, employment, and trade policies. Under this approach, the government cannot simply serve as a referee or arbiter of existing competing interests, because neither future generations of persons nor future technologies are adequately represented by the existing stakeholders. (In addition, as discussed in the introductory section of this article, some existing stakeholders may want to continue the present course because they are gaming the system.) Government should work with stakeholders to define far-future targets—but without allowing the agenda to be captured by the incumbents. Government should 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. Acting as a trustee takes the government beyond being a referee of those competing interests that might be at the table; trusteeship also means factoring interests of those future or existing alternative technologies and persons not yet parties to the political process, including future generations, as well as those who are here today but are under-represented.

The areas of government programs and initiatives in the United States are depicted in Figure 3. The 'wedges' in the figure relate to the different areas of sustainability concern, while the concentric circles identify areas of government authority and responsibility in the U.S. context. The figure is easily adapted to other national systems as well. There could be three different 'dartboard' diagrams for national, regional/state, and local governmental activity.

Integration requires (1) addressing multiple goals (e.g., economic development, employment, environment, and public health) in the same piece of legislation, or at least passing a group of complementary laws in parallel fashion, (2) planning regulatory and programmatic initiatives with participants from different governmental authorities, and (3) deliberate simultaneous or staged implementation and monitoring involving different governmental authorities. Ideally, integration also involves the merging of ministries, or at least increasing the porosity of departmental walls. However, the former is likely to be more of a hope for the future than something that can be achieved in the short run.

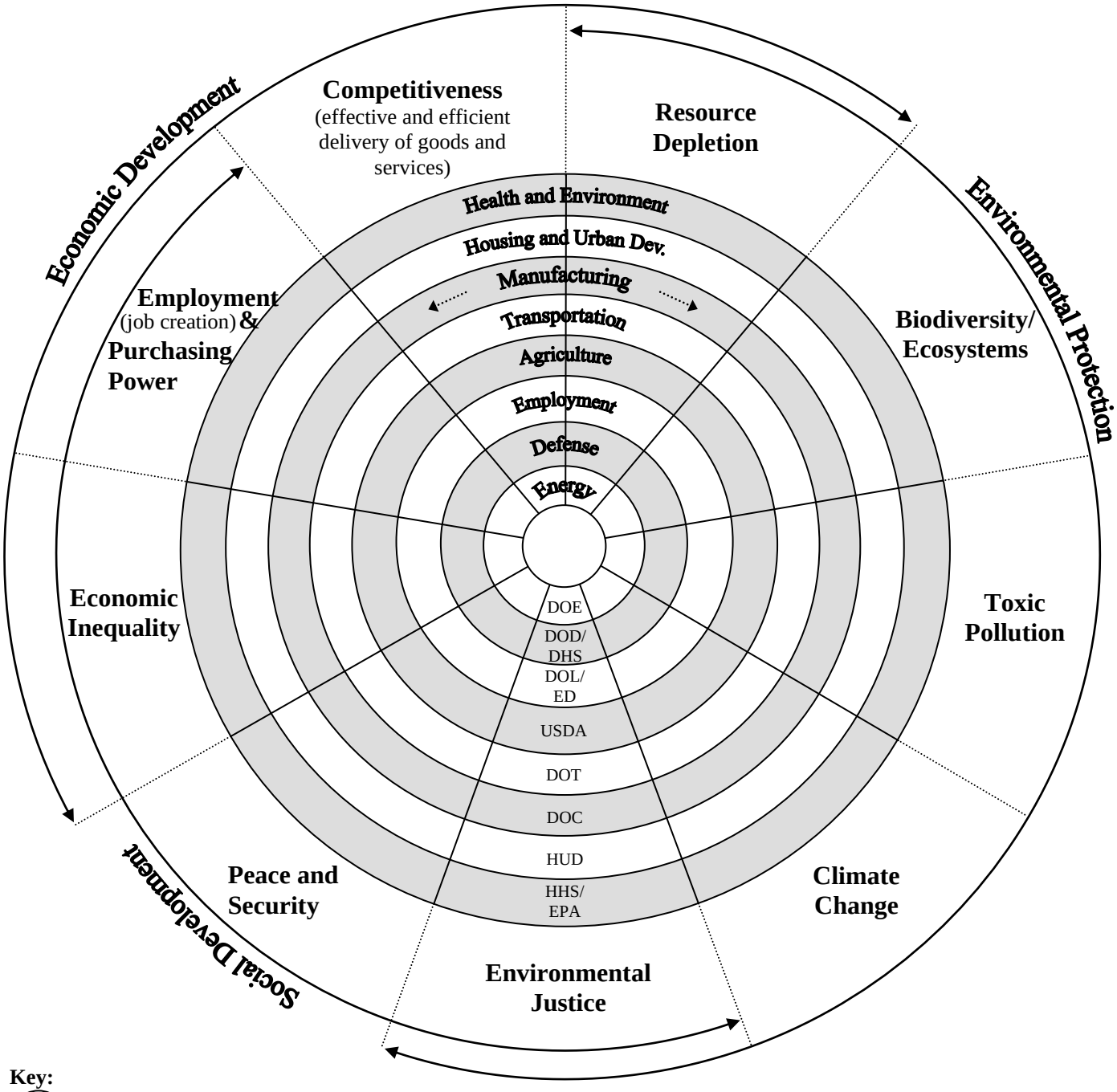
Integration found its first serious expression as *environmental* policy integration (EPI) as a consequence of the Brundtland Report [48] placing environmental consideration as a priority to be

