The Ecological Economics of Resilience: Designing a Safe-Fail Civilization

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

There is mounting evidence that sustainable scale thresholds are now being exceeded worldwide and environmental resource shocks (e.g. climate change, water and oil shortages) may be inevitable in some regions of the world in the near future. These could result in severe economic breakdowns, welfare loss, and in the worst-case, the collapse of modern civilization. Therefore, a pre-eminent challenge of our times is to determine how to design a resilient (safe-fail) economy – one that can endure, adapt to and successfully recover from breakdowns when they occur. Surprisingly, while ecological economic theory relies heavily on natural science concepts such as thermodynamics, insufficient attention has been paid to the important ecological concept of resilience, particularly as it applies to economic design. The three major policy goals of current ecological economic theory (sustainable scale, just distribution and efficient allocation) focus instead on preventing environmental resource shocks and breakdowns, but given their unpredictability prevention may not always be possible.

How resilience can inform the blossoming field of ecological economics is thus explored in this theoretical, transdisciplinary paper. Drawing on literature as diverse as archaeology and disaster planning, it develops six key principles of economic resilience and applies them to analyze the resilience of key societal systems including our money, electricity, water, transportation, information/communication and emergency response systems. Overall, economic resilience appears to be a unique concern that is not readily subsumed under any of the three existing ecological economic policy pillars. In fact, efforts to build in resilience have the potential to both complement and at times contradict the other three goals, especially efficiency. The need to further study these possible tradeoffs provides strong justification for adding a fourth distinct policy pillar, namely "Resilient Design", to core ecological economic theory. Indeed, ecological economist's longstanding criticism of economic growth meshes readily with the Resilience Alliance's own figure-8 adaptive cycle theory critiquing the resilience costs of growth, providing significant opportunities for the future collaboration of these two fields in broadening global system theory.

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I dedicate this thesis to my parents
and to God’s creation.

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Chapter 1: Introduction / Study Approach

1.1 Historical and Current Situation: Teetering on the Edge of Catastrophe

"The world is unhappy. It is unhappy because it doesn't know where it is going and because it senses that, if it did know, it would discover that it was headed for catastrophe"

French President Valery Giscard d'Estaing, 1974

Throughout history most human civilizations have experienced environmental resource shocks (Weiss and Bradley 2001, 609). Those that have collapsed at least in part due to environment and resource catastrophes include the Sumerian, Teotihuacan, Mayan, Greco-Roman, Khmer, Easter Island, Norse Greenland, Southeast Polynesian, Native American Anasazi, and recently Rwandan and Haitian societies (Wright 2004, Diamond 2005). In one of the best works on the collapse of civilizations, Jared Diamond (2005) classifies twelve main interlinked environmental problems that have plagued past and present civilizations. These include: loss of natural habitats, wild food sources, biodiversity, and productive soil; ceilings imposed by energy, freshwater, and photosynthetic capacity; creation and spread of toxic chemicals, alien species, and atmospheric gases; and population growth and per-capita consumption. He believes all "are like time bombs with fuses of less than 50 years…If we solved 11 of the problems, but not the 12th, we would still be in trouble" (Diamond 2005, 498).

International environmental studies and indicators reveal that our current global civilization is at a critical point in its history. Biodiversity and ecological footprint studies by the World Wildlife Fund estimate that we have exceeded our planetary carrying capacity by over 60% (WWF 2010). The United Nations' comprehensive Millennium Ecosystem Assessment concludes that "Human activities have taken the planet to the edge of a massive wave of species extinctions" (MEA 2005). Climate change is accelerating faster than predicted and serious impacts are now inevitable (Brown 2007; IPCC 2007). There is growing consensus among geologists that we have reached peak oil and natural gas supplies with no obvious fuel to replace them (Connor 2009; Gilbert and Perl 2008, 127; Bentley 2002). Serious threats from desertification, deforestation, oceanic die-off, water shortages and global pandemic loom large. Most ominously, humans are in the process of altering the biogeochemical cycles necessary for life on earth (Lovelock 2006). As this is occurring, the global economic system remains plagued by financial uncertainty, high public and personal debt, rising food and energy prices, increasing regional poverty, the U.S. trade deficit and the global credit crunch.

In this weakened state, global world order has become extremely vulnerable to shocks. It is now recognized that the "living machinery of Earth has a tendency to move from gradual to catastrophic change with little warning. Such is the complexity of the relationships between plants, animals, and microorganisms that these 'tipping points' cannot be forecast by existing science" (MEA 2005). As vividly demonstrated in the London smog catastrophe of 1952, environmental degradation and pollution can accumulate gradually in the environment yet because of complex feedback mechanisms and time lags it is detected only after it has already become "a critical destructive mass" (Davis 2002, 44; Rosser 1991, 262). Indeed, ice core analyses show that the earth's climate can change dramatically in only decades, and thanks to human activities we may be on the brink of another such flip that within a hundred years could see the planet's surface poisoned by hydrogen sulphide gas clouds released by acidified oceans (Alley 2000; Ward 2007). More immediately, since 2005 the possibility of catastrophe has gained a higher profile in the mainstream media following the Asian and Japanese Tsunamis, Gulf of Mexico oil spill and Hurricane Katrina disasters (the latter linked to global warming).

James Kunstler (2006, 5) predicts that converging environment and resource scarcity threats will lead to the Long Emergency, "a dire and unprecedented period of difficulty in the twenty-first century". He worries that "the social systems, subsystems, and institutions necessary to run advanced societies would be weakened, perhaps beyond repair, by the multiple calamities of the Long Emergency" (2006, 183). Likewise Diamond (2005, 498) concludes that: "Because we are rapidly advancing along this non-sustainable course, the world's problems will get resolved, in one way or another, within the lifetimes of the children and young adults alive today. The only question is whether they will become resolved in pleasant ways of our own choice, or in unpleasant ways not of our choice, such as warfare, genocide, starvation, disease epidemics, and collapses of societies".

It is within this sombre context that this thesis seeks to examine the resilience of our 21st century global economy: that is, its fundamental ability to endure and recover from what may be impending catastrophic change. Joseph Tainter (1988, 59) observes that "an understanding of collapse often depends more on the characteristics of the society than of its stresses". Indeed, Diamond’s 12 problems can be seen as symptoms of deeper defects in the philosophy, design, construction and performance of human social systems, including economies. Could consideration of the need for economic resilience have saved those prior civilizations from collapsing in the face of catastrophe? Could it still save our own?

If we wish to take the precautionary principle to heart in fields such as ecological economics, we must concern ourselves with planning for these sorts of worst case scenarios which seem increasingly less far-fetched. The more knowledge we gather about environments and economies the more we learn how little we know: “Because of ignorance and uncertainty, surprises will inevitably arise, even from our most knowledgeable decisions. If we recognize this, we can take steps to reduce the likelihood of surprises that are nasty and tragic, and to prepare ourselves to survive, even benefit from, surprises we cannot avoid” (Gibson 1992, 161).

1.2 Research Question

How can the concept and theory of *resilience* be incorporated into the study of ecological economics in order to improve our economy’s capacity to endure, adapt to and recover from impending environmental resource shocks and catastrophes? Would adding consideration of economic resilience enhance or undermine the three main ecological economic goals of sustainable scale, just distribution and efficient allocation? What are some practical implications for human economies?

1.3 Rationale

All complex systems can undergo catastrophic (unexpected and nonlinear) change, and economies are no exception: “human history has been one not of regular change but of spasmodic, catastrophic disruptions followed by long periods of reinvention and development” (Peterson et al., 2002, 92). Mounting evidence suggests that the modern global economy is pressing dangerously close to shrinking ecosystem boundaries, on a course that will be extraordinarily difficult to divert before sustainable scale is exceeded and critical thresholds are crossed (Speth 2008; Rees 2007 interview). Yet significant political barriers to action remain, since “it is difficult to detect strong signals of change early enough to motivate effective solutions" (Levin et al. 1998, 224). Post-Kyoto climate change negotiations, for example, are currently at a standstill. Furthermore, human activity has started some biophysical gears in motion on a planetary scale (e.g. climate change, biodiversity loss and non-renewable resource depletion) that may simply be impossible to reverse (Davis 2002; Gjerde 1999).

Because of this, environmental resource shocks in some regions of the world are nearly inevitable in the near future, potentially resulting in severe economic disruption and welfare loss. The spectacular 2005 breakdown in New Orleans following Hurricane Katrina highlighted the lack of resilience in that city, and more generally the entire United States government. In a worst-case scenario, converging catastrophes could lead to global socioeconomic collapse and the end of modern civilization as we know it. Therefore a pre-eminent challenge of our times is to figure out how to design an economy that will be resilient in the face of coming shocks: "Research needs to address whether or not our vital systems have sufficient capacity for resilience" (Levin et al. 1998, 233). Resilience can be defined very generally as "the ability of a system to remain functionally stable in the face of stress and to recover following a disturbance" (Redman and Kinzig 2003, 5).

The environmental movement has long depended on the spectre of catastrophe to help excite the public's imagination. While some doom-and-gloom predictions have not materialized to date, the "multibillion-dollar costs of many environmental problems justify a moderate frequency of false alarms" (Diamond 2005, 510). It is a common sentiment among environmentalists that it will take a catastrophe to trigger public and government awareness about the magnitude of the crisis that society is now facing (Cairns 2004, 34). Interestingly however, almost all environmental literature to date along with the vast majority of activist and policy efforts focuses only on how to prevent environmental resource shocks from occurring. Only in the area of global climate change has there been a move to also consider how to adapt to (or endure) impacts (Wilbanks et al. 2003).

It is only responsible and prudent to consider: what if our efforts to prevent the worst case scenario actually fail? Many experts have observed the widening gap between environmental problems and our ability to solve them (Homer-Dixon 2000; Berkes et al. 2003, 1). Levin et al. (1998, 224) warn that "We, as a society, find ourselves confronted with a spectrum of potentially catastrophic and irreversible environmental problems, for which conventional approaches will not suffice in providing solutions". On top of this, critical societal systems and those in charge of them remain woefully unprepared for a new age where ecological surprise and sudden rather than gradual change are the new normal (King 1995; Perrings 1998, 504). “Call it the resilience gap. The world is becoming turbulent faster than organizations are becoming resilient” (Hamel and Valikangas 2003, 1).

This thesis therefore takes a very different approach by examining how to design an economy able to minimize its maximum losses by ensuring that economic breakdowns caused by unforeseen shocks do not cascade into catastrophes or terminal collapses. This is among the first papers to focus on applying the concept and theory of resilience to macro-scale socioeconomic breakdowns. It proposes a change in mindset: assume the worst and plan accordingly (the principle of safe-fail). This is a logical extension of technological pessimism, a foundational value of the environmental movement which seems to have been forgotten lately amidst the hubbub over wind power, fluorescent light bulbs and carbon sequestration.

This is not to suggest in any way that continued efforts to anticipate and prevent approaching environmental resource shocks are futile or should be abandoned. Prevention tends to be far better and less costly than a cure (Lawn 2007 interview). This dire situation was created in the first place by our continual failure to watch for indicators and take corrective action once we were aware of various problems. Even now, the less preventative action we take, the worse the shocks will be. But the possibility of catastrophic change that we can never anticipate also implies we need to start preparing for the unpredictable eventualities we cannot prevent: “Collapses are going to happen – even perfect foresight cannot prevent them when social pressures or preferences push systems to the breaking point” (Gunderson and Carpenter 2001, 457).

The basic idea of making individuals and organizations better able to buffer change is often talked about in a superficial way following tumultuous events but usually forgotten just as quickly when normal times return. In the last two years for example, resilient has become a trendy word in the mainstream media who use it to describe firms and economic sectors that have managed to keep growing in the face of the economic downturn. This thesis, however, examines economic resilience at a deeper level than simply how to restore corporate profits or restart the old unsustainable consumption engine. A deeper understanding of resilience requires that we consider how to prepare our economy for worst case scenarios (such as physical shortages of water and oil) so that it will be able to simply *survive* the game-changing shocks headed our way. True desirable resilience can only work if we pay attention to it in the good times and consciously build it into our economies *before* things fall apart.

Yet the justification for preparing for catastrophe is not only about pessimistic survival: as a theory, resilience also provides a unique way of understanding the cycles of change in complex systems. Shifting to a truly sustainable society may require a flip in social attitudes towards a more eco-centric (or at least enlightened self-interest) worldview: "If the global system breaks down, the road back to general prosperity cannot rely upon simply reviving the same wasteful practices" (Greider 1997, 466). Sometimes positive change can only happen because of the opportunities for renewal created by crisis. Hence this thesis also covers how to lay the necessary economic groundwork so that at the crucial point of catastrophic change, society can be pulled back from the brink of collapse and hopefully placed on a better, more sustainable course.

These issues are on the brave new horizon of system thinking. As Low et al. (2003, 103) note, "The concepts needed to understand the behaviour of complex systems are not yet well developed by social scientists". Resilience in particular is not familiar in social sciences as a developed concept and theory (Davidson-Hunt and Berkes 2003, 59). Even in a cross-section of academic disciplines, there seems to be surprisingly little discussion of social or economic resilience, let alone what the key principles of a resilient economy would be, how these would be operationalized in practice, or what system characteristics we should desire to make resilient. Perhaps few are looking at building resilience into human economies because ecologists and environmentalists remain largely focused on preventing catastrophes and conventional economists and engineers remain largely ignorant of the likelihood and magnitude of threats we now face (King 1995, 963).

An alternative economic theory that integrates perhaps most readily with the concept of resilience is ecological economics. Ecological economics is well suited to considering the problem of resilience because unlike most traditional disciplines it is a holistic, emerging field open to new ideas, especially from ecology which is where resilience thinking has progressed furthest: "Ecological economics seeks to promote truly transdisciplinary research in which practitioners accept that disciplinary boundaries are academic constructs irrelevant outside of the university, and allow the problem being studied to determine the appropriate set of tools, rather than vice versa" (Daly and Farley 2004, xxiii). Because of its grounding in both ecological and economic concepts and theories, it is the most logical framework with which to analyze the complex dynamics of environmental resource catastrophes and economic system change.

Nevertheless, a survey of articles and books from this field, including the main journal *Ecological Economics*, shows that even here there is only limited consideration of how to prepare for possible environmental resource shocks, breakdowns and catastrophes. Ecological economist William Rees (2007 interview) believes that while a better understanding of system dynamics would necessitate a focus on economic resilience, for now ecological economics is simply not focused on the possibility of failure. Papers on the integration of resilience into the canon of ecological economics (using economic terminology) are largely absent. The demand however, exists: Holling (2004, 7) recommends that we start enhancing the ability of economies to adapt to change. Ehrlich (2008, 10) calls for ecological economists specifically to undertake studies that take stock of society's resilience in order to improve our organizational ability to respond to catastrophes like Hurricane Katrina. When resilience is discussed at all within ecological economics, it is almost always in terms of the resilience of natural ecosystems (see for example Brand 2009). While vitally important, ecosystem resilience is arguably already addressed to some degree by the sustainable scale goal of ecological economics. What is not being addressed is resilience of the human economic system, and ecological economics could bolster the richness and sophistication of its theory by paying attention to this important topic.

