

## CHAPTER 32

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## APPROACHING BUSINESS AND THE ENVIRONMENT WITH COMPLEXITY THEORY

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THE failure to establish an international agreement on climate change at Copenhagen in December 2009 highlights the challenge of managing complex problems at the interface of business and the natural environment (B&NE). Despite the broad consensus on the need for coordinated global action, Copenhagen represented a failure of collective action—and a triumph of inertia—as industries and countries struggled to reconcile narrow conceptions of economic interest with global demands for aggressive action. This unfortunate outcome can be understood in the context of the larger “sociotechnical system” within which business and policymakers are operating: a complex dynamic system comprising economic, technological, social, political, and ecological elements, generating complex interactions and unforeseen outcomes.

Yet even as recriminations were flying at Copenhagen, some welcomed the opportunity to move beyond a centralized, top-down model of global climate governance. Instead, they embraced the opportunity for businesses, non-governmental organizations (NGOs), and governmental agencies to experiment with a plethora of innovative approaches to reducing emissions, which offer new opportunities for learning and creative solutions (Hoffmann 2011). Complexity theory provides a grounded theoretical basis for this more optimistic perspective by explaining how networked actors can display adaptive learning and emergent self-organization.

In this chapter we examine the contribution of complexity theory to our understanding of B&NE, with a particular focus on climate change as an illustrative and representative example. We use the term “complexity” to refer to a group of concepts derived from systems theory, including complex dynamic systems theory, chaos, and emergence, among other disciplines. These provide insight into systemic tendencies towards

patterned behavior, frozen inertia, and sometimes extreme instability. At a macro level, complexity theory explains why systems are often hard to comprehend and forecast, let alone manage and control. Yet complexity also offers micro-level tools and concepts to help innovative organizations improve sustainability through local initiatives of loosely networked agents (Senge et al. 2008). The field thus offers insights for steering systems toward sustainable transitions and enhancing resilience, without the hubris of complete control (Smith, Stirling, & Berkhout 2005).

The existing literature on B&NE mostly focuses on the organizational level, where managers have authority and responsibility. While this literature is valuable, as exemplified in this Handbook, the narrow focus can obscure an appreciation of the emergent properties and holistic functioning of the broader sociotechnical system. Some (see Ehrenfeld [Chapter 33]; and Roome [Chapter 34] this volume) emphasize that sustainability is only meaningful as a concept at the system level. Even if firms embrace good environmental practice, the aggregate impact of our global production and consumption creates an unsustainable environmental trajectory for the planet and the businesses it sustains. Others (see Banerjee [Chapter 31]; and Gladwin [Chapter 38] this volume) link this dangerous inertia to the wider capitalist system in which business is embedded.

Complexity theory provides a link between macro-level analysis of systems and micro-level understanding of organizational initiatives that might contribute toward potential solutions. This presents a critically important research agenda for understanding and potentially overcoming the disjuncture between the beehive of corporate sustainability efforts and the deteriorating state of the planet. Complexity offers new ways of addressing environmental impacts at the system level, such as supply chains (see [Klassen & Vachon [Chapter 15] this volume) and geographic industrial ecologies (see Lifset & Boons [Chapter 17] this volume). Yet many questions remain if complexity theory is to be of practical use. What combination of top-down management and bottom-up initiatives is appropriate? How can points of leverage and influence be identified? What structural changes are needed to systems of finance, corporate governance, and energy pricing? What interventions might facilitate local initiatives and their coalescence into more sustainable production systems?

## COMPLEX SYSTEMS AND THE ENVIRONMENT

Complexity theory offers a conceptual framework that incorporates the essential unpredictability of economic and environmental systems with the emergence of distinctive and contingently stable patterns (Anderson et al. 1999; Ormerod 1998). Complexity was originally developed through advances in non-linear mathematics (Thom 1975), thermodynamics (Prigogine & Glansdorf 1971), and computational sciences (Simon 1962). These ideas were quickly adapted to social systems (Ulrich & Probst 1984) and during the 1990s interest exploded in relation to management and organizations (Ashmos & Huber 1987; Kiel & Elliott 1996; Levy 1994; Merry 1995). Complexity theory goes beyond

systems perspectives through advances in deterministic chaos theory (Lorenz 1963), power-law phenomena (Andriani & McKelvey 2009) and computational methodologies (Kauffman 1993; Davis, Eisenhardt, & Bingham 2007).