balanced along with economic and social concerns. Agenda 21, emerging from the 1992 UN Conference on Environment and Development in Rio, endorsed the integration of economic, social, and environmental issues in the pursuit of development [49]. As a principle, EPI has had mixed success, with the most impressive advances found in some countries of the European Union (EU) [50]. The EU placed environment at the center of its recent treaties advancing the union, but it was pushed back somewhat in the adoption of the Lisbon Strategy of the European Union to promote sustainable economic growth (via competitiveness) and employment, while respecting the environment. Economic concerns slowly re-emerged in importance and they have now found greater favor in the fragile balance among issues, especially after the 2008 financial crisis. Jordon and Lenschow [50] comment that "generally speaking, new centre-left governments have tended to push the hardest for EPI, whereas centre-right governments have held back or even dismantled EPI frameworks and instruments." These authors observe that "unless there is a high-level commitment to deliver greater EPI or a strong inducement, for example in the form of career enhancements, integration simply does not happen" [50]. They add that "'learning' or a 'change of awareness' seems to take place in response to political crises (for example, accelerating climate change) rather than the combined impact of different EPI instruments" [50].

The challenge of integrating programs occurs among the different *issues*, the different *kinds of authority*, and the agencies/authorities at *different levels of government*. In the traditional fragmentation of governmental missions, there are plenty of opportunities for philosophical, goal, and turf conflicts. That is why strong leadership from the top, supported by people well-trained in a trans-disciplinary way, is essential to optimize policy congruence and mutual reinforcement. Co-optimization rather than 'balance' distinguishes this approach from compromise [3]. Integration of goals in government (as well as private sector) actions is indispensible for achieving major advances in sustainable development, and is consistent with the view that the journey to sustainability is a *process*, rather than a particular end state. Ideally and ultimately, government needs to be radically restructured to reflect the realities of the new millennium. Instead of departments and ministries separated according to traditional areas such as environment, health, commerce, trade, energy, transportation, *etc.*, governmental structures should focus on problem areas representing overlapping concerns. Possibly these strategies can be overseen by larger super-ministries such as one for economic and social welfare, and one for trade and international relations. Enabling legislation for the traditional agencies needs to be revised to reflect mission broadening and changes. However, since the present infrastructure of government is not likely to be changed in the near to medium term, how else is useful integration to be accomplished?