This thesis attempts to further reunite and synthesize the long-lost twin disciplines of ecology and economics, which may be necessary if we are to have a sustainable future as a civilization. Leading ecological economists including Joshua Farley, Joan Martinez-Alier, and Philip Lawn (2007 interviews) believe this pursuit is beneficial. Peter Victor (2007 interview) notes: "Efforts have been made to add ecology and systems theory to economics but we have a long way to go. I suspect that part of the problem is that most of the contributors to ecological economics have been economists rather than ecologists and others". Indeed, Matutinovic (2001, 254) calls for "Further exploration of functional analogues between ecosystems and economies… for example the relationship between diversity, efficiency and adaptability in ecosystems and socioeconomic systems". This paper helps fill this major gap by examining for the first time how resilience relates to the three core goals of ecological economics, in the process exploring such difficult questions as the potential tradeoffs between efficiency, resilience, scale and distributional equity. In this way, it seeks to expand our understanding of how concepts from natural and general systems theory can enhance our understanding of how socioeconomic systems operate.

This thesis is specifically intended to build upon and refine ecological economic theory, so the target audience is ecological economists. Ecological economics is still in its infancy and stands to benefit from efforts to strengthen its theoretical foundation. The intended audience also includes academics interested in systems theory, economic reform, the rise and fall of civilizations, and environment and resource studies generally. The exploratory, normative character of this paper ensures the ideas discussed within will remain at the theoretical stage for some time, to be debated and improved.

Beyond academia, preliminary recommendations about how desirable resilience can be enhanced in real-world economic subsystems are intended for decision-makers (governments, firms and households) who are in a position to help build resilience into our economy. Doing so could also contribute to improving the economy's resilience to other kinds of shocks not related to humanity's impact on the environment such as financial breakdowns, terrorism or purely natural disasters. Future generations are also stakeholders: by focusing on the problem of surviving catastrophe, this study is attempting to ensure they will still have a civilization, however flawed, left to inherit.

Because of the scale of the problem it seeks to address, the findings of this paper are widely significant: "The reason why complex societies disintegrate is of vital importance to every member of one, and today that includes nearly the entire world population" (Tainter 1988, 2). Any way in which this paper ultimately assists the wider world community in preparing to weather environmental resource shocks represents an applied contribution.

1.4 Conceptual / Theoretical Framework

This thesis focuses on the intersection of the concept and theory of resilience with the theory of ecological economics. While ecological economics itself is founded on some concepts from ecology and the physical sciences, resilience is strangely absent in its discussions about socioeconomic decisions. This section will help explain the history and relationships between these and other concepts/theories which together provide the analytical framework used to answer this study's research question. Definitions of these theories and concepts can be found in the glossary.

The theory at the centre of this framework is Herman Daly's vision of ecological economics. Beginning in the early 1970s, it emerged as an effort to reintegrate the diverging disciplines of economics and ecology in response to growing awareness of the negative impacts of economic growth on ecosystems (Ropke 2004, 293; Costanza et al. 1997, 48). Conventional neoclassical economics (and its subdisciplines like environmental economics) assume that economic growth is always beneficial. However Nicholas Georgescu-Roegen and later Herman Daly and Robert Costanza applied the laws of thermodynamics to argue that economic growth is in fact limited by the physical reality of the earth as a finite system (Costanza et al. 1997, 62). Thus was born the first of three major policy goals of ecological economics: keeping the economy at a sustainable scale (Daly and Farley 2004, 13). From neoclassical economics, ecological economics carried over the goal of efficient allocation and from welfare economics the goal of just distribution.

The goal of sustainable scale is essentially to prevent environmental resource shocks from occurring by preserving critical natural capital and its associated ecosystem services. Ecological economists Daly and Farley (2004, 361) write: "Since we are dealing often with staying within biophysical limits, and since those limits are subject to much uncertainty and at times irreversibility, we should leave a considerable safety margin, or slack, between our demands on the system and our best estimate of its capacity. If we go right up to capacity, we cannot afford mistakes because they are too costly". Yet given that the global economy may already be over 100% capacity, it is surprising that ecological economics has devoted so little attention to the containment of economic breakdowns should they occur.

Paralleling the rise of ecology and ecological economics, the formalized theory of catastrophe emerged in the 1970s out of the work of René Thom and other mathematicians as a means of understanding the sudden discontinuous change observed in complex systems, which often flip after passing thresholds (Rosser 1999, 172; Lorenz 1989, 205). In spite of the negative connotations of the name, catastrophes are a natural phenomenon in the evolution of complex systems and can include beneficial nonlinear change like major new innovations. Nevertheless, "the bad catastrophes may be much more obviously discontinuous and dramatic than the good ones. It is much easier to have a sudden decline or collapse than it is to have a sudden improvement" (Rosser 1991, 320).

The phenomenon of catastrophe explained in part the need for the concept of resilience: "an ecosystem must also be able to cope with changes (which can be catastrophic) in environmental conditions: that is, it must be able to cope with stress" (Kay and Schneider 1994, 37). Resilience in ecosystems was first described by C.S. Holling in 1973: "the concept of resilience originated in ecology, and this concept has been applied and studied primarily in the context of ecosystems" (Batabyal 1998, 235). A theory of resilience has since been proposed by world system scientists encompassing the "figure-8" theory of complex system change - this thesis will consider this but especially focus on resilience as a concept.

It is important to note there is a continuum of disruptions from breakdowns to catastrophes to collapse, where collapse is the worst, least desirable from of system change precipitated by a catastrophe which in turn is usually caused by cascading breakdowns in a system. Resilience therefore deals with both preventing breakdowns from cascading into catastrophes, and avoiding collapse after a catastrophe. Additionally, catastrophes can motivate systems to transform in positive ways over the long term. In these cases, we may paradoxically not want certain attributes of our system to be resilient if they hold back such transformation.

Since its inception, ecological economics has attempted to apply lessons from the natural sciences (physics and ecology) to the mechanistic discipline of economics. To date, however, when they do apply ecological concepts, ecological economists mainly focus only on the implications of the laws of thermodynamics for the transfer of energy (throughput) in an economy. Important ecological concepts such as complexity and resilience have yet to make the transition into the majority of ecological economic literature. Perhaps this is partly because the neoclassical canon still underlying ecological economics remains rooted in mechanistic ideas about how the universe is constructed (predictable, deterministic, atomistic) which are antithesis to systems theory (Tisdell 2003, 41).

However, the problem of softening and surviving breakdowns and catastrophes provides newfound justification for examining how resilience and other related complex systems concepts fit into ecological economics: "To understand and address the challenges facing humanity, new perspectives, concepts and tools about the dynamics of complex systems and their implications for sustainability are now developing in parallel, influencing not only the natural sciences but also the social sciences and humanities" (Colding et al. 2002, 15). Indeed, "The concepts and tools developed by ecologists to deal with the evolution of multiple equilibrium ecosystems have the potential to change fundamentally the way we approach the economics of change" (Perrings 1998, 518). This approach is very much consistent with ecological economic theory, since "Systems analysis forms a more natural scientific base and worldview for the inherently integrative transdiscipline of ecological economics than classical, reductionist science" (Costanza et al. 1997, 52). From the perspective of ecological economics it is logical to think of ecological shocks, catastrophes and collapses as inseparable in the modern world from economic breakdowns, catastrophes and collapses: because of system linkages, disruptions of ecological systems can eventually cause breakdowns in economic systems, and vice versa.

Even when considering how to prepare for an uncertain future, the day-to-day purpose of the economy cannot be forgotten: to assign society's resources in an equitable and efficient manner. The just distribution of wealth is the second major goal of ecological economics, and its relationship with economic resilience in particular is largely unexplored. What effect do economic disparities within and between countries have on their resilience to shocks that frequently bring these hidden social problems to the forefront?

Achieving efficiency, the primary occupation of neoclassical economics (in the pursuit of growth and want fulfillment), remains important to ecological economics, but of third priority. In theory, the more efficient the allocation of natural and human capital within the economy, the larger is the scale that can be supported and the longer catastrophe can potentially be averted. On the other hand, traditional notions of efficiency often require specialization and optimization which may necessitate the sacrifice of system attributes like diversity and redundancy which could leave the economy very vulnerable to catastrophes. Is this paradox irreconcilable?

In some cases sustainable scale, just distribution and efficient allocation may complement resilience and in other cases compromise resilience. To the extent these four goals are mutually exclusive, maintaining the same material standard of living while building in resilience might require a level of resource consumption which is unaffordable and unsustainable. Just as Daly and Farley (2004) seek to balance efficiency with scale and distribution, these goals may need to be balanced and/or integrated with economic resilience.

This contentious set of relationships can be seen in many real-world examples, as will be explored in this study. For example, reasons why local small scale economies are preferable to globalization and trade are rarely articulated from an economic point of view: “Building self-reliant, sustainable, local, community economies requires not only good practice and policy, but also good theory” (Curtis 2003, 84). Studying the prevention of societal collapse may reveal a stronger theoretical underpinning for why localism truly does matter.

This thesis therefore brings the new perspectives of understanding provided by resilience thinking to examine the fundamental tensions and complementarities between economic resilience, efficiency, scale and distribution in the efforts to create a unified ecological economic theory. Exploring these relationships is of critical importance because it will help to determine how we should design our economy to meet the needs of the present while building in safeguards against collapse.

This thesis assumes there is a significant possibility that society is unable to achieve sustainable scale before serious catastrophes occur. The most likely reason for this is that the necessary political willpower for action cannot be mustered in time (due to lobbying by vested interests, entrenched ideologies and institutions among decision-makers, the collective action problem of a public failing to appreciate true costs and dangers etc.). By being realistic about the (un)likelihood that society can prevent shocks, this thesis strives to be practical in a theoretical way. However, this may lead some to wonder: if sustainable scale is exceeded due to a failure by society to appreciate the magnitude of the problem, how could society possibly be persuaded to care about resilience? As irrational as it may seem, small policy adjustments which could greatly enhance desirable resilience might be more politically acceptable than policies which try to keep the economy within sustainable scale. For example, governments are increasingly focusing more on adapting to climate change than mitigating it in the first place. Also, smaller vulnerable countries may wish to take action to prepare for coming shocks even though the political resolve for prevention among the major polluters is lacking.

If ecological economists were allowed to implement their agenda, society could hopefully stay well within sustainable scale and environmental resource shocks would be averted. Therefore some might also question why ecological economics should worry about incorporating economic resilience when prevention seems like the best solution of all. The first reason is that human actions may have already set catastrophic natural feedback systems in motion (climate change) which even ecological economic policies would be powerless to reverse (Diamond 2005, 409). “There is often a long time lag between the events that make collapse inevitable, and the collapse itself. In a global complex society, we are less likely to see warnings of a collapse in time to prevent it" (Farley 2007 interview).

The second reason is because chaos exists in the universe. In the 1990s, chaos theory evolved out of catastrophe theory to explain the unpredictability observed in nonlinear systems (popularly known as the "butterfly effect") (Gunderson et al. 2002). Chaos theory tells us that because the exact starting conditions of a system or phenomenon are never known, we can never fully predict their behaviour even with the most meticulous measuring instruments and computer models. Even simple systems with known laws can demonstrate chaotic behaviour as small initial variances become exponentially magnified over time. Contrary to the hidden assumption in conventional economics that people have perfect information even about the future, we therefore cannot reliably predict shocks, breakdowns or catastrophes, or what we need to do to prevent them, or whether our efforts will even work (Beers 2009). "It might seem that long-range forecasting of environmental conditions might help avoid overshooting environmental limits. Unfortunately, ecological research has demonstrated that predicting ecosystem thresholds or behaviour far in advance may be impossible" (King 1995, 964).

Indeed, resilience theory agrees that "change is ultimately inevitable and repeated, although repeated cycles may not follow the same pathway or result in analogous systems" (Redman and Kinzig 2003, 2). Thus, even if ecological economists were on track to meet sustainable scale, they would be well advised to practice the precautionary principle since not all shocks can be foreseen or prevented: "we're unlikely to prevent all forms of breakdown" (Homer-Dixon 2006, 30). In the near future, the main source of unpredictability/chaos is of course likely to be climate change. As a theory of social change, resilience may also help ecological economists make sense of the process by which ecological economics might one day gain ascendancy, emerge into the mainstream and ultimately supplant neoclassical economics. It may take a catastrophe to wake people up to the need for ecological economics, but ecological economists first need to advocate for building desirable resilience into the economy to ensure they will have a civilization left to inherit.

To summarize, ecological economics attempts to integrate concepts from the natural sciences and conventional mechanistic economics. This leads to three conceptual policy goals: just distribution, efficient allocation and sustainable scale. Within the umbrella of complex systems theory are the theories of catastrophe and chaos which together imply that sustainable scale cannot always be achieved and some unanticipated shocks, breakdowns and catastrophes are inevitable. From ecology and systems theory also comes the concept of resilience, which is largely missing from the theory of ecological economics in terms of its economic implications for designing a “safe-fail” economy. This thesis will therefore analyze how economic resilience can be integrated into ecological economics, while also examining the complex interplay between resilience, sustainable scale, just distribution, efficient allocation and catastrophe. Additionally, this thesis will seek to identify key sub-concepts such as redundancy, diversity, dispersity, autarky, adaptive capacity and transformability which together should provide a more comprehensive picture of what is meant by economic resilience. This thesis is not meant to be a critique of ecological economics so much as a contribution to the conceptual foundation of this emerging theory to help realize more of its tremendous potential.

Basic assumption 1 for the framework to be developed here is that resilience is a useful thing to have given the historical record. It should be noted, however, that short run resilience can be desirable or undesirable depending on whether a system’s attributes are beneficial and worth preserving (see Chapter 3 for more discussion on this). Assumption 2 is that ecological economics is a very suitable branch of economics for studying resilience. A final assumption underpinning this framework is that these existing concepts and theories from various disciplines are themselves applicable and legitimate, and that it is valid to apply them together to obtain insights to a new problem. This framework will be immensely useful for this study because the possibility of deriving new insights and perspectives on catastrophe and resilience is greatly magnified when one approaches the subject from a transdisciplinary vantage point.

1.5 Methodology

This study is mainly theoretical, focusing on breadth more than depth. The benefit of remaining broadly theoretical is that the results are more generalizable than if a narrower case study approach were adopted. The focus first and foremost is on establishing the relevancy of resilience to economists and their theories from which policy implications can follow.

This study is primarily qualitative rather than quantitative, which is justifiable because chaos theory and our perpetual ignorance of system linkages guarantees there will be vast uncertainties surrounding future catastrophes and their impact on economic systems (the only certainty will be surprise itself). This makes efforts to model them quantitatively not only difficult but potentially misleading. Gunderson (2003, 40) explains why traditional scientific methodology is not always appropriate for complex system research such as this study: “One mode of science focuses on parts of the system and deals with experiments that narrow uncertainty to the point of acceptance by peers; it is conservative and unambiguous by being incomplete and fragmentary. The other view is integrative and holistic, searching for simple structures and relationships that explain much of nature’s complexity… [and] assumes that surprises are inevitable, that knowledge will always be incomplete”. This thesis follows the trend towards post-normal environmental science, where “facts are uncertain, values in dispute, stakes high, and decisions urgent” (Ravetz 1999, 649).

To answer its research question, this study uses three main methods: a secondary literature research, primary research through key informant interviews, and finally, based on information gathered to that point, a substantial qualitative ecological economic analysis and application. This study is divided into 7 chapters that together are necessary to answer the original overarching research question. In spite of the numerical sequencing of these chapters, this study did not develop in a linear fashion. Instead, an iterative process was followed (see Palys 1997, 298): answers to the research questions were open to revision over the course of the study as new information and insights became available. This dynamic methodology based on a positive feedback loop is in the spirit of this study’s focus on complex system concepts. This paper’s research is both exploratory (aims to gain new insights) and relational (seeks to determine how variables are related, primarily in Chapters 5-7) (Palys 1997, 77).