Complexity theory recognizes that economic and environmental systems comprise a multitude of agents, from individuals to large organizations, with distinctive properties at each level. The economy, for example, comprises individual consumers and workers, firms, markets, industries, and national economies. While all these levels are interdependent, higher-level aggregations exhibit “emergent” properties that cannot easily be reduced to the interaction of lower levels (Holland 1998). Macroeconomics, for example, relies on constructs and theories that differ from those relating to individual firms and consumers. Some core properties of complex systems are shown in Table 32.1.

Understanding complexity has been a long-standing concern of organization theory (Simon 1962). It offers insights into the emergence of patterned structure and order in higher-level systems, such as the Earth’s climate, economic organizations and social institutions, but also provides methods for finding fundamental relationships and simplicity behind complex phenomena. Complexity helps explain how systems can evolve in unexpected ways, exhibiting dramatic instability (Rudolph & Repenning 2002) and even collapse (McKelvey 1999). The weather, the global climate, and the economy are complex systems that exhibit such chaotic behavior (Brock, Hsieh, & LeBaron 1991).

Chaos theory, a core science of complexity, explores systems in which the recursive application of non-linear functions gives rise to highly complex yet patterned behavior. Chaotic systems have several notable characteristics. First, they are unpredictable in the longer term, even though they are driven by deterministic rules. Weather conditions, for example, evolve due to well-understood interactions among variables such as humidity, air pressure, and temperature; however, the non-linear nature of these interactions makes it impossible to predict the long-term evolution of the weather system. The trajectory of chaotic systems such as these is highly dependent on initial starting conditions: the proverbial butterfly could theoretically cause perturbations that are amplified through successive interactions and reverberate throughout the entire weather system.

An important corollary is that, although chaotic systems never return to the same precise state, the outcomes have predictable boundaries that generate well-known

**Table 32.1 Features of complex dynamic systems**

1. Complex systems comprise a large number of dynamically interacting elements.
2. Interactions are rich and any element can influence any other.
3. Interactions are non-linear and typically short-range.
4. There are positive and negative feedback loops of interactions.
5. Complex systems are open systems, often under conditions far from equilibrium.
6. Complex systems are path dependent.
7. Individual elements are typically ignorant of the behavior of the whole system.

patterns (Dooley & Van De Ven 1999). Hurricanes emerge in late summer, though we never know their exact timing, path, or strength. Industries exhibit typical patterns of growth and maturity, yet evolve in unpredictable ways. These patterns are shaped by “strange attractors,” structural features of systems that constrain and mold their evolution. The patterns reflect macro-level emergent properties: hurricanes, economic recessions, and social movements exhibit system-wide patterns that are distinct from the properties of the components from which these systems emerge.

Another important feature of complex systems is that change can be endogenous; under certain conditions interactions can cascade into system transformation (Cheng & Van De Ven 1996). For example, an ecological system in which a rapidly expanding population exhausts a slowly replenishing food supply will produce the classic “overshoot and collapse” outcome (May 1976). Similarly, a stock market collapse can be caused by positive feedback mechanisms affecting investor confidence, liquidity constraints, and computer driven trading. Moreover, systems do not necessarily recover their original pattern after a collapse; rather, they can shift to a new pattern around a different attractor. The economy can become mired in a self-perpetuating depression, and the climate can become locked in an ice age. Crucially, these critical thresholds are hard to predict. Some relatively large perturbations might peter out while smaller ones can propagate into larger-scale shifts. Despite this unpredictability, however, the pattern of sudden shifts, from earthquakes to stock market crashes, tends to follow a power law (Andriani & McKelvey 2009), such that the frequency of large-scale events is inversely related to their magnitude. These features of chaotic systems provide an important basis for understanding the links between the economy and the environment.

## Economy and environment dynamic linkages

On the surface, business and the natural environment are very different types of systems. Business is a social system driven by human agents who make choices regarding their consumption and investment. The climate, by contrast, is primarily a physical and biological system driven by the dynamics of solar radiation, the carbon cycle, ice cover and ocean currents. These systems operate on vastly different timescales, with recessions occurring every decade or so, while ice ages occur about every 100,000 years. Yet from the perspective of complexity, these systems are interlinked elements of a larger socio-technical system. Business is directly dependent on the climate in a number of sectors such as agriculture and tourism, and for clean energy sources like hydroelectric and wind power. Business also depends on a reliable flow of seemingly low-cost natural resources, including water and fossil fuels. Likewise, the carbon emissions that drive climate change are a function of economic growth, technological choices, and corporate governance structures.