Certainly 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 valuable adjuncts in the transformation process. But in most cases these means and strategies are unlikely to be sufficient by themselves for significant transformations. They will not work without clear mandated targets to enhance the triple goals of economic development, improvement of environmental quality, and enhancement of employment/ labor concerns.

Figure 3. Schematic of areas of government programs and initiatives requiring policy integration.



Key:

Government activity areas (e.g., transportation, health, energy)

Challenges confronting sustainable development (e.g., climate change, resource depletion, toxic pollution)

DHS: Department of Homeland Security
DOC: Department of Commerce
DOD: Department of Defense
DOE: Department of Energy
DOL: Department of Labor
DOT: Department of Transportation
ED: Department of Education
EPA: Environmental Protection Agency
HHS: Department of Health and Human Services
HUD: Department of Housing and Urban Development
USDA: US Department of Agriculture

This integration thus needs to go beyond the historic focus of national governments on coordinating public and private sector policies. What is needed is a new form of leadership role for government. Government initiatives, policies, and instruments must be integrated so as to 'co-optimize' multiple goals—to foster innovation for sustainability and to use environmental, health, and safety regulation as well as trade policy to stimulate and encourage that innovation. That is, this integration must achieve

simultaneous and mutually reinforcing gains in the relevant economic, environmental, and employment realms.

Integration must be directed toward major technological, organizational, institutional, and social changes, not just incremental advances, to achieve five- or ten-fold improvements in material and energy use; meaningful reductions in exposure to toxic substances; significant opportunities for stable, rewarding, and meaningful employment with adequate purchasing power; and an adequate level and distribution of economic welfare. Major, non-incremental advances can be achieved through integration pursued deliberatively, even if piecemeal, by connecting key interventions, policies, and agency missions relevant to a specific policy domain. This integration also requires stringent banking, environmental, labor protection and labor market regulation, as well as the regulation of commerce, advertising, and financial transactions. Laissez faire market approaches are simply inadequate.

For example, advancing both energy technologies and green jobs requires co-visioning and the implementation of industrial innovation, energy demand-side interventions, and labor market policy integration. Although it presents more constraints, pursuing multiple goals also requires more flexibility in changing components or characteristics of a product or process. It thus presents different opportunities for optimization of each of the goals pursued in isolation. Factor-ten or more improvements require flexibility in design rather than changes in a small number of components while others are left unchanged. An example may be found in automobile design changes that simultaneously take both collision safety and fuel efficiency into account by mounting automobile engines differently so as to allow more room for piston movement which leads to greater compression ratios. (Reconfiguring the engine to improve safety also increases the distance that the pistons can travel within a cylinder, thereby increasing the engine's compression ratio and fuel efficiency.)

Multi-purpose design is also likely to require considerable public participation and societal support for aggressive, transformative initiatives. Greater support for these changes must be reinforced by 'opening up the participatory and political space' to enable new voices to contribute to integrated thinking and solutions.

Examples of governmental policy integration exist, although they do not go as far as the policy approaches suggested above. The integration of fuel economy and emission concerns is evident in the joint efforts of the Environmental Protection Agency and the Department of Transportation. Unfortunately, a third element of motor vehicle concern—safety—has not been optimally integrated in those efforts. In France, the French Agency Afsset has merged environmental concerns with those of occupational health and safety, distinguishing itself from most countries which separate the two policy areas. In the Netherlands, there is one combined agency for environment and spatial planning. In Greece, there is a single ministry for environment and land planning, although that ministry has been criticized for allowing land-use expansions that exacerbated the incidence of forest fires. Integration in mission titles in and of itself does not guarantee integration of all the areas in need of mutual gains.

To be sure, it may be unreasonable to expect that government can play too definitive a 'futures making' role. There is a great deal of serendipity and uncertainty in industrial transformation processes, and the long-term prospects may not be sufficiently definable to suggest obvious pathways or trajectories for the needed transformations. Rather than attempting tight management of the pathways for the transformations that may lead to sustainable development, the government role might be better conceived as one of 'enabling' or 'facilitating' change.