Secondary literature plays an integral role in answering the research question, along with identifying relevant definitions, concepts, and historical information. This thesis goes beyond a simple traditional literature review in that it collects and synthesizes a wide and extremely diverse body of literature on environmental catastrophe, the collapse of civilizations, resilience and economics. Journals, books and academic websites are cited from fields such as economics, ecology, systems theory, archaeology and disaster planning.

Because of the scale of this topic and its theoretical nature, primary research was not extensive. However, semi-structured key informant interviews were conducted in order to provide expert up-to-date input and personalized feedback on the validity of this author’s analysis and arguments. Five key professors in the field of ecological economics were the most logical individuals to interview given the research question focuses on the development of this particular theory. Professors were interviewed from institutions including York University, the University of British Columbia, the Gund Institute of Ecological Economics, University of California, Berkeley and Flinders University, Australia. These professors were chosen from academic specializations listed on university websites and from those known by the author to have expertise in ecological economic theory. Together they represent a reasonable sample of the major minds in the field. A sixth professor interviewed was a world expert in resilience and the environmental roots of conflict.

Interviews were conducted primarily through email to minimize the ecological impact of unnecessary travel, but one was conducted in person. Each key informant was asked to answer a set of qualitative questions that varied slightly depending on the interviewee's particular expertise. Both the data collection tools and the interview procedure itself first passed full University of Waterloo ethics clearance to ensure professionalism. Participants could choose to remain anonymous, and one did.

The third main method of this study is extensive analysis. This can be considered a "method" for purposes of this study because most of the gathered secondary data is not written from the perspective of ecological economics, nor is any single source likely to explicitly address all aspects of the research question. Hence, data analysis in this fundamentally theoretical paper had to go beyond simply summarization and the identification of patterns. Findings had to be integrated into this study's theoretical framework, and ecological economics more generally, by using creativity and theoretical logic to identify key relationships and new implications. Most importantly, because of the novelty of the research being undertaken, this author had to design and iteratively refine his own conceptual framework (within the larger study's overall theoretical framework). This unique framework introducing economic resilience and its principles is detailed in Chapter 4 and then tested in Chapter 5 to determine how it fits within the broader theory of ecological economics in order to answer the original research question. Finally, a new master framework incorporating both the concept of economic resilience (and principles) and ecological economics is in turn applied to real life economic sectors to illustrate the new insights it can provide (Chapter 6).

The methodology can be broadly summarized as gathering historical and secondary data (Chapter 2-3), synthesis and development of a conceptual framework of economic resilience

(Chapter 4), application of this framework to ecological economic theory (Chapter 5), application to real life examples (Chapter 6) and final theoretical and applied implications (Chapter 7).

1.6 Boundaries

This study's unit of analysis is the emerging transdiscipline of ecological economics. Since ecological economics is committed to real-world policy relevance (Daly and Farley 2004, 43), the unit of analysis is also by extension the global economy and its subsystems. The geographic boundaries of this study include all areas where human economies are presently operating. Temporal boundaries are also broad given that ecological economics encompasses inter-generational equity and long-term sustainability. Predicting with certainty when the next environmental resource shock will occur is impossible. Nevertheless, the net effects of shocks like climate change and peak oil are likely to manifest themselves by the middle of this century and be fully felt by its end (Diamond 2005, 498; Nadeau 2003, xi), so a time horizon of 100 years serves as a rough boundary. Being based on present-day economic, technological and cultural conditions, this analysis remains valid for as long as these conditions characterize society, and so long as the threat of environmental resource catastrophes remain. This study also draws on historical lessons from civilizations dating as far back as 3000 B.C.

The boundaries of the actual research this author conducted are m narrower. Because of the worldwide availability of information through libraries, the internet and digital communication technologies, this topic could be researched while remaining within the spatial boundaries of south-western Ontario. The fundamentally theoretical and conceptual nature of this paper did not necessitate doing primary field research in any specific location, outside of one key informant interview.

Due to space constraints this paper does not comprehensively identify or classify the many various types of environmental resource shocks and how each threatens to cause the breakdown of modern economies. As well as the quick summary at the beginning of this thesis, the threats facing our civilization have been covered in detail by other authors including Heinberg (2007), Homer-Dixon (2006) and Kunstler (2006). This thesis assumes at least some of these shocks will threaten our economy, which seems reasonable given that many like Rees

(2003) assert that humanity is more at risk now than at any earlier phase in our history. Moreover, "The vulnerabilities of complex systems often cannot be foreseen in detail. It is possible to classify general patterns of failure, but even elaborate schemes of classification cannot predict which particular failures will be most important" (Lovins and Lovins 2001, 177). Chaos theory instead implies we must be prepared for all eventualities. This thesis also does not cover how to prevent these shocks – that is the domain and objective of most other environmental literature, and again falls more under the sustainable scale (and to a lesser degree efficient allocation) goals of ecological economics.

Some may wonder whether it would take a global-scale catastrophe in order to cause the collapse of any nation since unlike in the past, countries can now come to one another's aid (as seen so successfully after the Asian Tsunami). However, as will be explored in later chapters, globalized systems are now interlinked to such a degree compared to past civilizations that the risk of simultaneous failure is equally great (as seen in recent world financial crises) (Homer-Dixon 2006, 180). A breakdown in just a few key countries could spread worldwide: "Collapse, if and when it comes again, will this time be global. No longer can any individual nation collapse. World civilization will disintegrate as a whole. Competitors who evolve as peers collapse in like manner" (Tainter 1988, 214).

Whether the initial shock is local or global, this thesis focuses primarily on sudden large scale breakdowns where outside subsidies from other regions are either not available or not sufficient alone to prevent catastrophe. Even if outside help saves a particular community from complete collapse, it is still important to have resilience to lessen damage. There is certainly merit in considering whether gradual small scale perturbations would best be addressed within ecological economics under resilience or some other goal such as efficiency, but smaller scale disturbances largely lie outside the boundaries of this thesis.

Since this is an economic paper first and foremost, it does not dwell on the traditional application of resilience to purely ecological/natural systems, aside from sampling that body of literature for ideas which are relevant to economics. From an ecological economic standpoint, maintaining resilience in ecological systems is probably already encompassed sufficiently within the sustainable scale goal. Natural systems do a far better job regulating their own resilience than humans ever could, and so the primary way that ecological economists can help build the resilience of environmental systems is to control the scale of human caused disruptions imposed on them by our economy. Nor does this study focus on social and political governance implications of building resilience that do not directly impact economic decisions. This paper is also concerned with the economic challenge of building resilience ahead of time (i.e. the physical capacity to respond), rather than for example the specifics of how emergency response teams and community leaders should behave during a crisis which is better covered in disaster management literature.

Finally, this thesis concentrates on the mitigation of environmental resource shocks and catastrophes caused by unsustainable economic throughput. It may note brief lessons but does not focus on entirely random breakdowns, entirely natural shocks (e.g. most earthquakes, asteroid impacts) or entirely human-caused shocks (e.g. terrorism, computer viruses, war and economic downturns caused primarily by losses in consumer and investor confidence). This scoping choice was made because human-instigated environmental resource shocks and catastrophes have been primarily responsible for many of civilization's greatest collapses (Wright 2004; Diamond 2005). Given current rates of population and economic growth, environmental resource shocks seem to be the most urgent and dire threat now facing many regions on earth. Environmental resource shocks and catastrophes are the ones best suited for ecological economics to examine because they result from the interaction of physical (ecological) and human (economic) systems. Nevertheless, the line between environmental resource and purely natural/human-caused shocks and catastrophes is becoming increasingly blurry, for example as human activities influence global weather systems and wars are fought over resource scarcity (Renner 1996). Ultimately, building resilience into the economy could prove beneficial to societal recovery regardless of the origin and combination of specific stresses that precipitate a catastrophe (Robb 2007).

1.7 Limitations

This thesis has several limitations. First, the relative infancy of ecological economics and resilience thinking places limits on the amount of prior literature for this analysis to draw on. Second, in terms of historical analysis (Chapter 2), because catastrophes and collapses through history have usually thrown governments into disarray, "record keeping during these periods is often poor, which can inhibit detailed reconstructions" (Redman and Kinzig 2003, 12).

Third, the generalization of concepts from ecology or the natural sciences to human systems can be a contentious academic and political exercise: "Simply taking the concept of resilience from the ecological sciences and applying it to social systems assumes that there are no essential differences in behaviour and structure between socialized institutions and ecological systems" (Adger 2000, 350). This author shares the concern that there is a potential for invalid generalizations to be made, yet believes the particular concept of resilience, when applied in a rigorous way, is fundamentally relevant to the specific problem of preparing economies for the very real threat of catastrophic change.

Fourth, trying to answer such broad, complicated and multivariable research questions increases the chance that this thesis could miss details or make inaccurate conclusions. Yet taking a holistic approach may be the only way to properly examine such a complex problem. Focusing on too narrow a scale implies one is trying to assess large scale systems by generalizing from smaller systems, a reductionistic assumption that is not in the spirit of ecological economics. This study has instead chosen to approach the problem of economic resilience from primarily a macro-scale perspective, in keeping with many ecological economic analyses, but will also examine various microeconomic decisions where appropriate. As Holling et al. (2004, 9) observe: "No social-ecological system can be understood by examining it at only one scale".

Fifth, this study is undertaking only limited primary research and experimentation, however this is justifiable given the scale and temporal properties of the phenomena being studied. Breakdowns and catastrophes are erratic events that do not occur regularly making them extremely difficult to do a controlled experiment on. For example those presently working in the fields of agriculture, energy or transportation may have little to no experience with the kind of large-scale system breakdowns which could be instigated by environmental resource shocks, so surveys and interviews of these professionals might be of only limited use. This paper will therefore be constrained by the predictive assumptions of this author and his academic interviewees and the information contained within secondary literature.

Sixth, this study will conduct only limited empirical analysis, which may impact its ability to support conclusions and definitive recommendations: "The major strength of catastrophe theory is to provide a qualitative topology of the general structure of discontinuities. Its major weakness is that it frequently is not associated with specific models allowing precise quantitative predictions" (Rosser 1991, 2). This thesis will hopefully help pave the way for more applied studies of economic resilience in the future. In particular, this study identifies and explores but does not try to resolve various potential conflicts and tradeoffs between resilience and other ecological economic goals like efficiency, instead leaving the door open to future research.

Regarding biases, this author has been exposed to a wide spectrum of conceptual and theoretical approaches to economics and environment and resource studies over the course of his education, and so hopefully can examine these issues with a balanced and informed perspective.

1.8 Overview of Paper to Come

Chapter 2 will introduce the concepts of breakdown, catastrophe and collapse and examine some of the reasons why civilizations through history are thought to have failed under stress, and how this has related to the design of their economies. As Diamond (2005, 8) explains: "We know that some past societies collapsed while others didn't: what made certain societies especially vulnerable?" This is some of the best evidence that exists since modern society has only suffered isolated breakdowns to date. The chapter will also briefly review how the concepts of catastrophe and collapse have been used in conventional economics.

Chapter 3 will introduce the general concept of resilience, differentiating between the traditional engineering and ecological definitions of the term as well as between the useful concepts of Fail-safe and Safe-fail. It will then discuss the development of resilience as a broader theory centred around the figure-8 adaptive cycle of complex system change. The chapter will also briefly examine the resilience of historical civilizations and the degree to which resilience has been used to date in academic fields ranging from ecology to conventional economics.

Chapter 4 proposes a new definition of resilience uniquely tailored to economies. As part of this definition, it evaluates various potential principles that the literature identifies as important for enhancing the resilience of a system. From this the author chooses six key principles which appear central to improving the economy's capacity to endure and successfully recover from environmental resource shocks: redundancy, diversity, dispersity, autarky, adaptability and transformability. This framework of understanding economic resilience will be useful throughout the remainder of the paper.

Chapter 5, the heart of the paper, represents a first attempt at integrating the conceptual framework of economic resilience developed in Chapter 4 with the emerging theory of ecological economics. Deep consideration is given as to whether building resilience into economies would be compatible or at odds with the three existing ecological economic goals of a) sustainable scale, b) efficient allocation and c) just distribution. Each is evaluated in turn from a theoretical perspective.

Chapter 6, the most applied part of the paper, analyzes how some of the most vital systems and linkages in real-world modern economies can be made more resilient to shocks. This chapter seeks to illustrate how the largely theoretical ecological economic framework from Chapters 4 and 5 can be used to generate practical insights. Systems examined include the money supply, electricity and energy utilities, the water supply, the transportation network, the communication and information system, the emergency response system, and the general interrelationships of urban systems.

Chapter 7 concludes by exploring the central question: how should resilience be built into the theory of ecological economics? Should it stay as a niche concept or become a guiding principle or even a fourth policy goal? The chapter ends by identifying areas for further study as well as reflecting on some general but important implications of resilience thinking for governments and communities seeking to prepare for the great changes ahead.

Chapter 2: Historical Catastrophe and Collapse

To understand the need for economic resilience, it is useful to begin by reviewing theories about why whole civilizations (and their economies) have collapsed. This chapter examines the impact that environmental resource shocks, breakdowns and catastrophes have had through the history of human civilization. It analyzes the role that the structural design of economies have been theorized to play in their collapse and then looks at five sample civilizations that collapsed primarily due to self-inflicted environmental resource catastrophes: the Mayans, Anasazi, Romans, Sumerians, and Norse Greenland societies. It concludes with a look at modern collapses and how the idea of collapse has been used in conventional economics.

2.1 Defining Breakdown, Catastrophe and Collapse

In his classic book on the collapse of civilizations, archaeologist Joseph Tainter (1988, 3) writes: "Although collapse has been of interest for as long as societies have proven vulnerable, it has been a difficult mystery for historians and social scientists. Perhaps because of this, the development of political complexity has attracted more scholarly attention than collapse, its antithesis". What do scholars mean by collapse? Some like Heinberg (2004) and Diamond (2005) use the word to encompass the whole spectrum of sudden and gradual societal breakdowns: "collapse may or may not result in the destruction of society's primary institutions" (Heinberg 2004, 10). Homer-Dixon (2006, 110) prefers the word breakdown to describe short-term system damage that can be repaired, reserving the terms catastrophic failure or deep collapse (borrowed from C.S. Holling) to describe a long-term loss of knowledge and social order.

This thesis will adopt a somewhat similar approach by beginning with the term breakdown to describe the initial crisis point when failures start to occur. Breakdowns can occur when a shock overwhelms the traditional stability (robustness) mechanisms of a system and interrupts normal predictable operations and organization. Economic breakdowns can be characterized by the disruption of traditional market exchanges and supply chains, the sudden decline of paid employment in certain sectors, and normally abundant goods and services rapidly becoming scarce. These events typically lead to fear, anger, suffering and/or irrational behaviour among economic actors.

A system experiencing breakdown initially remains within the same basin of attraction, however breakdowns can potentially cascade within and across different systems to the point where they cause the system to cross a threshold that significantly alters the behaviour and/or characteristics of that system. This is called a catastrophe, and occurs when a system crosses a threshold and flips to a new state, and potentially a new and unfamiliar basin of attraction. A catastrophe event is a point of key change in any system, where the future composition of that system, and even its survival, is most uncertain and most at stake. Opportunity and risk are both extremely high. Sometimes, systems can take on more desirable characteristics following a catastrophe, but there is also a danger they could collapse outright.

A collapse is a terminal, long-lasting reduction in the size and/or complexity of a system. In terms of human civilizations, this thesis adopts Diamond's (2005, 3) definition of collapse: a "drastic decrease in human population size and/or political/economic/social complexity, over a considerable area, for an extended time". To this is added the following economic criterion: significant economic welfare loss among the population must also occur.