At a deeper level, business and climate are both complex dynamic systems, with simultaneous tendencies toward stability and collapse. Both are susceptible to fundamental problems of governance: limits to comprehension, prediction, and control. The recent financial crisis illustrates the difficulties in anticipating and responding to an imminent

economic meltdown. As the ice-caps quite literally melt down, the problems of collective action regarding climate change are becoming acute.

The economy-environment linkages have long been understood by environmentalists who argued that the Earth's natural support systems cannot withstand infinite economic and population growth. At some point, growth would be constrained by the lack of natural resources and the inability of the oceans and air to absorb our waste. The Club of Rome's early efforts at system dynamics modeling highlighted these Limits to Growth, and the authors forecast that the system was headed for "overshoot and collapse" (Meadows, Randers, & Meadows 2004). The core insights of the Limits to Growth thesis are borne out by current rates of depletion of fossil fuel, water, forests, arable land, and even species.

These dynamics and interdependencies have become increasingly visible in recent years. In the years leading up to 2008, rapid economic growth in emerging markets drove a dramatic rise in oil, food, and other commodity prices, a trend that was reinforced by financial speculators eager to ride the lucrative wave, until oil prices peaked at nearly \$140 a barrel. These high prices spurred substantial investment in alternative energy sources, but also provided at least one of the triggers for the severe recession that began in fall 2008. The recession led to sharp cuts in oil prices and clean energy investment, while also reducing greenhouse gas emissions in the US .by about 10 percent in 2008 and 2009, reversing the long term growth trend (EIA 2010) . The recession in turn led governments to provide huge fiscal stimulus packages with some clean energy components, yet the ensuing deficits appear to have sapped the resources and political will for assertive longer-term action on emissions. Traditional linear economic models are inadequate to describe these dynamic relationships (Ormerod 1998).

The structure and character of complex dynamic systems raise important questions for governance of both the economy and the environment. Most central is the question of whether complex systems can be understood, their behavior predicted, and their outcomes managed and controlled. These questions are particularly acute for business-environment systems such as climate change that present the potential for major threats to our well-being. In the next section, we examine some of the features of the business interface with the climate system that present challenges for timely and effective governance.

## SYSTEMIC CHALLENGES TO CLIMATE GOVERNANCE

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Perhaps the most serious challenge for effective climate governance is overcoming the inertia of our fossil fuel based economy. Unruh (2000: 817) has used the term *carbon lock-in* to refer to the "interlocking technological, institutional and social forces . . . that perpetuate fossil fuel-based infrastructures in spite of their known environmental externalities and the apparent existence of cost-neutral, or even cost-effective, remedies."

Carbon-intense technologies become locked in due to economies of scale, network economies, and path dependency (Arthur 1994), and the longevity of assets such as power plants and airports. Complementarities between system components are an important source of inertia (Geels 2004). Electric cars, for example, face hurdles related to the absence of a battery-charging network and the historical dearth of investment in battery technology compared to internal combustion engines.

As significant as technological lock-in, however, is that “carbon lock-in arises from systemic interactions among technologies and institutions” (Unruh 2000: 818). Institutions such as unions, government agencies, and professional bodies generate standards, rules, norms, and routines that stabilize and co-evolve with the dominant technologies. The automobile, for example, is intimately connected to our patterns of work and leisure. Levy & Rothenberg (2002) have suggested that US automobile manufacturers were reluctant to examine lower emission technologies because of conservative managerial mindsets which eschew the idea that consumers might actually embrace smaller cars or clean diesel engines. On the political level, incumbent businesses with vested interests forge powerful coalitions to perpetuate the status quo. Unruh argues (2000: 825) that “The highway lobby is still recognized today as one of the most powerful interest groups in US fiscal policy.” It is this inertia in the energy system that constitutes “perverse resilience” (Gallopín 2006), a highly stable subsystem that threatens the stability of both the global climate and economy. The challenge is to break this inertia into components that include understating and simulating complex systems, recognizing a crisis within it, and determining how to intervene in the system.