Policy integration must also account for the fact that developed nations especially now operate in a globalized market and the integration of domestic-focused policies must extend to trade policies. For example, the U.S. promotion of hormone treatment of livestock to increase milk production and accelerate growth has run afoul of European Union trade sanctions. This has direct impacts not only on competitiveness in agricultural markets but also on trade deficits.

Policy integration must occur at the international level as well. The World Trade Organization (and other trading regimes) and the International Labour Organization address commerce and employment concerns, respectively. The multilateral environmental accords themselves are largely neither integrated nor coordinated. For example, the use of the precautionary principle differs significantly in the Sanitary and Phytosanitary agreements and the Biosafety Protocol. A World Environment Organization would provide a more uniform and coordinated environmental and public health perspective internationally, but would not contribute much to integrating commerce, employment, and environmental concerns. Trade in commercial products is governed by the World Trade Organization, which depends on principles of protection for environmental or public health concerns that are sometimes at variance with principles incorporated into many multilateral environmental accords. A World Sustainability Organization has been suggested in lieu of having three separate international organizations [51]. Whatever is done internationally, national policies will need to account for the globalized nature of the social, environmental, and economic concerns.

Even in the absence of major restructuring of national and international governmental institutions, there are several pathways to more integrated decision-making and execution of government programs [3]:

1. The level of government at which integration is best accomplished (*i.e.*, federal/national, regional, state, urban, or local government) may depend on the specific socio-technical goal. For example, integration of land-use planning, transportation, and housing is acknowledged to be best accomplished at the urban or local level, while integration of environmental pollution, workplace exposures, and product safety might best be accomplished at the federal/national level. Integration of planning for new industry and job creation initiatives might best be carried out at the regional level and involve state or provincial departments of commerce and labor.
2. Leadership for integration has to be emphasized at the top levels of the appropriate governmental units, and the performance of government employees has to be rewarded on the basis of multiple criteria, not only those relevant to a particular mission-agency's traditional goals.
3. The top-level and mid-level managers of mission agencies, whether at the federal/national, regional, or state level should be frequently rotated amongst those agencies so that fresh multi-faceted expertise and interest is continually evolving. For example, the head of the federal or state department of commerce might move to department of labor, and then again to the department of environmental protection. Slowly, this will hopefully engender multi-dimensional thinking and planning, as well as tolerance for different missions and agencies.
4. Trans-disciplinary working groups, made up of different relevant mission-agency personnel should be constituted to work on different socio-technical problems, and housed together for periods of 6 months to 2 years to work on problems requiring different concerns—such as environment, public health, and transportation.

5. Continuing education, reinforcing the related concepts relevant to inter-agency activities, needs to be provided to employees of different agencies in jointly-held sessions and workshops.

Experiments at inter-agency joint action should be encouraged and failures tolerated and learned from. A process of discovery should lead to the optimal levels and structures likely to spawn success. For all of these efforts, willingness to depart from narrowly-defined goals must be a starting point. As important as these integration processes are, however, a final question remains: what specific government policies are needed to achieve the breakthrough innovations that are needed?

6. Options for Government Intervention to Open Up the Problem Space for Envisioning, Designing, and Implementing More Sustainable Policies

The different determinants of willingness, opportunity, and capacity, discussed in Section 3 above, offer a variety of different starting points for government policies for stimulating technological and organizational innovation to achieve a more sustainable industrial system. This represents an opportunity as well as a challenge. The opportunity is that government need not depend on a few specific instruments, but may have command of a whole variety of measures. The challenge is choosing and shaping the right instrument or instruments needed to do particular jobs. There are a variety of instruments from which to choose. These include direct performance of research and development (R&D); financial support of R&D in academia and industry through grants, subsidies, and tax incentives; removing regulatory barriers to innovation; stimulating innovation by getting the prices right for natural resources including energy; using government regulation to stimulate more environmentally-sound, inherently-safer, and employment-creating 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; 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 [36].