Schwartz and Nichols (2006, 6) note that "In the archaeological literature, collapse usually entails some or all of the following: the fragmentation of states into smaller political entities; the partial abandonment or complete desertion of urban centres, along with the loss or depletion of their centralizing functions; the breakdown of regional economic systems; and the failure of civilizational ideologies." Renfrew (1979, 483) lists successive stages that economies of collapsing civilizations pass through: the end of centralized wealth redistribution or market exchange, the end of the issuing or exchange of coinage, a significant decline in trade, the abandonment of central administrative organizations and buildings, disappearance of the traditional elite class, the despecialization of labour and agriculture (reverting to local homesteads with diversified farming) and settlement shift and population decline. Finally Greer (2008, 83) describes four phases of civilization collapse: declining energy availability, economic contraction, collapsing public health and finally political turmoil.

Thus there is a continuum of events involved in the failure of any system. An initial shock, either endogenous or exogenous, leads to one or more breakdowns in various system components. If these components are serious or if the breakdown is allowed to spread, it can take the system to the point where it is crosses one or more thresholds. This is the period of catastrophic change. Finally, a collapse is the worst-case outcome for the system following a catastrophe. Eisenstadt (1988, 236) concludes: “The so-called collapse of ancient states and civilizations is one example, possibly the most extreme one, of the larger problem of how social boundaries are restructured and reconstructed”.

2.2 Historical Environmental Resource Shocks

Tainter (1988, 198) maintains that “Societies collapse when stress requires some organizational change”. The particular type of stress this thesis focuses on are environmental resource shocks, which are sudden and unexpected scarcities of natural resources and/or failures of ecosystem services due to unsustainable levels of economic throughput and/or human population. The direct anthropological link between environmental degradation and the catastrophic upheaval and deep collapse of some of history’s grandest economies has been explored quite well in recent years, especially by Wright (2004) and Diamond (2005). The Sumerian, Greco-Roman, Mayan, Anasazi, Southeast Polynesian, Norse Greenland and Easter Island civilizations have all collapsed in large part due to self-inflicted environmental resource catastrophes (Wright 2004, Diamond 2005).

All are believed to have followed a broadly similar pattern of collapse: rapid population growth led to unsustainable agricultural practices (primarily deforestation) that caused environmental degradation, paradoxically leading to food shortages. The resulting civil strife and open warfare, often together with a final decisive environmental resource catastrophe, was enough to seal their collapse: “A true collapse results in a society’s extinction or near-extinction, during which very large numbers of people die or scatter. Recovery, if there is one, takes centuries, for it requires the regeneration of natural capital, as woods, water and topsoil slowly rebuild” (Wright 2004, 84).

It is valuable for ecological economists to look at the fate of these once mighty agrarian economies because they provide vivid examples of the fundamental link between nature and a society’s survival and prosperity. Heinberg (2003, 33) wonders: “Why would a group of people intelligent enough to have built impressive temples, roads and cities suddenly lose the ability to maintain them? Why would a society capable of organizing itself into a far-flung empire, with communications networks and distribution systems, suddenly lose its ability to continue?"

Diamond (2005) proposes a five-point framework of possible contributing factors to collapse: environmental damage, climate change, hostile neighbours, friendly trade partners, and society's response to its environmental problems. These serve as input variables which he compares with the output variables of survival or collapse. Heinberg (2004, 10) observes that in some cases collapse may take as long as 100 to 500 years to run its course (like the Roman, Minoan Crete and Western Chou Empire): "Complex societies that are limited to a single bioregion, such as the Classic Maya or the Anasazi, are more likely to collapse quickly as a result of damage to the ecosystem, while those of greater geographic extent typically persist for decades or centuries longer" (Heinberg 2004, 148). Wright (2004, 84) observes that:

> civilization is therefore most unstable at its peak, when it has reached maximum demand on the ecology. Unless a new source of wealth or energy appears, it has no room left to raise production or absorb the shock of natural fluctuations. The only way onward is to keep wringing loans from nature and humanity. Once nature starts to foreclose – with erosion, crop failure, famine, disease – the social contract breaks down. People may suffer stoically for a while, but sooner or later the ruler's relationship with heaven is exposed as a delusion or a lie. Then the temples are looted, the statues thrown down, the barbarians welcomed…

Diamond (2005, 509) agrees that a key lesson "to be learned from the collapses of the Maya, Anasazi, Easter Islanders, and those other past societies (as well as from the recent collapse of the Soviet Union) is that a society's steep decline may begin only a decade or two after the society reaches its peak numbers, wealth and power".

Tainter (1988, 59-60) nicknames Diamond's explanation of collapse "The Dinosaur": complex societies become so well adapted to existing circumstances that undertaking necessary change is very difficult. He calls Wright's type of hypothesis the "The House of Cards" model of collapse: "It suggests that complex societies, either as a rule or in certain kinds of environments, are inherently fragile, operating on low margins of reserve, so that their collapse is inevitable". But Tainter believes both these, and other failure to adapt explanations, are too simple to account for the capacity of human societies to be flexible and rational in their decisions. Since it challenges his core hypothesis, Diamond (2005, 420) takes deliberate aim at Tainter's earlier work, labelling it a refusal to admit that humans can mismanage their environment and resources, even though historical evidence reveals they have in fact done so repeatedly. Diamond then proposes various reasons why a society may fail to anticipate a problem before it arrives, may fail to perceive it when it does arrive, may fail to try to solve it after perceiving it, and may fail to solve it after trying.

Homer-Dixon (2006) acknowledges that the factors responsible for collapse will be debated endlessly by historians but he begins by proposing that a society is more likely to experience catastrophes when it is hit by many severe stresses simultaneously that combine to magnify their impact through the links among people, organizations and technologies in a society (synchronous failure). Yet Tainter (1988, 206) also has problems with this argument:

> Catastrophe theories suffer from the same flaw as resource depletion arguments. Why, when complex social systems are designed to handle catastrophes and routinely do, would any society succumb? If any society ever succumbed to a single-event catastrophe, it must have been a disaster of truly colossal magnitude. Otherwise, the inability of a society to recover from perturbation must be attributable to economic weakness, resulting quite plausibly from declining marginal returns.

Indeed, there seems to be a connection between the design and structure of a society's economy (primarily its complexity) and its propensity to break down due to shocks, because "The exuberant flowering of complex societies seems invariably to be followed by their unceremonious wilting and collapse" (Rees 2002, 264).

2.3 Economic Susceptibility to Collapse

Tainter (1988) famously hypothesizes that the reason civilizations eventually collapse is because their increasing complexity is subject to the economic law of diminishing marginal returns. By complexity, Tainter (1996), means "such things as the size of a society, the number and distinctiveness of its parts [including technologies], the variety of specialized roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole…. Hunter-gatherer societies (by way of illustrating one contrast in complexity) contain no more than a few dozen distinct social personalities, while modern European censuses recognize 10,000 to 20,000 unique occupational roles, and industrial societies may contain overall more than 1,000,000 different kinds of social personalities".

Just as ecological economists advocate applying the microeconomic "when to stop growing rule" (when marginal benefits = marginal costs) to the scale of the macroeconomy (Daly and Farley 2004, 20), Tainter believes the law of diminishing returns also applies. As a civilization grows, it has a natural tendency to respond to every problem by becoming more complex. This trend follows an inverse u-curve, "where continued investment in complexity yields higher returns, but at a declining marginal rate" (Tainter 1996). This is because economies pursue solutions that give the best returns first and leave costlier, less effective solutions for later. Unless they continually find new inputs, Tainter asserts that all civilizations tend to pass a point of no return where collapse becomes inevitable because the population finds local organization more efficient and independence more attractive than an imperial superstructure with ever rising costs (Wright 2004, 92). Tainter observes that collapse is not always a disastrous event, as reverting to a less complex structure may actually increase welfare.

Tainter (1988) seems to implicitly view complexity as the direct cause of collapse rather than a factor jeopardizing society's ability to endure and recuperate from catastrophe. It is unclear why he believes catastrophes caused by natural resource depletion are necessarily incompatible with his collapse theory, since greatly reduced energy inputs would exacerbate diminishing returns. Perhaps his original refusal to admit the possibility of environmental mismanagement revealed a belief in linear change and faith in human intelligence. Indeed, Tainter's stand on this issue appears to have softened over the years. He has gone on to write in the ecological economic literature (Tainter 1996) that a society is likely to collapse at the point of diminishing returns in part because "new emergencies impinge on a people who are investing in a strategy that yields less and less marginal return. As such a society becomes economically weakened; it has fewer reserves with which to counter major adversities. A crisis that the society might have survived in its earlier days now becomes insurmountable".

Therefore it is possible to reconcile the two major theories of collapse described above (environmental mismanagement versus flaws in the structure of the economy) by ascribing the trigger point of breakdowns to environment and resource depletion, but the actual collapse to a lack of economic resilience caused in part by overinvestment in complexity. Indeed, Homer-Dixon (2006) attempts to do just that. He tweaks Tainter's hypothesis by focusing on diminishing EROI (energy return on investment): each successive unit of a particular energy resource is more and more costly to extract. Thus with rising complexity and diminishing energy returns, "the society's resilience declines. An expanding portion of its wealth is sucked into the task of maintaining existing complexity, while its reserves to deal with unexpected contingences fall, making it more susceptible to sudden, severe shocks from the outside" (Homer-Dixon 2006, 222). Consequently, "In History, we can find many examples of civilizations that have been pushed over the edge to collapse by the combination of multiple stresses and weakened resilience" (Homer-Dixon 2006, 124). Eakin (2008) agrees that "the hazard serves as a 'trigger' or stimulus that acts synergistically with existing (socioeconomic and biophysical) structural conditions to shift a population into a situation of crisis".

Tainter (1988) acknowledges he was not the first to draw a link between economic structure and vulnerability to collapse, and several earlier theories sound similar. Flannery (1972) and Rappaport (1977) argue essentially that disruptions can be cushioned in less complex societies, but in complex societies with interlinked parts, disruptions can spread quickly because self-sufficiency and autonomy are reduced as specialization increases. Renfrew (1979, 488) argues that efficiency and specialization are the engines that allow population growth, but under stress, civilizations lack the option or understanding to diversify to save themselves, and instead depend ever more on productive efficiency and specialization until they inevitably break down. Likewise, Phillips (1979) "argues that societies using resources efficiently (i.e., fully) experience inflexibility in resource allocation, since with more benefits a particular activity becomes harder to abandon" (Tainter 1988, 60). On the other hand, Stuart and Gauthier (1981) contend that "complex societies use resources inefficiently and that this is one of their weaknesses" (Tainter 1988, 60). Some like Adams (1988, 21) also challenge the idea that the collapse of civilizations is inevitable or predetermined by the conditions that created them.

2.4 Brief Civilization Sample Cases

Whichever model is most correct in its details, the greatest contribution of Tainter-type models of collapse is that they focus our attention on the structure and design of a society's economy. Decisions made here have as much to do with whether an economy can avoid collapse as the particular shocks it is subjected to: "catastrophe arguments present an incomplete causal chain: the basic assumption, rarely explicated, must be that the catastrophes in question somehow exceeded the abilities of the societies to absorb and recover from disaster…if the assumption is correct, then the interesting factor is no longer the catastrophe but the society" (Tainter 1988, 53). Indeed, Wright (2004) views humanity's many failed civilizations as "black-boxes" that can help tell us what went wrong so we can try to avert the same breakdowns. Given this, it is valuable to briefly review what anthropologists can tell us about the design of five historic economies that collapsed because of some combination of environmental resource shocks and lack of resilience: the Mayan, Anasazi, Roman, Norse Greenland and Sumer civilizations.

2.4.1 Mayans

The Mayan civilization of Mexico's Yucatan Peninsula was the most advanced in the New World before European arrival. It was actually a series of competitive kingdoms with high population densities packed into large bustling cities (Tainter 1988, 169). Right up until their collapse between 800 and 900 AD, the ambitious Mayan kings invested more and more societal resources into the construction of lavish art, monuments and defensive works as projections of their religious and economic power (Wright 2004, 102). The forested hillsides surrounding the cities were clear-cut to provide fuel and construction materials, as well as to make room for the intensive agriculture needed to support burgeoning population growth (Diamond 2005, 169). Likewise, "The growing population depended heavily on a single, locally grown crop (maize) for food" (Lewis and Tietenberg 2009, 2). Perhaps as a result, the Mayans had little resilience in food production: "The topographical redundancy of the Lowlands environment (over relatively short distances) created a situation where highly diversified production systems were not likely to exist in any local setting, and where neighboring populations would be experiencing nearly the same productivity cycles" (Tainter 1988, 170).

Decreasing yields followed from deforestation and associated soil erosion and local climate change, culminating in a shock: the longest Central American drought (750-800 AD) in a millennium. Because kingdoms experienced concurrent productivity declines, harvests could not be averaged across the group and there was no forest food to fall back on (Greer 2008, 25). Raiding and open warfare between Mayan groups accelerated and populations living behind defensive walls farmed only adjacent areas, hastening the ecological exhaustion (Weisman 2007, 292). Eventually the building and maintenance of ziggurats and administrative and residential structures ceased completely (Gugliotta 2007, 108). Population fell gradually, but by the time Europeans arrived it had collapsed by 90-99%, depending on the kingdom. What did fall apart quickly were all the signs of a complex society: the monuments, institutions of kingship and the Long Count calendar (Diamond 2005, 171).

2.4.2 Anasazi

The Native American Anasazi of New Mexico's San Juan Basin lived primarily in the densely populated Chaco Canyon. Their comfortable lifestyle was subsidized by poorer satellite settlements: "different Anasazi groups supplied food, timber, pottery, stone, and luxury goods to each other, supporting each other in an interdependent complex society, but putting the whole society at risk of collapsing" (Diamond 2005, 155). To facilitate trade, the Anasazi invested in a centralized food energy averaging bureaucracy: "By participating in this network, each local group could insure itself against the fluctuating, unpredictable climate of this arid land, thereby increasing subsistence security, and accommodating a growing population. In effect, the scale of the production and consumption unit was raised from the local group, occupying a restricted area, to the regional population, occupying a diversified territory" (Tainter 1988, 190).

Initially, "Outlier communities were incorporated from the high diversity, high productivity Basin edge. In time, though, communities came to be added that increasingly duplicated the resource bases of existing members [and] were situated in poorer, less productive areas… The result was that, as the ratio of communities/diversity deteriorated, so also did the effectiveness of the network" in terms of buffering productivity downturns (Tainter 1988, 190). A construction boom coincided with diminishing returns from complexity, and a prolonged drought from 1134-81 AD was enough to trigger civil war and economic catastrophe. Because of deforestation and especially depletion of groundwater, "When the Chaco society did collapse, its inhabitants could no longer reconstruct their society in the way that the first farmers of the Chaco area had" (Diamond 2005, 156).

2.4.3 Rome

The fall of the Western Roman empire has probably been the most analyzed collapse ever, with theories ranging from mass lead poisoning to the pacifist influence of Christianity. Undoubtedly a series of converging stresses placed simultaneous strain on the Empire, but once again environmental mismanagement and the underlying structure of the economy were probably most important. Barbarians were always waiting at Rome's frontiers, but they could not hope to successfully invade until Rome was weakened due to environmental and economic problems (Diamond 2005, 14).