## Challenges to understanding and simulating complex systems

Effective governance presumes an ability to understand a system, forecast its development, and intervene with some confidence regarding the outcomes. Complex dynamic systems present challenges to all three elements of the managerial process. The social world is populated by cognizant, emotional agents whose behavior is essentially unpredictable at the individual level (Stacey 1996: 187). Even when system function is well understood at the micro-level, forecasting system behavior at the macro-level remains problematic. Simulation models are frequently employed to represent complex systems, because they can better account for iterative and non-linear interactions over time. Weather forecasts, for example, rely on computer simulations that model the atmosphere as a grid whose elements interact in well-defined physical relationships. With a given set of starting conditions, a computer can generate a forecast that is reasonably accurate for about the next five days, and better than random guessing for about ten.

Simulations, however, are always simplified, and thus imperfect, representations of reality. First, the fixed-step, finite resolution of computation misses the continuous dynamics at the molecular level exhibited in natural and social systems. Second, starting conditions are not known with perfect accuracy. Third, the specification of relationships does not capture some more subtle feedbacks, for example, regarding clouds and the

ocean-land atmospheric interface. Weather forecasters have attempted to improve accuracy by employing faster supercomputers to tackle models with finer temporal and spatial resolution, but the improvement is marginal, because errors in model specification and starting conditions are magnified through iterative calculations.

Although climate modeling has made remarkable progress and provides a good fit with the historical record, models do not yet reliably incorporate longer-term shifts in ocean circulation, ice and forest cover, and other factors that make the climate chaotic on longer time scales. Neither do they capture interaction with political and economic systems in a detailed way, beyond some broad scenarios. As a result, we can speculate about positive feedback effects that could lead to collapsing ice caps and runaway warming, but it is very difficult to predict if and when we might pass the critical thresholds.

## Recognizing a crisis

The dynamics of complex systems make it hard to recognize the approach of critical thresholds and to take timely action to avoid crises. First, it is hard to differentiate between “normal” fluctuations and more drastic transformations. Hurricane Katrina did not raise many alarms regarding climate change, nor did most observers take the collapse of Bear Stearns as a signal of the onset of the global financial crisis. It is only in retrospect, in conjunction with other data, that we are able to see broader patterns and put such events in context. Moreover, complex systems often have regions which appear relatively calm, even while structural pressures are building up. Prior to the financial crisis in October 2008, data on corporate profits and employment gave little cause for concern, even as rising debt and inflated housing prices generated disequilibrium tensions. Similarly, the climate appears relatively stable to casual observers, despite rapidly rising greenhouse gas concentrations.

Fundamentally, the recognition that a crisis demands action is primarily a social and political process. Mass media play a critical role in framing events within a broader narrative context, a role which has been especially evident in the case of climate change (Boykoff, Goodman, & Curtis 2010). Defining a situation as a crisis usually entails allocation of responsibility and demands for redress. However, energy-intensive industries and high-emission countries have tried to minimize concern about climate change, presumably because mitigation measures could adversely impact them. Moreover, there are organizational and psychological barriers against recognizing a crisis. We are biased to ignore warnings about catastrophe, and to presume that what appeared to work yesterday will continue tomorrow (Kahneman, Slovic, & Tversky 1982). Within organizations responsible for complex systems, such as the space shuttle or nuclear power plants, intense organizational pressures frequently silence the expression of valid concerns about risks. These pressures arise from power hierarchies, budgetary pressures, and masculine organizational cultures that deride concerns of risk as weakness (Perrow 1989; Vaughan 1996).

Even once an impending crisis has been acknowledged and a need for active intervention recognized, several major impediments to effective action are well explained by

complexity theory. The following section explores the difficulties of intervening in complex dynamic systems, including problems of collective action, unintended consequences, and inherent limitations on effective management.

## Challenges to effective intervention in complex systems

Intervention in sociotechnical systems entails coordinated action by large numbers of actors, raising the problem of collective action. Hardin's (1968) "Tragedy of the Commons" describes the tendency toward inaction in the face of the overuse of a common resource, such as the atmosphere, when private actors can free-ride and have little incentive to change their behavior. Various societal institutions have evolved to address such collective action problems (Ostrom 1990), but large-scale systemic crises require costly measures that demand an often lengthy process to build consensus.