Tax policy can be particularly important. Others have called for taxing the ‘bads’ (like pollution) and not the ‘goods’ (like employment). But even within the present system, less bold but important changes in incentives can be fashioned. For example, if more employment is desirable, financing unemployment and workers compensation from charges on employers on a per capita (worker) basis creates disincentives to hire new workers; these could be replaced by a tax on sales or profits. Similarly, providing accelerated tax depreciation for safer and less-polluting industrial processes, rather than for end-of-pipe pollution control or injury minimizing technology, would incentivize cleaner and inherently safer technology. These require changes in law and regulation. In order for law and regulation to have its necessary stimulatory effect, it must be certain enough to change medium to long-term strategic decisions for both industry and (state and local) governmental entities. Thus, the adoption of a temporary or short-term suspension of ‘payroll taxes’ may not lead to changes in employment.

As difficult as it may be to transform industrial economies into more *environmentally* sustainable systems, the challenges facing the creation of more satisfying, rewarding, and safer jobs with

improvements in purchasing power is even more daunting. Simply 'priming the pump' to encourage economic growth is a blunt instrument when it comes to creating more employment—especially since replacing old facilities with new facilities usually results in shedding jobs—and greening the economy (without attention to the redesign of jobs as well) may return only a small 'double dividend.' Therefore, many call for a reduction in hours in the standard workweek as a means for spreading out available work, or even increasing the demand for work, but because workers are unlikely to be able to secure the same wages for less work, and because of the payroll tax on wages reflecting the funding of social benefits, employers, as well as current workers, are much more inclined to promote overtime, rather than hire new workers. Workers, on the other hand, are likely to demand higher hourly wages for a shorter work week to maintain wage parity or seek a second job, leading to higher job turnover and net unemployment for some groups. For this reason, the French adoption of a 35-hour workweek was not very successful, leaving the overall level of employment unaffected [52]. Longer term policy, cultural, and societal changes may be needed.

Developed countries (and pundits within them) are deeply divided as to whether Keynesian spending to stimulate the economy in order to create jobs and lead to greater consumer purchasing is what is needed to address low economic growth and high employment, or whether creating more flexible work rules, allowing for wage concessions or relaxing hiring/firing practices, will be more effective. Germany instituted more liberal labor policies but also adopted the 'Kurzarbeit' (short work) policy by which employers were encouraged to keep workers, although on furlough or a shorter work schedule with the wage shortfalls made up for by a government fund to which employers had contributed in better times [53]. A kind of 'German miracle' led to an annualized growth rate of 9 percent based on the 2010 second quarter growth. This experience supports the view that direct protection of jobs rather than indirect monetary and fiscal policies may be a better policy direction.

Deceasing demand for the consumption of material and energy-intensive products and services may not alleviate unemployment or underemployment. However, utilizing more human, rather than physical, capital may yield that result. For example, instead of a household spending its disposable income on material and energy-intensive goods and services beyond the basic necessities, it can engage persons to deliver services that employ mostly human capital, such as tutors, language teachers, music and art teachers, financial advisors, and persons engaged in providing others social services. Also, increasing the teacher-to-student ratio in schools would be an important start. (While a discussion of comprehensive educational reform is beyond the scope of this work, we regard it as essential. Basing the financing of schools on property taxes which are constrained by legal limitations should be eliminated in favor of federal financing of education.)

The multiplier effect of employing human, rather than physical or natural capital, could be significant. To increase the demand for human capital in this context, would, of course, require significant cultural changes of a medium to long-term nature, and large corporations that have organized the current means of production driven by economies of scale and that use advertising to create artificial demand would be less likely to be interested in 'selling' these services.

Investing in better education and lifelong learning is of course central to cultural change and shifting demand towards the use of more human capital. Training professionals in a more trans-disciplinary way will also yield benefits. These professionals will then be able to simultaneously

address problems of the economy, environment, public health, and employment in a more systematic way.