Like our current global economy, Rome was obsessed with economic growth. Its Empire was built on the monetary, labour and land subsidies of captured territory and with each new conquest, Rome's bureaucracy, army, cities and economy became more complex (Aldrete and Mattingly 1999, 203). But after the first century AD, further expansion failed to pay for its own costs since the only enemies left to invade were strong eastern opponents (leading typically to pyrrhic victories) or northern barbarians living in marginally productive lands. To maintain their legitimacy among the public, emperors overspent on extravagant monuments, spectacles and public works. As part of its "progress", the city of Rome had deforested, drained, overgrazed and paved the Rhone Valley it depended on for much of its agriculture, leading to erosion and localized climate change that reduced available food supplies (Van der Leeuw and De Vries 2002). It then exported its environmental degradation to North Africa and the Middle East (Wright 2004, 93).

As costs of complexity progressively rose and benefits declined, the empire began to suffer from a thermodynamic Energy Return on Investment crisis: it was unable to generate enough high-quality energy to support the economic and military apparatus needed to administer, garrison, and defend its provinces (Homer-Dixon 2006). Indeed, its increasingly desperate efforts to get more energy only made its bureaucracies and taxation more onerous. Tainter (1996) therefore believes "The Roman Empire provides history's best-documented example of how increasing complexity to resolve problems leads to higher costs, diminishing returns, alienation of a support population, economic weakness, and collapse. In the end it could no longer afford to solve the problems of its own existence".

Homer-Dixon (2006, 243) explains what happened next:

> Abruptly Rome found itself overextended: the empire's now vast territory, much of it captured and till then administered using the proceeds of conquest, had to be run using the solar energy from its annual food output, a flow barely enough to cover the empire's normal needs. Emperors and their administrators soon found they had no buffer – no surge capacity – to cope with nasty surprises. The situation became acute in the years following 165 CE, when Marcus Aurelius faced converging

> challenges, including repeated poor harvests, savage barbarian attacks that penetrated as far as Italy itself, and a devastating plague that killed one-quarter to one-third of the population.

From then on, Rome would endure near continual shocks, including fires, earthquakes and floods. "Such mayhem created havoc in the region's agriculture, causing famines that in turn ripened conditions for epidemics of disease" (Homer-Dixon 2006, 60). Tainter (1996) continues: "To avoid oppressive civic obligations, the wealthy fled from cities to establish self-sufficient rural estates. Ultimately, to escape taxation, peasants voluntarily entered into feudal relationships with the land holders". Further barbarian invasions cut Rome off from its critical imports and were the final shocks that exposed a rotting and unresilient economic core (Tainter 1988, 188).

Dramatic catastrophes began in 363 AD when the Empire could no longer govern itself and was forced to split into Eastern and Western states. Catastrophes like the sacking of Rome and Battle of Adrianople followed. Urban decay and rampant inflation set in, trade and economic interactions rapidly declined, and the population of Rome dropped precipitously, only recovering to Imperial levels in the 20th century. By 476 AD, when the last Western Emperor was deposed, the Western Roman Empire was little more than a collection of Germanic kingdoms that, ironically, "were more successful at resisting invasions, and did so at lower levels of size, complexity, permanent military apparatus, and costliness" (Tainter 1988, 188). These resilient kingdoms would form the basis of modern Europe.

2.4.4 Sumeria

Much like the Mayans and Easter Islanders (with their Moai statue cult), the ancient Sumerian Empire of Ur was controlled by a top-heavy priesthood elite who increasingly squandered its economic surplus on massive building projects at the expense of the environment and Sumer's slave-labour underclass (Wright 2004, 79). As deforestation led to severe flooding shocks, Sumer unwisely chose to invest in supposedly efficient mass irrigation projects to help support its growing population and standing army. However, these had the unintended consequence of bringing salt-laden river and groundwater onto their arid fields, creating barren salt pans and resulting catastrophe. Collapse followed in 2000 BC from which the Mesopotamian landscape has never recovered.

2.4.5 Norse Greenland

The Norse colony that once occupied Greenland collapsed due to three of Diamond's (2005) factors: environmental resource stresses, their exports and imports being cut off by their principal trading partner (Norway), and a failure to adapt to new circumstances. When they arrived in 1000 AD, the Norse set about their accustomed practice of deforesting and overgrazing the landscape. But when the demand for their primary export, walrus ivory, dropped dramatically following the rediscovery of African ivory during the Crusades, the Norse colony was cut off. Their lack of alternative food sources and refusal to learn from Inuit knowledge led to their collapse around 1300 AD (Diamond 2005, 267).

All of the previous examples were of environmental resource shocks which contributed to economic breakdowns and catastrophes and in turn societal collapses. Running out of resources and facing environmental disruptions is fundamentally an economic problem (economics being the study of how to provide society's scarce resources). People may have difficulty imagining civilizations that preceded the formal introduction of market theory (around 1700) as having economies, but like today their societies depended on their economy which depended on the environment. Trying to draw artificial disciplinary lines between economy, ecology and society is not compatible with the ecological economic perspective.

2.5 Modern Collapses

Turning to the present day, several authors, including Diamond (2005) and Homer-Dixon (2006), point to Rwanda, Haiti and to a lesser degree Somalia and Sudan as leading modern examples of societies that have partially collapsed due in part to environmental resource catastrophes partly of their own making. These miniature collapses are not great examples of Tainter's complexity theory but can serve as lessons of what might happen in richer countries if self-created environmental shocks disrupt fundamental societal linkages.

Diamond (2005) also believes the Soviet Union suffered collapse. Certainly, as a political institution the USSR no longer exists, and the complex Soviet command system greatly decreased in complexity. In Russia, the core of the USSR's empire, factories closed, GDP fell by half and birth rates and life expectancy decreased. Yet it may be too early to tell for certain, as Russia's economic and political power is again on the upswing. Many citizens of former Warsaw bloc countries would say their welfare has actually increased now that they are independent (of course, this would still be consistent with Tainter's theory that the collapse of central authority can sometimes benefit a population). Homer-Dixon (2006, 126) likewise believes that the British and French empires collapsed, at least in terms of area occupied.

Heinberg (2004, 113) argues that "North Korea is probably the most dramatic existing example of a modern industrial society falling into an energy-led collapse". With the disintegration of the Soviet Union in 1990, North Korea was cut off from its main energy supplier. The resulting chronic shortages of oil, coal and electricity, the relatively poor quality of North Korean agricultural land, and the imposition of U.S. sanctions have left North Korea especially vulnerable to natural disasters. Multiple floods, droughts, tsunamis and typhoons have repeatedly destroyed vital crops and infrastructure. As a result of these converging economic catastrophes, millions have died and much of the population is malnourished. Like Norse Greenland, the North Korean case illustrates how vulnerable a society can become if it is cut off from key imports.

One of the best examples of a recent environmental and resource shock leading to a catastrophe and isolated collapse in a modern industrial nation is Hurricane Katrina's impact on New Orleans (discussed in greater detail in Chapter 6). The city is projected to have permanently lost as much as 40% of its population (L. Gunderson, March 27 2008 presentation at University of Waterloo), which meets Diamond's definition of collapse. This decline has been compounded by the subsequent Gulf oil spill catastrophe in 2010.

It is debateable whether other catastrophes in the last century (aside from warfare) have led to true collapses as defined by Diamond (2005). For example, the Great Depression was a sudden but medium-term, global and psychological catastrophe (in terms of loss of consumer and investor confidence) resulting in part from the 1929 stock market shock. Yet most industrialized countries recovered within a decade thanks to another perturbation, the Second World War (Levin et al. 1998, 225). The 1971 and Asian financial catastrophes were also partly psychological in nature, while the 1973 oil shock was a political breakdown with only an indirect relationship to the world's real depletion of non-renewable resources. None of these global catastrophes resulted in major long-term collapse. In Canada, the Prairie Dust Bowl of the 1930s and the 1992 Maritime cod fishery catastrophe were environmental resource shocks that led to medium-term but regionally contained economic breakdowns (Newfoundland's economy is now recovering thanks to rising oil and gas revenue).

Overall, the relative absence of large-scale collapses among modern market economies does not necessarily reveal their inherent resilience. Tainter (1988, 216) cautions: "However much we like to think of ourselves as something special in world history, in fact industrial societies are subject to the same principles that caused earlier societies to collapse". It is therefore disconcerting when Homer-Dixon (2006, 262) warns that: "Today, just as in the late Roman empire, deep stresses are rising and system resilience is declining". Empires typically keep getting more lavish and their citizens continue seeing signs of normalcy all around them until their sudden collapse. The Mayans, Romans and Easter Islanders built their most impressive structures as their collapse was already in motion since their leaders wished to show off their riches and keep impressing the populace that everything was all right. The artistic and architectural excesses that today make these civilizations famous was in fact only made possible by their unsustainable drawing down of their natural capital (Gugliotta 2007, 101). Rather than being in their prime, these self-confident societies were living beyond their economic means, effectively accidents waiting to happen (Weisman 2007, 293).

Therefore we must not mistake a lack of examples to date for proof that modern market economies are immune to the environmental problems that brought down previous civilizations. Every indicator suggests multiple large scale, converging environmental resource problems are festering under the surface and building to a critical mass that will finally give modern market economies their first true test. Climate change and peak oil threaten to hit every country at once, overwhelming traditional global response systems. Kousky et al. (2009, 4) additionally note: "There has also been significant scientific research on the effect of climate change on more localized disasters, such as heat-waves, flooding, droughts, and hurricanes. What has received significantly less attention is the possibility that a number of smaller disasters all occurring over a relatively short time period, especially in close proximity, could mutually reinforce each other in such a way that the resulting cascade of consequences becomes a global catastrophe." Regardless of the particular stresses we face, the façade of our technologically advanced, comfortable life is not proof we are immune to history. New Orleans, a major city in the richest country in the world, descended into complete anarchy in only four days, revealing that the veneer of civilization can be very thin.

For their part, ecological economists have varying opinions on the usefulness of studying past civilizations. Some believe there is a vast difference between past systems and those we have created today (Anonymous interviewee 2007), or that the scale of present change has no precedent in human history (Martinez-Alier 2007 interview). Farley (2007 interview) concludes:

> Conventional economists argue that the human mind is the greatest resource and will find substitutes for all scarce resources. These past collapses show that this is not true. Conventional economists argue that these civilizations did not have the magic of the market to rely on, but we are currently facing collapse of critical ecosystem services that send no price signals to the market. We must recognize however that in a globally interconnected ecological economy subject to unprecedented rates of change, we now confront collapse on a global scale. Lessons learned from the collapse of smaller civilizations and smaller ecosystems provide lessons, but are not perfect analogs of our current situation.

It is useful to briefly explore further how conventional economists regard catastrophe and collapse.

2.6 Breakdown and Catastrophe in Conventional Economics

As we approach the era of the market economy, the study of catastrophe and collapse leaves the domain of anthropology and becomes a matter to be discussed in economics. The recent financial crisis has renewed short term interest in financial breakdowns like investment bubbles, but traditionally extreme events like catastrophes "tend to escape the attention of economists, who are most comfortable with large data sets, well-behaved functions, and readily understood phenomena" (Zeckhauser 1996, 113). Neoclassical economic literature that does consider physical catastrophes usually focuses on the sharing of financial risk through instruments like insurance or catastrophe bonds (Jaffe and Russell 1997; Froot 2000; Niehaus 2002).

For example, Zeckhauser (1996, 129) analyzes the "production" and "consumption" of catastrophes: "There are two major economic problems in dealing with potential catastrophes: reducing their magnitude, and spreading the risk of whatever losses do result". Zeckhauser looks at liability and insurance systems and government safety regulation to see if they create the incentives that lead to efficient decisions about risk. But in treating catastrophes as a problem of financial efficiency rather than designing for physical resilience, these sorts of analyses implicitly assume that society is never in any real danger of collapse. Indeed, because many neoclassical economists have an almost religious faith in technological innovation, they tend to deny that the possibility of collapse due to environmental resource depletion even exists (Nadeau 2003, 82). Growth is a very familiar concept to economists but breakdowns are not. Economic forecasters "do well in predicting rates of growth while on a growth plan. They do a poor job at times of recession, or even worse at times of looming depression" (Holling 2003, xv).

As capitalism began to show chinks in its armour in the late 19th century, a tradition of progressive economists emerged (the most influential being Marx and Keynes) who studied the macroeconomic factors responsible for economic breakdowns, if not so much the events that unfolded during the breakdowns themselves (Rosser 1991; Tisdell 2003, 40). While environmental resource breakdowns are a more modern problem that is largely ignored in Keynesian economics, volumes have been written about human-caused economic downturns like the Great Depression (e.g. Galbraith 1955, Rothbard 1975). By-and-large these analyses view catastrophes as exceptions to the economic tendency towards general-equilibrium and linear change (i.e. the business "cycle"), that could have been prevented if only the right policy prescriptions were followed (Rosser 1991, 97). These economists remain concerned primarily with the psychology of the consumer and associated levels of aggregate demand, savings and investments and have trouble viewing environment and resource problems as fundamentally being economic scarcity issues that can lead to much more severe and long-lasting physical economic disruptions.

Indeed, "Viewing the world as fundamentally continuous contrasts sharply with viewing the world as fundamentally discontinuous. A smooth world represents the Newtonian-Victorian dream of a gradual and steady upward movement of reality through a gentle, Darwinian, evolutionary process…By and large, neoclassical economics has emphasized continuity over discontinuity as a fundamental phenomenon" (Rosser 1991, 1). Zeeman (1974) was the first to apply nonlinear catastrophe theory to economics in his investigation of the crashes of speculative bubbles. More recently, Sachs and Radelet (1998) have argued that international financial crises are unforeseeable because they result from self-fulfilling prophecies. Some like Lorenz (1989) have attempted to introduce chaos and catastrophe theory to economics, in the process being critical of the linear mechanistic assumptions of neoclassical economics inherited from 18th century physics.

But overall, the implications of catastrophe and chaos theory for the way that economies are designed remains largely unexplored, including in ecological economics. The simple fact that human behaviour alone can be highly unpredictable (as demonstrated by the various financial crises this century) eluded most economic models until recently. Research on the potential for sudden, unpredictable events has appeared in non-economic journals, such as Yasutomi's (1995) model of the autonomous emergence and collapse of money as a unit of exchange. But even in resilience theory literature dealing with economies (e.g. Carpenter et al. 2002), the focus remains on the collapse of local natural systems and stocks rather than entire macroeconomic systems. With that said, Chapter 3 will introduce the idea of resilience as a concept and theory.

Chapter 3: Resilience in Concept and Theory

The last chapter explored some of the warnings from history that societies can collapse when their internal design leaves them with insufficient resources to cope with simultaneous shocks, often of their own making. Given that economies throughout history have suffered breakdowns due to human induced environmental resource problems, resilience is clearly an important consideration in their design, since vulnerability to shocks is "influenced by build-up or erosion of resilience both before and after disasters occur" (Adger et al. 2005, 1036). But what exactly do we mean by resilience? This chapter will start by defining the two major types of conceptual resilience used in the literature and then explain the notion of safe-fail which is important to understanding resilience thinking. This will be followed by a discussion of resilience as a more elaborate theory explaining how complex systems tend to undergo cycles of growth, catastrophe and renewal. The chapter will end with a brief discussion about the resilience of past civilizations and how the concept of resilience has been used in conventional economics.