In part, such delays and disagreements reflect differences in technical understandings of complex systems. Action on climate change, for example, has been delayed while various parties argue over the best course of action: cap-and-trade versus carbon taxes, nuclear power versus renewable energy. Yet these differences are also deeply political, reflecting the asymmetric ways in which actors perceive that a crisis and remedial action will affect them. The fiercest proponents of action on climate change are the low-lying countries likely to be swamped by rising sea levels. In contrast, the countries and sectors who strongly oppose action tend to be heavily dependent on fossil fuels. Some rich countries might be willing to pay 1–2 per cent of GDP to cut emissions, but developing countries demand massive transfusions of capital if they are to transition from cheap fossil fuels. The failure to reach agreement in Copenhagen was largely due to these deep divisions.

Problems of collective action are exacerbated by the need to coordinate multiple forms of intervention in complex dynamic systems. Neither a carbon tax nor a single technological breakthrough will, by itself, solve the climate problem, a point made by Jones (2009) in his system dynamics model of the evolution of the solar industry. Intervention in complex systems is also hindered by the likelihood of undesired and unanticipated consequences. Raising vehicle fuel economy standards reduces the cost of travel per mile, encouraging more car travel. Incentives to raise production of biofuels could raise food prices, and perhaps encourage clearcutting forests.

These uncertainties have led some to suggest that complex systems are essentially unmanageable. Perrow's (1989) study of the nuclear accident at Three Mile Island concluded that catastrophic accidents were "normal" in the context of highly complex socio-technical systems. Even the most carefully designed systems, Perrow argued, could not always prevent occasional human or technological failures from cascading into major disasters. The explosion and massive oil leak from BP's oil well in spring 2010 highlights the challenge of anticipating every potential eventuality, especially when regulators and managers are under pressure to overlook risks to meet deadlines and profit targets.



## ENVIRONMENTAL ACTION IN COMPLEX SYSTEMS

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Despite the failure to reach agreement at Copenhagen, some observers point optimistically to the multitude of climate- and energy-related initiatives at local and regional levels being undertaken by cities, state agencies, companies, and NGOs, often in the form of public-private collaborations (Ostrom 2009a). “Far from lacking climate governance in the face of multilateral deadlock, the world is rather awash in governance initiatives shaping how individuals, communities, provinces, regions, corporations, and nation-states respond to climate change” (Hoffmann 2011: 3). For instance, the ICLEI Climate Program is a network of more than 500 cities and local governments dedicated to local action on sustainability and climate change (Betsill & Bulkeley 2004). In Berkeley, California, the Property Assessed Clean Energy (PACE) model was developed to finance the up-front cost of residential renewable energy and efficiency investments, with repayment through an assessment on property taxes. This solves the problem facing homeowners who lack the requisite financing or are uncertain when they might move home.

In the business world, companies are developing low-carbon products and services, engaging in collaborations with NGOs and government, and forging alliances such as the US Climate Action Partnership to push for more aggressive action on climate (Hoffman 2006; Pinkse & Kolk 2009). GE’s Ecomagination program has doubled its investment in R&D for environmental products to \$1.5 billion, and Citigroup has committed to a \$50 billion “green” initiative that includes investments in clean energy and reducing its global carbon footprint. Perhaps more impressive are initiatives to redesign supply chains, markets, and entire industries. For example, the USGBC’s LEED building certification system has helped generate a \$12 billion green construction industry, leading to long-term efficiencies in materials and energy utilization (Senge et al. 2008).

This rise of local initiatives contradicts conventional theories of collective-action which predict that “no one will change behavior and reduce their energy use unless an external authority imposes enforceable rules that change the incentives faced by those involved. This is why many analysts call for a change in institutions at the global level” (Ostrom 2009b: 7). In contrast, Ostrom shows how actors often have local incentives that do *not* depend on coordinated action: “Even without major taxes imposed on energy at a national level, however, families that decide to invest in better insulation and more efficient furnaces and other appliances, to join a carpool whenever feasible, and to take other energy-conserving actions can save funds over the long run” (Ostrom 2009b: 15). Similarly, cities can enjoy the co-benefits of reducing fossil fuel use, such as cleaner air and improved public health. Ostrom emphasizes that cooperation can emerge within networks of actors when sufficient trust, social capital, leadership, and communication are present, encouraging expectations of reciprocity and mutual learning. She concludes that “many groups in the field have self-organized to develop solutions to common-pool resource problems at a small to medium scale” (Ostrom 2009b: 10). Ostrom’s allusion to

self-organization within a “polycentric order” suggests an awareness of the potential for effective approaches to emerge “bottom-up” from networks of actors.