7. Conclusions

This article addresses a crucial problem in achieving sustainability—lock-in or path dependency caused by the failure of firms to envision, design, and implement policies that would simultaneously achieve social, environmental, and economic goals. Policy interventions are needed to increase not only capacity, but also willingness, opportunity, and motivation on the part of incumbents and new entrants to change the present industrial state into a more sustainable one. Structural interventions at all levels of governance are needed to foster breakthrough technological innovations. These structural interventions should integrate environmental, health, and safety decision-making with decision-making on employment and trade policies. Other interventions include specific legal and policy instruments that will encourage and even force such innovations in a manner that will achieve environmental, economic, and social objectives in a mutually reinforcing way.

Who is likely to win and who is likely to lose from an industrial transformation is also a question that should be considered. Persons, firms, and governments who benefit from maintaining the status quo or continuing its trends can well drive us deeper into unsustainability. They create a major source of lock-in and path dependence—entrenched economic and political interests that gain from the present system and advancement of its current trends through the exercise of monopoly power, financial privilege and control, advertising, and regulatory and political capture, even though the citizens as a whole in a nation may not benefit, or may even be harmed. Further, they stand in the way of different actors who may provide better pathways. To address these concerns requires a different focus of (mostly) legal interventions than those directed towards enhancing the *capacity* to change through a deepening and integration of interventions that open up the problem space. Policies are needed to 'open up the participatory and political space.' These include using the power of legal compulsion through law and legal institutions, antitrust law, legal changes in the chartering of corporations, the limiting of unjustified profiteering, the restraint of advertising, the cessation of rewarding excessive consumption of both materials and energy, subsidizing the wrong kind of production and provision of services, countering and punishing financial corruption and fraud, and fair employment and wage policies.

Such interventions 'open up the participatory and political space' and are different from other interventions discussed in this article—opening up the problem space for envisioning, designing, and implementing technological innovations that achieve social, environmental, and economic goals in mutually reinforcing ways—but they can be of equal importance. Finally, it should be clear that we are advocating stronger, not bigger government. Integrating governmental policies and initiatives could very well result in smaller government than one that operates in a fragmented way.

Acknowledgements

This article draws heavily from a book in press: Nicholas A. Ashford and Ralph P. Hall, *Technology, Globalization, and Sustainable Development: Transforming the Industrial State*, Yale University Press: New Haven, 2011.

References

1. Ashford, N.A.; Heaton, G.R.; Priest, W.C. Environmental, health and safety regulations and technological innovation. In *Technological Innovation for a Dynamic Economy*; Hill, C.T., Utterback, J.M., Eds.; Pergamon Press: New York, NY, USA, 1979; pp. 161-221.
2. Ashford, N.A.; Ayers, C.; Stone, R.F. Using regulation to change the market for innovation. *Harvard Environ. Law Rev.* **1985**, *9*, 419-466.
3. Ashford, N.A.; Hall, R.P. *Technology, Globalization, and Sustainable Development: Transforming the Industrial State*; Yale University Press: New Haven, CT, USA, 2011.
4. Kemp, R. Technology and environmental sustainability: The problem of technological regime shift. *Futures* **1994**, *26*, 1023-1046.
5. Kemp, R. *Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments*; Edward Elgar: Cheltenham, UK, 1997.
6. Charles, T.; Lehner, F. Competitiveness and employment: A strategic dilemma for economic policy. *Compet. Change* **1998**, *3*, 207-236.
7. Vogel, D. *Trading Up: Consumer and Environmental Regulation in a Global Economy*; Harvard University Press: Cambridge, MA, USA, 1995.
8. Bhagwati, J. The global age: From a sceptical south to a fearful north. *World Econ.* **1997**, *20*, 259-283.
9. Ekins, P.; Folke, C.; Costanza, R. Trade, environment and development: The issues in perspective. *Ecol. Econ.* **1994**, *9*, 1-12.
10. Schmidt-Bleek, F. Factor 10, the mandatory technological choice. In *Proceedings of the Workshop on Technological Choices for Sustainability*, Maribor, Slovenia, 13–17 October 2002; pp. 1-13.
11. Schumpeter, J.A. *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process*; McGraw-Hill: New York, NY, USA, 1939.
12. Schumpeter, J.A. *Capitalism, Socialism and Democracy*; Harper Torchbooks: New York, NY, USA, 1962.
13. Allen, T.J.; Utterback, J.M.; Sirbu, M.A.; Ashford, N.A.; Hollomon, J.H. Government influence on the process of innovation in Europe and Japan. *Res. Policy* **1978**, *7*, 124-149.
14. Ashford, N.A.; Heaton, G.R. Regulation and technological innovation in the chemical industry. *Law Contemp. Probl.* **1983**, *46*, 109-157.
15. Abernathy, W.J.; Clark, K.B. Innovation: Mapping the winds of creative destruction. *Res. Policy* **1985**, *14*, 3-22.
16. Utterback, J.M. Innovation and industrial evolution in manufacturing industries. In *Technology and Global Industry: Companies & Nations in the World Economy*; Guile, B.R., Brooks, H., Eds.; National Academy Press: Washington, DC, USA, 1987; pp. 16-48.
17. Moors, E.H.M. Metal making in motion: Technology choices for sustainable metals production. Delft University of Technology: Delft, The Netherlands, 2000.
18. Luiten, E.E.M. *Beyond Energy Efficiency: Actors, Networks and Government Intervention in the Development of Industrial Process Technologies*; Utrecht University: Utrecht, The Netherlands, 2001.