3.1 Defining Resilience: Ecological vs. Engineering

Resilience is the capacity to successfully buffer and adapt to change. It can be thought of as elasticity or the ability to bend but not break: "Resilience provides the capacity to absorb shocks while maintaining function" (Colding et al. 2002, 13). Perrings (2001, 323) notes resilience is simply the conservation of future opportunity. Resilience is commonly defined in two ways in the literature: engineering resilience and ecological resilience. Engineering resilience, the more common definition, is the ability to return to an existing steady state following a perturbation. Engineering resilience assumes that systems "exist close to a stable steady-state…. This idea of disturbance away from and return to a stable state is at the center of economic theory as well" (Pritchard et al., 2002, 530).

In contrast, ecological resilience assumes systems are characterized by multiple potential equilibria (Perrings 1998, 504). As first described by C.S. Holling in 1973, ecological resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Holling et al.

2004, 6). Ecological resilience "is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behaviour" (Pritchard et al. 2002, 530). Hence ecological resilience focuses on the size of the stability domain which determines how easy it is to shift a system out of one particular stable state and into another one (the often used metaphor of a system as a marble being moved from one bowl to another).

Thus the difference comes down to "a focus on maintaining efficiency of function (engineering resilience) versus a focus on maintaining existence of function (ecological resilience)" (Pritchard et al. 2002 530). The engineering definition assumes systems exhibit only one stable state and that all others should be avoided. It tends to use more simplified models designed to manipulate and gain control over systems. Ecological resilience looks at multiple functional stable states and the flipping between them that occurs. Ecological resilience does not require continued functioning in exactly the same way (Common and Stagl 2005). Indeed, Adger et al. (2005, 1036) tweak the standard Holling definition to read "retain *essential* structures, processes and feedbacks", rather than the same ones. The question of how much change is allowed before a system is considered so altered that its resilience has been compromised is, in some respects, a metaphysical one with no clear answer in the literature. What is agreed is that enough of the system must be preserved at any one time to prevent its terminal collapse.

Both definitions can be useful under different circumstances (Batabyal 1998, 237). While perhaps influenced by the assumptions of the disciplines in which they originated, the terms "engineering" and "ecological" do not mean these definitions of resilience are applied only to engineering or ecological problems. Theses terms have now simply become part of the general lexicon used throughout resilience literature. Overall though, because complex systems theory disagrees with seeing the world as near a single equilibrium, ecological resilience is the more sophisticated and accurate definition when examining natural and social systems, and the one that will be used more often in this thesis (Colding et al. 2002, 15).

3.2 Ecosystem Resilience and Sustainability

The first proposed application of resilience was to ecosystems and the majority of resilience literature has remained in this discipline or within the framework of general (world) system theory. Indeed, the largest number of articles written on resilience can be found in the journal Ecology and Society (Janssen 2007). Henceforth the term "ecosystem resilience" will be used in this thesis to refer specifically to the resilience of natural systems as distinct from "ecological resilience", one of the general definitions of resilience.

When describing ecosystems, some thinkers like Kay and Schneider (1994) have defined resilience as the capacity for an ecological system to stay within the basin of the attractor (avoid catastrophe) and used another term like self-organizing capacity to describe a system's capacity to re-organize after crossing a system threshold. This thesis will adopt the Resilience Alliance understanding of the term to mean incorporating both aspects, and thus define ecosystem resilience as the capacity of an ecological system to endure, adapt to and successfully recover from shocks in order to both prevent breakdowns from cascading into catastrophes (stay in the same basin of attraction), and avoid collapses following a catastrophe if the system crosses a threshold, preferably while retaining or regenerating desired system characteristics and functions.

Ecological systems attain resilience through the mutual nonlinear interactions of organisms which allow novel structures and behaviour to emerge in far-from-equilibrium states (Nadeau 2003, 182). The concept of resilience has improved formerly simplistic understandings of why diversity is so important for ecosystems: by preserving its genetic library, biodiversity enhances not the "stability" of an ecosystem in an equilibrium sense, but rather its long term resilience and self-organizing capacity (Kay and Schneider 1994, 36). At a smaller scale, "Biological systems have the resilient learning and corrective process built in, centered not on ability to predict or avoid stress but on ability to cope with stress. This provides the adaptability that has carried these systems through several billion years in which environmental stresses were so great that all designs lacking resilience were recalled by the Manufacturer and are therefore no longer around to be studied" (Lovins and Lovins 2001, 182). Indeed, geologically we have evidence of meta system stable states (periods and epochs) that saw the same types of organisms persist for millions of years until shocks like meteor impacts or climate change led to catastrophic extinctions, with the most resilient species becoming the new dominant life forms.

Twentieth century resource and environmental science and management techniques focused on conquering and controlling nature's variability because fluctuations pose problems for meeting production goals. These measures (founded in assumptions of human superiority and independence from nature) have often been successful in producing stability of resource flows in the short term but have also negatively simplified ecosystems through the introduction of techniques such as monocultures, reducing their diversity and resilience: "The insurance for dealing with the unexpected has been driven down by suppressing disturbance and reducing the diversity of the environment" (Folke et al. 2003, 353).

Resilience thinking has provided an increasingly powerful alternative to these outdated views on environmental management. Most resilience studies have been based on specific social-ecological system (SES) regions and their particular environmental management issues, especially the collapse of resource stocks (Holling 2004, 5; Perrings 1998, 504). When discussion of resilience does cross into the social sciences, it is primarily only in the analysis of small-scale decision-making institutions such as the Gunderson et al. (2002) discussion of Florida Everglades management institutions.

One possible reason why the concept of resilience has not been as influential outside of ecology is because of the failure to agree in environmental and social science circles on how it differs from other popular catch-all terms like ecosystem health or sustainability. This may stem from confusion over when resilience truly matters to a system (namely, in the face of an emerging potential catastrophe) and hence which aspects of environmentalism do and do not fall under it (Lele 1998, 252).

One way to view the difference between sustainability and resilience is to think of sustainability as focusing on preventing environmental resource shocks from occurring whereas resilience is about preparing systems to survive them when they do occur. Berkes et al. (2003, 15) however believe the terms are synonymous: "The concept of resilience… provides a way for analyzing how to maintain stability in the face of change. A resilient social-ecological system, which can buffer a great deal of change or disturbance, is synonymous with ecological, economic and social sustainability". Moreover, Abel et al. (2006, 21) and King (1995, 979) advocate that regions and nations should replace sustainability with resilience as the concept underpinning their environmental policy.

However, this author largely agrees with Lele (1998, 252) who thinks dynamic stability, health and resilience are probably attributes within the larger meta-objective of sustainability. Resilience does not replace sustainability as an overarching concept, but the long run sustainability of a system depends on the resilience of that system: "increased resiliency leads to a greater degree of sustainability - the ability of a system to absorb changes and still persist"

(Petak 2002, 1). The relationship between resilience and sustainable scale will be explored further in Chapter 5.

3.3 Safe-Fail versus Fail-Safe

The concept of safe-fail, while not a central one in the resilience literature, is nevertheless very helpful in enhancing our understanding of what differentiates resilience from other strategies for mitigating shocks and stresses. Safe-fail is an approach to design and planning that advises taking the lowest risk path in order to minimize maximum losses in the event of unforeseen disasters, stresses or developments (i.e. you're safe if the system, or some part of it, should fail). A safe-fail system is designed to survive and recover from nearly any failure. Failure can be precipitated by anything from small scale localized perturbations all the way up to large scale shocks.

Safe-fail is a feature of most resilient systems, which exhibit "reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences; and reduced time to recover" (Tierney 2003). Indeed resilience has been defined as "the capability of a system… to degrade gracefully when it must" (Allenby and Fink 2005, 1034). Safe-fail systems do not pose a threat to valued components of socio-economic systems in the event of failure (Gibson 1992, 166). As a concept safe-fail is broader in scope than the individual resilience principles discussed in the next chapter but not broad enough to be a synonym for resilience.

On the other hand, a fail-safe system is one designed to predict and prevent or evade all foreseeable failures. This approach has more in common with the engineering definition of resilience, and is also the dominant mitigation strategy used in the world today. Politicians, economists and even environmentalists simply do not see failure as a real possibility and so focus on preventing environmental and resource shocks in order to make our economy and society fail-safe (Rees 2007 interview). Fail-safe systems are highly engineered and protected to ensure failure is very unlikely, but tend to be more dangerous or suffer more damage if they do fail.

In systems which depend on not failing, safeguards must be thought of in advance and designed in ahead of time (Perrow 1999, 94). Safe-fail systems, however, leave more time and room to come up with buffering solutions and adaptations. Homer-Dixon (2006, 290) argues: “In our organizations, social and political systems, and individual lives, we need to create the possibility for what computer programmers and disaster planners call ‘graceful’ failure. When a system fails gracefully, damage is limited, and options for recovery preserved. Also, the part of the system that has been damaged recovers by drawing resources and information from undamaged parts”. Safe-fail is more consistent with the resilience idea of cushioning damage or loss and this represents a very different approach than trying to forecast and prevent all problems.

Highlighting the difference between safe-fail and fail-safe helps to show the difference between considering resilience in design and largely ignoring the concept. Lovins and Lovins (2001, 185) contrast resilience with traditional notions of reliability:

> the engineering-for-safety approach ‘emphasize a fail-safe design at the price of a safe-fail one.’ If the inner workings of a system are not perfectly understood and predictable, efforts to remain within its domain of stability may fail, leading not to safety but to collapse. And if, as is inevitable, the full range of potential hazards is not foreseen, but simple precautions nonetheless give an illusion of security by controlling the most obvious and frequent risks, then the ability to cope with major, unexpected risks may well decrease.

The technological fixes and safety mechanisms which fail-safe designs typically depend on often increase complexity and coupling by increasing hidden interactions: “We have produced designs so complicated that we cannot anticipate all the possible interactions of the inevitable failures; we add safety devices that are deceived or avoided or defeated by hidden paths in the system” (Perrow 1999, 11). For example, in the 2010 Louisiana oil disaster, the blowout preventer, in the words of British Petroleum CEO Tony Hayward, was a "fail-safe mechanism that clearly has failed" (UPI 2010). The failure to contain the oil spill revealed how unprepared and unresilient the BP operation was once their prevention strategy had failed. Safety devices also often fail to work because the extra margin of safety they provide just encourages people to push the system harder and faster to increase production and profit i.e. “efficiency”, leading to no net reduction in risk (Perrow 1999, 180).

Of particular concern to systems is the cascade effect of synchronous failures, where small breakdowns cross to higher system scales: “If some form of synchronous failure does occur, it’s likely to be in a way that we’ve never anticipated, because the range of permutations is almost infinite” (Homer-Dixon 2006, 17). As a result, “accidents, and thus potential catastrophes are inevitable in complex, tightly coupled systems with lethal possibilities" (Perrow 1999, 354). As chaos theory warns, even tiny flaws can become magnified across systems. It is the interaction of multiple failures that often leads to catastrophe and collapse (Perrow 1999, 7).

Indeed, complex systems inevitably suffer from unexpected interactions and failures which cannot be prevented, hence Perrow (1999, 5) calls the problems afflicting such systems Normal Accidents. His Normal Accident theory holds that multiple failures coming together in unexpected ways can defeat safety devices and cascade through a system: "The fundamental difference between Normal Accident Theory and High Reliability Theory is that HRT believes that if only we try harder we will have virtually accident-free systems even if they are complexly interactive and tightly coupled, while NAT believes that no matter how hard we try we will still have accidents because of intrinsic characteristics of complex/coupled systems" (Perrow 1999, 369). Fiksel (2003, 5330) notes that "Engineered systems cannot be designed to anticipate all future possibilities, as evidenced most recently by the *Columbia* shuttle disaster and the Northeast electrical power blackout of 2003".

The Titanic provides another excellent example. Its water-tight compartments were a highly advanced engineering safeguard against predicted catastrophes. The idea to isolate failures by sealing off bulkheads had some safe-fail logic, but was still not fundamentally resilient because if too many compartments failed (i.e. a threshold was crossed), the ship was still doomed: "Over 1500 perished in the Titanic disaster in 1912, partly as a result of an overconfident captain imperturbably sailing into a field of icebergs at night, thinking he had an unsinkable ship. An iceberg sliced open five watertight compartments; the designers had assumed that no more than three could ever be damaged at once" (Perrow 1999, 178).

"Thus in the case of the Titanic, the new ability to control most kinds of leaks led to the understocking of lifeboats, the abandonment of safety drills, and the disregard of reasonable caution in navigation" (Lovins and Lovins 2001, 185). Having more lifeboats and training drills would have made the Titanic more resilient and safe-fail no matter what went wrong, and thus would have been the superior design strategy. Rather than trying to save the whole ship, it would have been more sensible to distil the problem down to what needed to be preserved most (lives in this case). If so many lives had not been lost, the Titanic would not be known as the disaster it is today.

The distinction between engineering/fail-safe and ecological resilience/safe-fail is fundamental to challenging the newest argument by environmental sceptics: that we can simply adapt to whatever climate change occurs. For example, trying to build walls around every major coastal city to hold back rising sea levels is likely a losing proposition (as seen by the failure of Japanese sea walls to hold back the March 2011 tsunami). Aside from issues of cost feasibility, investments in flood and coastal protection often encourage development in flood prone zones. Thus "The net effect is that the resilience of the system (its capacity to recover from major storms) falls at the same time as its capacity to withstand minor storm damage rises" (Perrings 1998, 516). Likewise, in trying to prevent the worst impacts of climate change, geoengineering proposals (e.g. solar shields, sulphate injections into the atmosphere) are fail-safe measures that introduce tremendous risks in light of human ignorance about the long term effects of manipulating large scale environmental systems (Kousky et al. 2009, 11).

Another concept related to this discussion is robustness. Robustness and resilience are often confused and used interchangeably, but robustness shares much more in common with the fail-safe strategy, in that it focuses on maintaining all the parts of a system so that they will not suffer damage or breakdown even when hit with a shock (Tierney 2003). In contrast, resilience focuses on maintaining the critical function of the whole system to ensure its survival, even when individual parts might fail. The origin of the word resilience is from the Latin *resilire*, "to jump back", whereas robustness comes from the Latin *robustus* meaning "hard and firm". Robustness is the ability to rigidly resist changing, whereas resilience is the ability to flexibly respond to change. A large robust tree stands firm to regular winds but risks being snapped and broken by a fierce wind, while a more slender resilient tree can bend with the wind and snap back. In the basin of attraction analogy used for complex systems, a robust marble would rather disintegrate than move, whereas a resilient marble could move up the side of the bowl and roll back, or roll into an entirely new equilibrium bowl if required to ensure its survival.

Even though robustness recognizes that some stresses cannot be predicted, it is still fundamentally a fail-safe strategy based on trying to predict and prevent all possible breakdowns. Is it even possible to design a system which can shrug off every shock, when the tiniest failures can lead to magnified disruptions? Janssen and Osnas (2005, 99) for example note that robust systems "are adapted to certain disturbance regimes, but can be fragile to new types or frequency of disturbance. Perhaps, there is a trade-off between specialized adaptation and adaptive capacity to regime changes". Fiksel (2006, 16) explains furthers:

> Engineering resilience has emphasized resilience or robustness as recovery from perturbations, but ecological resilience also emphasizes adaptive capacity, which may lead to new equilibria. Resilient systems, including biological and socioeconomic entities, are able to survive, adapt and grow in the face of uncertainty and unforeseen disruptions…. Traditional systems-engineering practices have tried to anticipate and resist disruptions, but may be vulnerable to unforeseen factors.

For these reasons, robustness will not be covered further as a principle of resilience in this thesis, though a case could be made for doing so, as Anderies et al. (2004) argue.