The theory of emergence provides understanding of how dynamic systems generate order (Lichtenstein & Plowman 2009; McKelvey 2004) and exhibit “self-organization” (Holland 1998). In this section, we apply this theory to the emergence of business responses to climate change, with models drawn from a range of perspectives including order-creation in complex adaptive systems, far-from-equilibrium conditions that give rise to new opportunities and markets, the critical role of local experiments and learning in emergent systems, and a growing literature on self-organization in supply chains.

## Far-from-equilibrium conditions

Many complexity researchers have argued that far-from-equilibrium conditions—pushing systems beyond their normal range of activity—is a key factor driving emergence (Meyer, Gaba, & Colwell 2005). Climate change, for example, creates pressures from consumers, activists, competitors, and regulators for change; similarly, resource scarcity is a force for innovation. Perhaps the leading scholarship in this area has been done by Chiles and colleagues (2010) who have developed a “radical subjectivist” approach to show how the uncertainty facing entrepreneurs leads to market *divergence*, a process stronger than equilibrium-based *convergence* towards imitation. Divergence increases heterogeneity, the driver for innovation, experimentation, and co-evolution (Lewin & Volberda 1999).

The rise of the clean energy sector reflects a slow but persistent system-wide emergence of technologies, regulations, and demand patterns that catalyze the creation and expansion of businesses growing in sheltered market niches. For example, as technologies around solar power develop, business and policy entrepreneurs have identified practices and models that overcome market, technological, and political lock-in. The market begins to “self-organize” as venture capitalists, entrepreneurs, consumers, and regulators interact in a network and create self-sustaining norms, rules, practices, and institutions. Over time, expectations and interactions lead to loosely coordinated self-organization of the market, and the emergence of new technologies and business models. “Thus, entrainment of entrepreneurs’ activity/thought patterns in competitive entrepreneurial markets may spontaneously create a far-from-equilibrium market order that is both heterogeneous and coherent” (Chiles et al. 2010: 39). Shai Agassi’s Better Place project to create a national replaceable battery infrastructure for pure electric vehicles illustrates how an entrepreneur can mobilize other actors to transform markets and overcome systemic obstacles in infrastructure and scale.

## Experimentation for emergence

Studies of the order-creation process show that far-from-equilibrium systems tend to generate local experiments aimed at creating a solution to the internal tension (Prigogine

& Stengers 1984; Lichtenstein 2000). These experiments are more intentional and solution-oriented than the random variation exhibited in Darwinian evolutionary processes; they tend to “bubble up” in organizations (Fuller, Warren, & Argyle 2008) or market regions (Chiles et al. 2010) as an adaptive response to these conditions, and the more successful experiments can grow by replication and attracting more resources.

Sustainability experiments have emerged in a variety of industries with a high utilization of natural resources. A special issue of the *Journal of Cleaner Production* (Jegatheesan et al. 2009) highlighted experiments for transitioning from resource-intensive manufacturing toward innovative approaches that reduce energy and material sources, such as producing biopolymer-based plastics without petroleum. These experiments and others like them are focused within individual industries, but can be linked into broader production systems.

Business initiatives for sustainability interact dialectically with government experiments, not only responding to regulatory pressures, but also creating the political space for policy development. Hoffman & Eidelman (2009: 2) describe the profusion of climate governance experiments in terms of self-organization: “Governance is about making rules above, below, and between established political authorities. Experimentation implies innovation and trial and error with new forms of governance.” They classify fifty-eight unique experiments, each of which intentionally aims to influence awareness and behavior at various levels. These classifications include *Networks* like the Evangelical Climate Initiative, *Infrastructure Builders* like ICLEI and the American Carbon Registry; *Voluntary Actors* such as the e8 Network of Expertise for the Global Environment; and *Accountable Actors*, such as WWF’s Climate Savers.

Hoffman & Eidelman (2009: 2) suggest that “While individual experiments arise for idiosyncratic reasons, experimentation is a broader, patterned process driving significant innovation.” They describe a process in which political agents are “adaptive actors embedded in a co-evolutionary or mutually constitutive relationship with their governance context”, so that “There is constant feedback between actors’ beliefs, interests, and actions. . . . Without centralized planning, the experimental initiatives may form a system of governance where networking, a combination of competition and cooperation, the emergence of communities of practice, and the development of redundancy in the system are likely (Hoffman & Eidelman 2009: 13).