19. Partidario, P.J. *"What-If": From Path Dependency to Path Creation in a Coatings Chain: A Methodology for Strategies towards Sustainable Innovation*; Delft University of Technology: Delft, The Netherlands, 2003.
20. Ashford, N.A.; Hafkamp, W.; Prakke, F.; Vergragt, P. *Pathways to Sustainable Industrial Transformations: Cooptimising Competitiveness, Employment, and Environment*; Ashford Associates: Cambridge, MA, USA, 2002.
21. Christensen, C.M. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*; Harvard Business School Press: Cambridge, MA, USA, 1997.
22. Freeman, C. *The Economics of Industrial Innovation*, 2nd ed.; Frances Pinter: London, UK, 1982.
23. Nelson, R.R.; Winter, S.G. In search of useful theory of innovation. *Res. Policy* **1977**, *6*, 36-76.
24. Christensen, C.; Utterback, J.M.; Suárez, F.F. Strategies for survival in fast-changing industries. *Manage. Sci.* **1998**, *44*, S207-S220.
25. Utterback, J.M.; Acee, H.F. Disruptive technologies: An expanded view. *Int. J. Innov. Manage.* **2005**, *9*, 1-17.
26. Jaffe, A.; Peterson, S.; Portney, P.; Stavins, R. Environmental regulation and the competitiveness of U.S. manufacturing: What does the evidence tell us? *J. Econ. Lit.* **1995**, *33*, 132-163.
27. Rennings, K.; Kemp, R.; Bartolomeo, M.; Hemmelskamp, J.; Hitchens, D. *Blueprints for an Integration of Science, Technology and Environmental Policy (BLUEPRINT)*; Zentrum für Europäische Wirtschaftsforschung (ZEW): Mannheim, Germany, 2003.
28. Porter, M.E. America's green strategy. *Sci. Am.* **1991**, *264*, 168.
29. World Economic Forum; Yale Center for Environmental Law and Policy; Yale University; Center for International Earth Science Information Network; Columbia University. *2002 Environmental Sustainability Index: An Initiative of the Global Leaders of Tomorrow Environment Task Force, World Economic Forum*; World Economic Forum: Geneva, Switzerland, 2002.
30. Ashford, N.A. Understanding technological responses of industrial firms to environmental problems: Implications for government policy. In *Environmental Strategies for Industry: International Perspectives on Research Needs and Policy Implications*; Fischer, K., Schot, J., Eds.; Island Press: Washington, DC, USA, 1993; pp. 277-307.
31. Strasser, K.A. Cleaner technology, pollution prevention and environmental regulation. *Fordham Env. Law J.* **1997**, *9*, 1-106.
32. Van de Poel, I.R. On the role of outsiders in technical development. *Tech. Anal. Strategic Manage.* **2000**, *12*, 383-397.
33. Porter, M.E.; van den Linden, C. Green and competitive: Ending the stalemate. *Harv. Bus. Rev.* **1995**, *73*, 20-134.
34. Porter, M.E.; van den Linden, C. Towards a new conceptualization of the environment-competitiveness relationship. *J. Econ. Perspect.* **1995**, *9*, 97-118.
35. Ashford, N.A. Porter debate stuck in 1970s. *Environ. Forum* **1999**, *September/October*, 3.
36. Ashford, N.A. An innovation-based strategy for a sustainable environment. In *Innovation-Oriented Environmental Regulation: Theoretical Approach and Empirical Analysis*; Hemmelskamp, J., Rennings, K., Leone, F., Eds.; Physica-Verlag Heidelberg: New York, NY, USA, 2000; pp. 67-107.