Pritchard et al. (2002, 530) summarize: "*Resilience* has been defined in two different ways in the ecological literature, each reflecting different aspects of stability. One definition focuses on efficiency, constancy and predictability – all attributes of engineers' desire for failsafe design. The other focuses on persistence, change and unpredictability – all attributes embraced and celebrated by evolutionary biologists and by those who search for safefail designs". Thus, "The concept of resilience is a profound shift in traditional perspectives, which attempt to control changes in systems that are assumed to be stable, to a more realistic viewpoint aimed at sustaining and enhancing the capacity of socialecological systems to adapt to uncertainty and surprise" (Adger et al. 2005, 1036). A safe-fail, rather than fail-safe, approach is advisable given perpetual human ignorance of the environment and the less than perfect historical track record of the "great experiment" we call civilization (Wright 2004).

3.4 Resilience (Adaptive Cycle) Theory

"The pessimist sees difficulty in every opportunity.
The optimist sees opportunity in every difficulty."
Winston Churchill

Holling and others from the Resilience Alliance have also expanded the concepts of ecological resilience and catastrophe into the adaptive cycle theory of complex system change. This theory asserts that all complex systems go through a continuous loop of growth and decline that resembles a figure-8. As a concept, "resilience switches attention away from long-run equilibria, and towards the system's capacity to respond to short-run shocks and stresses in a constructive and creative way" (Perrings 1998, 517). Resilience theory, however, often focuses on the very long term. This model asserts that "change is neither continuous and gradual nor consistently chaotic. Rather, it is episodic" (Redman and Kinzig 2003, 1).

Each of the figure-8s operating at different scales and speeds within a system is embedded within an overarching figure-8 (in the case of national economies, this would be a figure-8 representing global civilization itself, that might in turn be part of an even larger figure-8 representing say global climate). Redman and Kinzig (2003, 1) explain:

> Resilience theory seeks to understand the source and role of change, particularly the kinds of change that are transforming, in adaptive systems. It is a theory of dynamic cycles…. Individual adaptive cycles are nested in a hierarchy across time and space. These nested hierarchies may have a stabilizing effect due to the fact that they provide the memory of the past and of the distant to allow recovery after change occurs. They may also have a destabilizing effect when dynamics across scales become 'overconnected' or 'brittle,' allowing small-scale transformations to 'revolt' and explode into larger-scale crises. Taken together this theoretical framework is called 'panarchy'.

Figure 1 in this thesis is based on the traditional figure-8 diagram commonly found in resilience theory literature. It illustrates simplistically how a system's attributes evolve as it goes through this cycle. It is useful to think of the cycle as a roller coaster in constant motion, going down loops faster than up them. In fact, the figure-8 itself is an optical illusion – the track of the roller coaster is actually more of a u-shape (imagine the outline of a horse saddle) that does not physically cross itself but instead runs parallel at points.

A given system state begins in the exploitation phase (r) in the bottom left corner of the diagram. Here pioneers, entrepreneurs and opportunists dominate (Gunderson et al. 2002, 323). During this phase the system enjoys rapid growth as it slowly travels up the front of the loop. This growth is achieved by the system becoming more and more efficient, integrated and connected, but at the same time available resources are used up, the system locks itself into familiar patterns of behaviour, and resilience is lost (Peterson 2000, 326).

Once it reaches the conservation (K) phase at the top right corner of the loop, a system has grown to its maximum size. Conservation of its few remaining untapped resources has become its primary concern and so it has become extremely organized, controlled and connected to ensure resources are used with maximum efficiency. It is brittle because it has lost most of its remaining resilience and is stable only under a decreasing range of conditions (Holling et al. 2004, 6). Opportunities for innovation are largely non-existent. Those that can best compete or consolidate resources and power are dominant.

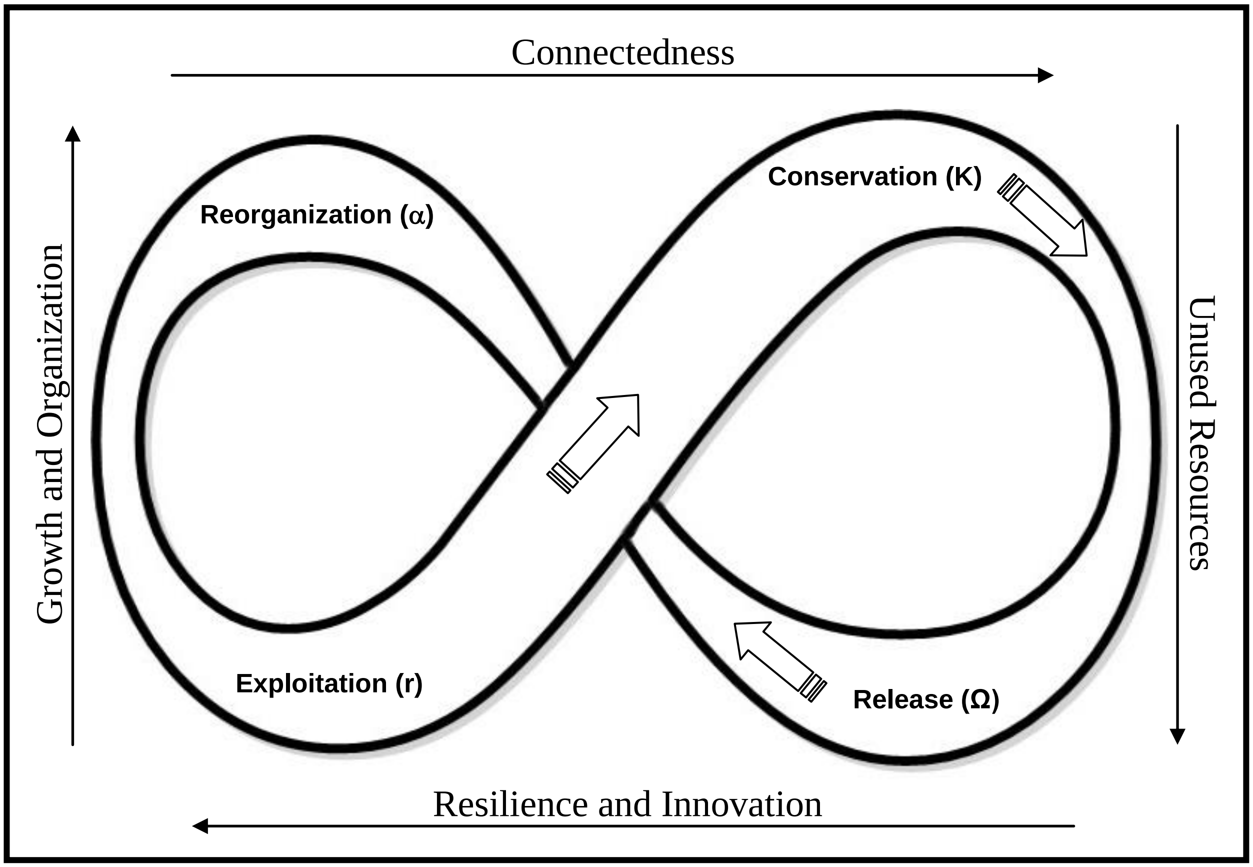

Figure 1: Figure-8 adaptive cycle from resilience theory

The extreme lack of resilience in the system means that external shocks that could have been buffered in other phases instead lead to system breakdowns triggering the catastrophic release phase (Ω). During this phase the system descends quickly to the bottom right portion of the diagram and then wraps around on itself so it eventually ends up in the back left corner of the diagram. Most accumulated system organization is lost in the resulting chaos.

> The resulting loss of control leads to the release of the accumulated capital (nutrients and organized carbon in ecosystems; money, skills, contacts, and experience in organizations) and to its decay or dissociation into constituent elements in the alpha phase. At this stage the system becomes ill defined and

> loosely coupled… High risks are matched by great opportunity. In human systems, it is the stage where the individual, for good or ill, has the greatest potential for influencing the future. (Gunderson et al., 2002, 326)

In this reorganization (α) phase, efficiency has been lost but system resilience is restored. Connectedness and control are weak and confused allowing for the greatest innovation and novel combinations between variables. Figure 1 is a stylized symmetrical figure-8 rendered in the interests of simplicity and visual elegance: while the reorganization phase appears to be at the same relative height as the conservation phase, in reality the system cannot grow and become organized again until after it has freed up and mobilized enough available energy to loop around and re-enter the exploitation phase. There growth will start again but likely with different resources and new characteristics, potentially creating a new basin of attraction.

Overall, the point of panarchy theory is not so much that downturns are predetermined, but that breakdowns are just as likely as upward growth over the long run in a world where unpredictability and entropy are the norm. System actors use the release and reorganization phases to explore for better alternatives and the exploitation and conservation phases to take advantage of what they already know. To have material growth you need deterioration, and vice versa. Therefore a major insight of resilience theory is that the breakdown (release) phase is simply a normal part of any complex adaptive system and constrained breakdown is entirely compatible with resilience. Thomas Homer-Dixon (2007 interview) notes "Resilient systems themselves actually go through these periods of great difficulty and breakdown".

The key however is to make sure that breakdowns do not cascade into catastrophes, and if they do, that those do not lead to terminal collapses. The resilience of the system before the point of collapse is key to determining how steep the decline phase is. Catastrophes present systems with a bifurcation point (i.e. a fork in the road): with sufficient resilience, a system is able to loop back and enter the reorganization phase to start anew. With insufficient resilience, there is the potential for deep collapse where the curve drops off completely, never to recover or reach the reorganization phase (see Figure 2).

The adaptive cycle is thought to characterize all systems, though human systems may have greater potential for both unresilient rigidity and creative novelty, leading to cycles that are faster or more extreme (Gunderson et al., 2002, 327). In economic systems, this cycle implies that a slow gradual build-up of capital and skills is followed by fast unpredictable phases where capital is freed up and novel use of it can occur. Periodic restructuring is thus necessary to create opportunities for renewal and innovation. The adaptive cycle can be differentiated from other seemingly similar theories like Kondratieff's "long wave cycle" of economic behaviour because long wave theory has no provision for breakdown, reorganization or fundamental system change – it follows the classical ideal of continual forward progress and growth, even though there might be dips along the way. The figure-8 is actually one full Kondratieff wave turned back on itself to form a loop.

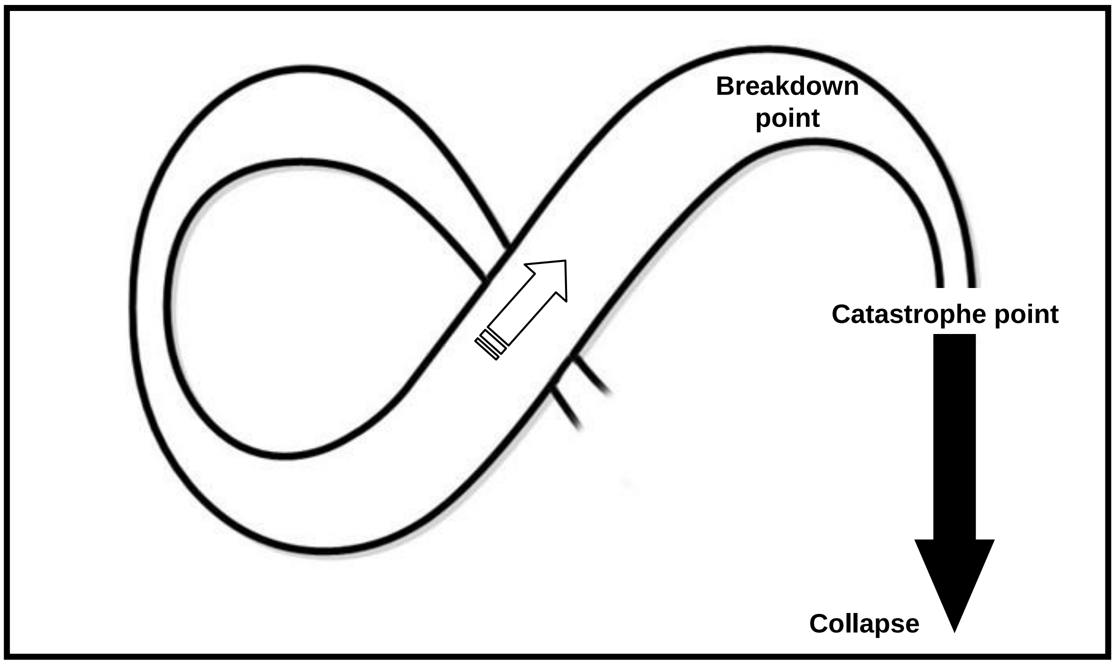

Figure 2: Terminal collapse of system with insufficient resilience

3.5 Resilience of Historical Civilizations

Holling's adaptive cycle occurs within and between all scales but in human systems it may be easiest to witness at the macro scale of civilizations, which is where this thesis will confine most of its consideration of panarchy. The figure-8 theory of resilience complements Tainter's argument for why civilizations collapse (Chapter 2): in both theories, growth leads to increasing complexity and less and less resilience until the system eventually breaks down. The examples in Chapter 2 show that history has neither been entirely glorious or entirely disastrous – instead a continuous cycle of catastrophe and revival has occurred where learning has been incorporated into succeeding cultures.

Unfortunately we have not found enough evidence from the few civilizations that apparently did not collapse to know whether they persisted because their economies were resilient to stress and/or effective at reorganizing after catastrophe to avoid collapse, or because they were simply very good at preventing shocks and catastrophes by maintaining their socio-ecological system health over long periods of time. Wright (2004) notes the Egyptians and Chinese are the only civilizations in history that have persisted for millennia, but he believes this is because they were simply blessed with especially fertile soils. More likely, China and Egypt may have been able to manage the scale of their activities sufficiently well relative to their natural endowments that they did not suffer subsystem breakdowns of the same magnitude as other civilizations. Certainly they would have had many localized shocks resulting from droughts, wars and other such phenomena, but perhaps due to luck these were not of the scale necessary to cause their collapse. The ability of their central governments to ensure redundant stockpiles of key supplies including food may have helped them weather these storms. Many of the cultural changes that Egypt and China did go through were due to internal political and religious upheaval or the influence of outside cultures rather than due to exceeding their own environmental or resource limits. These two particular civilizations may have simply been lucky that their economic resilience was never deeply tested (again limiting their usefulness as examples).

Viewing historical civilizations through the lens of resilience theory also entails examining their passage through the reorganization phase of the adaptive cycle. Redman and Kinzig (2003, 12) point out that "many historical studies see the collapse of a civilization as the end of the discussion, because the period, dynasty, or even society appears to be at an end. Happily, resilience theory recognizes that collapse, release, and reorganization are just as integral as the exploitation/growth phase". Indeed a new area of archaeological research studies how smaller scale urban societies reappeared from the ashes of collapsed civilizations (Schwartz and Nichols 2006). Their case-studies of earlier cultures illustrate how institutions, ideologies, and political/social resilience from the pre-collapse periods can heavily influence the regeneration of social complexity.

For example, Kolata (2006, 217) believes the apparent ability of the Chinese civilization to avoid collapse may be an illusion, and instead it was skilled at practicing "template regeneration": empires that are able to reappear after disintegration with essentially the same structure, following a historically ingrained model of social and political organization. They can achieve this in part because their literacy and bureaucracy (detailed record keeping) allows them to faithfully recreate former government and culture and there is a long-term persistence in ideology held in common by the population. Greer (2006) is similarly prepared to ascribe their longevity in part to their resilience: "Civilizations such as ancient Egypt and imperial China, which were based on sustainable resources, cycled through this process many times, from expansion through overshoot to a self-limiting collapse that bottomed out when capital stocks got low enough to be supported by the steady resource base."