## BETWEEN COLLAPSE AND EMERGENCE

We have presented two very different perspectives on business and the natural environment. The pessimistic macro-view, informed by system dynamics and chaos theory, suggests that environmental externalities and collective action failures are leading to a “tragedy of the commons.” The inherent difficulties in understanding and controlling chaotic systems can turn us into unwitting accomplices in the ineluctably unfolding “overshoot and collapse” of natural ecosystems and the businesses embedded within

them. However, complexity theory also presents a more optimistic micro-level view of system-wide order emerging from self-organized solutions in local contexts. Between these poles, a number of approaches exist which suggest that a limited degree of prediction and managerial intervention is not only possible but necessary to steer our economic and environmental systems away from catastrophe. Here we take a brief look at several approaches including systems dynamics modeling, and the development of sustainable supply chains and ecodistricts.

Many types of complex systems are sufficiently tractable that computational models can provide a degree of forecasting and planning. Global climate models are increasingly able to reproduce the historical record as well as regional features such as the El Nino phenomenon. Likewise, systems dynamics models (Forrester 1971; Sterman 1989) can portray cyclical and chaotic behavior, as well as tendencies toward stability or collapse, providing tools for better understanding threshold effects, unexpected outcomes, and likely responses to intervention (Warren 2004). Using these tools, Jones (2009) found that a sequenced combination of policies such as incentives, information, and research support is much more effective in inducing systemic shifts in an industry than reliance on a single tool such as subsidies.

In contrast to modeling approaches that aspire for prediction and control by autonomous agents standing “outside” the system, an emerging environmental literature on managing sociotechnical transitions draws from complexity to emphasize the limited yet tangible power of managers who are inextricably embedded *within* systems. Managers can *steer* the path of a system, rather than precisely determine outcomes (Garud & Karnoe 2003). At the same time, actors within the system have differential interests and power, resulting in potential conflicts over the direction in which to steer. This insight prompted Smith & Sterling (2006: 1) to suggest, “In short, we need to move from a view of ‘steering as management’ to an understanding of ‘steering as politics.’”

Environmentally favorable new technologies and practices often face hurdles because initially they exhibit relatively poor technical and economic performance, as well as being incongruous with existing infrastructure, interests, incumbent firms, and regulations (Geels 2004; Meadowcroft 2005). Thus, the transitions approach points to the importance of “strategic niche management,” encouraging new models to emerge in niches that are protected from the dominant market regime, and the subsequent diffusion and hybridization of innovations into the mainstream in a co-evolutionary process (Kemp, Schot, & Hoogma 1998; Raven 2007).

Likewise, sustainable supply-chain management and industrial ecology represent efforts to improve environmental performance at the system rather than firm level. As Lifset & Boons ([Chapter 17] this volume) state, “A central premise of industrial ecology is that environmental problems and remedies should be viewed from a systems perspective.” Klassen & Vachon ([Chapter 15] this volume) similarly argue that organizations can only thrive sustainably when they consider the supply chain as a whole. More specifically, research into supply chains has shown that agents can organize themselves in ways that increase efficiency and improve environmental performance (Choi, Dooley, & Rungtusanatham 2001). Across numerous studies, supply chains have been shown to

exhibit self-organization and improve the sustainability of the entire network through adaptive innovation and stronger connections among local firms, suppliers, and customers (Lichtenstein, in press; Pathak et al. 2007; Varga et al. 2009)

A similar process of self-organization across economic entities is at the core of industrial ecology (Ehrenfeld 2009) and eco-industrial parks (Rosenthal & Cote 1998). Based on an operational analogy between ecological habitats and industrial regions, the idea is that one or more of the outputs (“waste”) from one business, such as lumberyard scraps, can become the inputs for another business, such as a paper factory. Successful eco-industrial parks have been set up throughout the world, where each participating firm helps identify and transfer resources that other firms can utilize in their production process (Spiegelman 2003). These adaptive network organizations often connect a wide range of industries, as Klassen & Vachon (Chapter 15) show for the Kalundborg case.

Complexity theory, as well as empirical studies, suggests that adaptive self-organization of supply chains requires particular conditions. According to the NK Landscape models (Kauffman 1993), when a system contains agents who are rigidly connected with a very high degree of interdependence, the computational ecology can “freeze up”—what McKelvey (1999) called a “complexity catastrophe”: the system becomes highly inflexible and unable to adapt. Loose networks, in which autonomy is balanced with interdependence, facilitate adaptive experimentation as well as diffusion of the more successful innovations. Complexity research employing agent-based models also points to the value of integrating bottom-up efforts with top-down guidance and structure. Empirical evidence from these models suggests that self-organizing of autonomous agents can create only minimal degrees of order (McKelvey & Lichtenstein 2007), whereas modern organizations are necessarily composed of seven or eight hierarchical levels (Jacques 1989).