37. Jaffe, A.B.; Palmer, J. Environmental regulation and innovation: A panel data study. *Rev. Econ. Stat.* **1997**, *79*, 610-619.
38. Robinson, J. The impact of environmental and occupational health regulation on productivity growth in U.S. manufacturing. *Yale J. Reg.* **1995**, *12*, 388-434.
39. Walley, N.; Whitehead, B. It's not easy being green. *Harv. Bus. Rev.* **1994**, *May-June*, 46-52.
40. Jänicke, M.; Jacob, K. Ecological modernisation and the creation of lead markets. In *Towards Environmental Innovation Systems*; Weber, M., Hemmelskamp, J., Eds.; Springer: Heidelberg, Germany, 2005; pp. 175-193.
41. Beise, M.; Blazejczak, J.; Edler, D.; Jacob, K.; Janicke, M.; Loew, T.; Petschow, U.; Rennings, K. *The Emergence of Lead Markets for Environmental Innovations*; FFU-report 02-2003; Forschungsstelle fur Umweltpolitik (FFU): Berlin, Germany, 2003.
42. Blazejczak, J.; Edler, D. Could too little and too much turn out to be just right? On the relevance of pioneering environmental policy. In *Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change*; Jacob, K., Binder, M., Wieczorek, A., Eds.; Environmental Policy Research Centre: Berlin, Germany, 2004.
43. Caldart, C.C.; Ashford, N.A. Negotiation as a means of developing and implementing environmental and occupational health and safety policy. *Harvard Environ. Law Rev.* **1999**, *23*, 141-202.
44. Jänicke, M.; Jacob, K. Lead markets for environmental innovations: A new role for the nation state. *Global Environ. Polit.* **2004**, *4*, 29-46.
45. Bhagwati, J. The case for free trade. *Sci. Am.* **1993**, *November*, 42-49.
46. Daly, H.E. The perils of free trade. *Sci. Am.* **1993**, *269*, 50-54.
47. Diwan, I.; Walton, M. How international exchange, technology and institutions affect workers: An introduction. *World Bank Econ. Rev.* **1997**, *11*, 1-15.
48. World Commission on Environment and Development (WCED). *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
49. United Nations (UN). *Earth Summit. Agenda 21*; University Press: Oxford, UK, 1993.
50. Jordan, A.; Lenschow, A. Environmental policy integration: A state of art review. *Env. Pol. Gov.* **2010**, *20*, 147-158.
51. Charnovitz, S. A world environment organization. *Columbia J. Environ. Law* **2002**, *27*, 323-362.
52. Estevão, M.; Sá, F. The 35-hour week. *Econ. Policy* **2008**, *23*, 417-463.
53. Kulish, N. Defying others, Germany finds economic success. *New York Times*, 13 August 2010.