## CONCLUSIONS AND FUTURE DIRECTIONS

Complexity approaches contain a core tension between two perspectives on the dynamic interactions between business and natural environment. A macro-level systems perspective emphasizes structural inertia, misaligned incentives, and failures of collective action. It therefore offers a pessimistic view that we are headed toward environmental overshoot and collapse, with dire consequences for business and society. A more micro-level perspective, however, suggests that under certain conditions, networked actors will engage in a multitude of local initiatives and experimentation, leading to systemic learning and adaptation. A related tension exists in the complexity field between those with confidence that the scientific method can be applied to the development of sophisticated theory and modeling tools, enabling systems to be modeled and controlled, and those who think that complex systems are essentially beyond human management. These tensions are linked, because it is the same characteristics that make complex dynamic systems unpredictable that can facilitate self-organization and emergent order.

Within the context of B&NE, our review suggests the need for a complementarity of local experiments and macro-level governance. Locally designed initiatives have considerable energy and creativity, but in order to grow and scale, they require coordination and a favorable context. In the climate case, this implies economic incentives and political pressures for change, national regulations, and international agreements. Together, these provide some predictability, an alignment of expectations across sectors and geographic boundaries, and coordination mechanisms to generate consensus around goals.

Even with the failure to reach formal agreement at Copenhagen, a consensus around the 2 degrees Celsius ceiling for global warming emerged out of the debates leading up to the international climate conference in 2009, and now serves as a loose policy coordinating mechanism. However, macro-level processes on their own cannot provide the embedded leadership necessary to solve local sustainability challenges, as this requires local initiatives, expertise and participation by businesses and other organizations in specific industries and geographic regions. Thus, progress requires a combination of action at the local level, with coordinated leadership at higher levels.

Ecodistricts and sustainable supply chains illustrate this combination of top-down management and bottom-up self-organization. Regional initiatives for mixed industrial zoning, economic incentives, and integrated infrastructure are often required to initiate the process. Likewise, life-cycle analyses can help identify resource synergies among partner firms. The linkages among the firms, however, need to be enacted by system agents rather than through external forces, in order to generate firm-level commitment and continued innovation.

Opportunities exist here for research into the appropriate form and combination of top-down governance and bottom-up experimentation. While complexity theory has produced some general insights into the conditions needed for self-organization, these are difficult to apply and operationalize in particular circumstances, such as supply chains and local climate governance experiments. Moreover, the sustainable supply chain and industrial ecology literatures are overly reliant on material and energy flows, while neglecting the social, political, and economic structures in which these systems are embedded.

This integrative perspective on bottom-up initiatives and top-down control represents a new and important understanding of complex systems. The notion that self-organization is feasible only in the absence of top-down hierarchical control reflects an inaccurate but popular understanding of complexity science that has generated a fadish wave of organizational consultants invoking complexity in a metaphorical, even mystical manner. Implicit in this approach is a free-market ideology that celebrates individual initiatives and frowns on governmental guidance. Further research can explore the degree, pace, and effectiveness of local environmental initiatives, in the context of complementary dynamics of wider, more structured coordination. If these local initiatives need protection within strategic niches, research is needed into the means of doing so without stifling the active diffusion of successful innovations into the larger system.

The development of modeling tools to represent the complexities of business-environment interactions offers substantial potential for future research. Even as we

recognize that limitations on long-term forecasting in complex systems, models that are well specified with realistic structures and parameters promise to generate insights into our current environmental and economic trajectory, critical thresholds, and future dangers, as well as points of leverage and intervention. A more modest goal, which is increasingly embraced by systems dynamics researchers, is to develop models using visual representations in an interactive, collaborative manner with decision-makers. These models draw on the collective expertise of professionals in a range of locations across system to capture the core dynamics and interactions at play. The purpose is not just to develop useful models, but more importantly, to encourage participants to develop an understanding of complex systems and forge consensus about likely outcomes and potential interventions. The current polarization and paralysis regarding climate change highlights the need for a broader awareness of the character and behavior complex systems at the interface of business and the environment.

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