In other cases, the archaeological record shows an aversion to returning to prior authoritarian or centralized regimes: "The deliberate rejection of previous ideologies and institutions may also have played a significant part in the process of regeneration" (Schwartz and Nichols 2006, 11). Kolata (2006, 219) explains: "So, rather than the regeneration of similar institutions of power, governance and sociocultural practices, we may in postcollapse scenarios see the emergence of new forms of socially complex institutions – new class relations, new patterns of production, new forms of the circulation of wealth, and a pluralizaing of ideology". Indeed regeneration of complexity can follow any number of structural pathways depending on externalities present during the process and is also contingent on unique local conditions, making cross comparison to develop a theory of regeneration more difficult (Kolata 2006, 208).

Overall, while hunter gatherer societies may be a different story, it is possible that no large civilization has ever specifically designed itself to be resilient to both breakdowns and catastrophes. Perhaps then the best lesson we can take from them is that relying on luck alone is not sufficient given the high odds of previous civilization failure. We are quite likely to lose if we gamble with resilience.

3.6 Desirable and Undesirable Resilience

In socio-ecological systems, a catastrophe or even collapse is only regrettable if the relevant systems were desirable and their post flip replacements are worse. It is important to recognize that resilience is not always a good thing to have. In certain cases resilience can actually be undesirable if it leads to the preservation of system characteristics that are unwanted or damaging to the long term health and integrity of the system. Such undesirable components or attributes can be stubbornly resistant to change. In ecosystem management for example, efforts to remove invasive species can prove very difficult. Moreover, system characteristics that were beneficial at earlier phases in the adaptive cycle, such as a focus on growth, can later turn harmful as the system's environmental situation changes: "To adapt too well, too fully, and too effectively to present conditions may be to restrict the flexibility of response available to cope with a future change in those conditions" (Renfrew 1979, 487).

An example of this type of undesirable resilience at work in a civilization is the pre-Mayan city of Teotihuacan that collapsed in part due to drought, where "The price paid for political continuity may have been the suppression of the potential for radical internal change and transformation" (Millon 1988, 158). Similarly, on one hand the central autocratic governments of China and Egypt might have played some role in their success by providing an important organizational and stabilizing effect during catastrophes, one that could quickly institute powerful measures to aid adaptability. On the other hand, the inequitable nature of their governments and their tendency to resist fundamental change may have just as likely made them a liability to long term resilience.

In more recent times, dictatorships like Stalin's regime have of course been very resilient and very undesirable. More broadly, current dominant economic systems and other institutions at many scales are undesirable simply because they are unsustainable. Heinberg (2004, 140) writes:

> The managers in charge of the world's economic, political and military regimes are immensely powerful within the context of the present world system, but they may be utterly incapable of preventing the disintegration of that system, since the only actions they can take that will be significantly effective toward that end will also tend to undermine their own power and authority vis-à-vis competing regimes and managers. Thus, the system actively discourages steps towards its own preservation.

In our modern society we see how environmentally damaging consumer habits such as high energy consumption have proven both very resistant to change and quite adaptable to small short run stresses: "It's one thing for society to be resilient to exogenous shocks, it is another to be resilient to any attempt by members of society to alter its course should they believe it to be potentially catastrophic" (Lawn 2007 interview). Indeed, systems that seek to resist change by living outside the capacity of their natural and social capital are really not resilient at all – at best, they have short term adaptability. Long term resilience is by definition desirable because it means the economy of civilization must be doing something right to avoid collapse as it goes through successive iterations of the adaptive cycle.

Therefore, when seeking to build resilience into society we want to preserve some of the structures and functions (and delivered benefits) of the current system, but begin preparing to eliminate or adjust other aspects whose trajectory has no future. From the perspective of everyone currently alive on earth, enhancing the current system's short term resilience is necessary to ensure, for example, we all have something to eat and a home to sleep in after a breakdown occurs. As Keynes famously stated, in the long term we're all dead. Future generations likewise require that our civilization survives long enough to inherit it. Yet, we should not let the need for short term resilience prevent us from keeping our other eye on longer term resilience and the profound changes we must make in our present system to achieve it. After a catastrophe and release phase, we do not want to simply return to doing the same things that precipitated the breakdowns in the first place.

The key challenge is to maintain or prop up enough of the current system's attributes to provide short term resilience to shocks and breakdowns, without locking down structures and behaviours so much that they compromise the system's overall ability to make desired and necessary transformations: "Because human social and economic systems are essentially self-organizing in the face of circumstance, the big questions are how much disorder must we endure as things change, and how hard will we struggle to continue a particular way of life with no future?" (Kunstler 2006, 239). Resilience therefore demands continually thinking about both the short and the long term. Both aspects are equally important: short term resilience is required to preserve the capacity of the economy and broader civilization to transform following catastrophe into something more sustainable over the longer term.

Thinking about desirable resilience challenges us to tackle profoundly difficult value questions such as what system characteristics we wish to preserve, which we would be better off without, and what system characteristics we wish to foster: "we have to reflect on what precisely it is that is being made resilient, in the face of which specific dynamics, for whom (and by what criteria) this is good or bad, and whether such resilience is consequently problematic or not" (Stirling and Smith 2008, 21). This is an exercise outside the scope of this thesis (though future shocks and breakdowns however are likely to bring these festering discussions about what society should look like to the forefront). For now, the broad focus herein on building resilience to shocks that threaten all of civilization skirts around the problem to some degree in that everyone can probably at least agree that civilization itself is a project worth preserving and making resilient. This is probably a good, albeit simplistic starting point for introducing resilience into ecological economics. From this point forward, it is therefore assumed we are only talking about desirable resilience unless otherwise stated.

3.7 Resilience in Conventional Economics

A number of the ideas generated about resilience are also potentially applicable to social systems including economics: "it has been argued that the concept of resilience offers a useful way of thinking about the sustainability of non-environmental dynamical systems" (Perrings 1998, 504). For example resilience ideas have been applied on a limited scale in natural disaster (particularly earthquake) management literature (Tierney 2003, Liao and Rose 2005).

Yet very little existing literature addresses resilience in conventional economics, which tends to ignore most complex system concepts. Writing in the journal of *Environmental and Resource Economics*, Perrings (1998, 517) notes: "The concept of resilience provides a different perspective on economic dynamics than that normally adopted by economists…. Instead of focusing on the system equilibria and the properties of the system at equilibrium it focuses on the basins of attraction around those equilibria, and the susceptibility of the joint system to change at different points in the basin".

Offut (2005, 1) from the United States Department of Agriculture looks at the resilience of the U.S. food and agriculture sector to shocks, primarily bioterrorism: "resilience relates to the ability of an economy to bounce back from adversity, essentially on its own. This is fundamentally an economist's view that individual actors in the economy, if permitted or encouraged, will be able to make choices that moderate the impacts of a surprise, adverse event." She tries to add a spatial dimension to a traditional market equilibrium model: "Where something happens is now very important because it affects the range of substitution possibilities. Traditional economic models have no spatial dimension [and] don't need it to find market equilibrium. If there's a drought in Kansas, the supply curve for corn shifts inward, and we get a new equilibrium price" (Offut 2005, 2).

Briguglio et al. (undated) at the University of Malta have examined how to enhance the resilience of countries trading in the global economy. They believe countries have inherent vulnerability arising from intrinsic features of their economy, but that resilience can be enhanced through good governance, sound macroeconomic management, microeconomic market efficiency, social cohesion and sound environmental management. They have come up with a resilience index ranking countries. Sample ratings include: Singapore 0.903 (highest), United States 0.791, Canada 0.778, U.K. 0.614, Japan 0.568, Mexico 0.464, China 0.350, Madagascar 0.078 and Pakistan 0.013 (lowest). However, these scores are all in terms of the capacity of these economies to keep growing their GDP in spite of disruptions in global demand for their products – not environmental disruptions or disruptions of basic societal services.

Some non-economist system theorists have also briefly explored aspects of resilience relevant to economics. For example Rosser (1991, 323) discusses some possible implications of resilience for macroeconomic design:

> Certainly central socialist planning may create a falsely stable order that proves to be catastrophically unresilient [as demonstrated by the economies of Eastern Europe]. On the other hand while the Austrian [laissez-faire economic] solution promises spontaneous order and creativity, there remains the danger of a profound instability that can lead to disastrous results…. In the face of potential catastrophe and chaos, every economic system faces difficult challenges that cannot be resolved by mere rhetoric, sloganeering, or blind ideological faith.

On the other hand, in the book *Frontiers of Environmental Economics*, Perrings (2001) as usual only applies resilience to ecosystems, not to the economic system as a whole, a pattern repeated by Brock et al. (2002) in their empirical microeconomic model of resource stocks.

In the journal *Econometrica*, Hommes and Brock (1997) try to explain the logic behind the adaptive cycle using game theory (a popular tool in economics for understanding human decision making). They suggest that at first, a resilient equilibrium is exploited by agents pursuing a more profitable (yet ultimately naïve) strategy that sacrifices resilience. Increasingly all agents shift to this cheaper model to compete until the equilibrium starts to become unstable and fluctuate wildly. It is ultimately stabilized by agents again adopting the expensive, resilient model.

Yet overall, since resilience lacks any sort of formal theoretical underpinning in economics, the word is used in very different ways depending on the author and often only superficially at that, such as in the 2003 paper by Hamel and Valikangas in *Harvard Business Review*. Following the global 2008 downturn, economic articles in the mainstream media have often informally used resilience as a popular buzzword to refer to the capacity of the economy and consumer spending to return to their historical levels of growth in order to continue pursuing maximum economic gain. Yet true economic resilience is not simply about restarting the engine of economic growth once more. As the Resilience Alliance has discovered in complex systems and incorporated into their adaptive cycle, growth is one of the factors that can actually cause a system to *lose* resilience by weakening its built-in coping mechanisms and accelerating the onset and severity of environmental shocks that will test those mechanisms.

Because conventional economists believe the world is largely made up of single equilibria, if they do consider resilience at all, it is usually from the engineering perspective of returning to a steady state, since this agrees most readily with their own simple equilibrium models. There is thus a fundamental theoretical disconnect between the ecological definition of resilience and the assumptions of neoclassical economics. This reveals why an emerging field such as ecological economics that is not weighed down by such increasingly outdated assumptions is more readily able to incorporate a truly sophisticated understanding of resilience as both concept and theory.

Chapter 4: Resilience in Ecological Economics

Clearly, resilience is a well developed concept and theory that has been applied successfully in several fields of study other than ecological economics. The previous chapter explored some of the different understandings of resilience and this chapter will now set about synthesizing from these options a definition appropriate for ecological economics. Incorporating resilience into ecological economics is vital to keeping ecological economics relevant in a rapidly changing world: because we have already overshot the sustainable scale of planet earth, economic resilience becomes paramount to softening the worst of the breakdowns we are almost certain to experience yet cannot reliably predict due to catastrophe and chaos theory. As the historical record of many unsuccessful previous civilizations demonstrates, a base level of resilience will need to be consciously built into the structure of the economy to avoid collapse. This chapter will look at principles that other authors and disciplines have identified as being fundamental to resilience and will then choose six principles of economic resilience (not necessarily from those) to create a new framework for analyzing resilience from the perspective of economics and ecological economics more specifically.

4.1 Absence to Date

In spite of Joseph Tainter being an honorary ecological economist, and the writings of William Rees and some others, most ecological economists have not spent much time looking at the processes that underlie the collapse of civilizations (Lawn and Victor 2007 interviews). Rees (2007 interview) observes that Panarchy may not have yet entered the lexicon of ecological economics because Holling's idea of collapse and renewal cycles may apply more readily to ecosystems than economies. Rees worries that modern human civilization may be a one-off cycle (e.g. there may be no recovery from a collapse caused by nuclear war). Yet Lawn (2007 interview) notes: "I think we [ecological economists] can learn from the collapse of past civilizations, particularly in terms of the role that belief systems and institutions (or lack of appropriate institutions) can play in the eventual collapse or development of a society".

Likewise, resilience as an economic concept remains largely unexplored in ecological economics. While ecological economics purports to take major concepts from ecology, it tends to look only at thermodynamic energy flow. The precautionary principle and adaptive management advocated by ecological economists can be thought of as following the safe-fail approach (Farley 2007 interview), yet ecological economists still focus overwhelmingly on the prevention of environmental resource shocks rather than the survival and recovery of global economic systems that have suffered major breakdowns. However Farley (2007 interview) readily acknowledges that the design of an economy would be key to containing breakdown. The question is whether any existing branch of literature in ecological economics is paying much attention to such concerns.

The textbook by Common and Stagl (2005, 53) is one of the few ecological economic books to cover the concept of resilience, but except for one brief mention of trade, only discusses it in the context of the resilience of ecosystems, not economies. The same applies to the chapter on ecological economics in Goodstein (2008). Rosser (2001) considers the implications of chaos and catastrophe theory for fishery management in the journal *Ecological Economics*, but again this examination remains isolated to ecological rather than economic problems. Similarly resilience articles in ecological economic publications focus primarily on ecosystem resilience and associated management issues.

Indeed, ecological economists still have a ways to go in divorcing ecological economics from neoclassical economics, if that is their sincere objective: most papers published in the journal of Ecological Economics do not even mention the laws of thermodynamics (Victor, Rees and Lawn 2007 interviews). If some like Colding et al. (2002, 15) are willing to claim that complex systems thinking underpins ecological economics, then ecological economics needs to live up to this billing. Ecological economists already use the uncertainty of information and irrationality of humans as arguments for not having blind faith in markets, but they need to go further and consider the implications of uncertainty for human faith in the construct of civilization itself and what we can do as economists to help bolster it: "Ecological economics needs to go the extra step and make human ignorance a central feature of ecological economic theory and practice" (Lawn 2007 interview). Tisdell (2003, 46) agrees: "It is clear that ecological economics will need to incorporate 'new paradigms' – e.g. irreversibilities, discontinuities, ‘jumps’ and chaos – in order to model and analyse our economic and ecological prospects effectively”. Resilience is one of these much needed paradigms.

On the other side of the gulf, the promised synthesis of social-ecological systems in the work of groups like the Resilience Alliance is largely illusionary – as noted in the last chapter, the great body of existing resilience literature focuses mostly on attempting to manage ecological systems while failing to examine the design of human economies at the root of ecological degradation. Even joint articles fail to bridge this gap. For example, the article “Economic Growth, Carrying Capacity and the Environment” authored in part by the father of resilience thinking (Holling), one of the founders of ecological economics (Costanza), and a famous conventional economist (Arrow), provides little more than a one line mention of the link between resilience and economics in terms of natural systems: “If human activities are to be sustainable, we need to ensure that the ecological systems on which our economies depend are resilient” (Arrow et al. 1998, 37).

While studying the resilience of ecological systems and natural resource management systems is certainly of value to ecological economic theory, the fact that it has been the main focus to date, and furthermore can likely be subsumed in many ways under the existing goal of sustainable scale, provides justification for the remainder of this thesis focusing on a potentially more profound, largely unexplored concept: the resilience of economic systems. In a future likely to be defined by environmental resource shocks that threaten aging human systems, ecological economics stands to gain in prestige and credibility among competing economic disciplines if it is better prepared theoretically and analytically to address these threats.

Hanley (1998, 244) critiquing Levin et al. (1998), notes that even in the limited number of cases where resilience is applied to socioeconomic systems, the concept and its implications are often poorly defined and seem to add nothing new to the debate. A lack of common definitions has led to resilience being watered down and pulled in all directions between disciplines until it starts to lose its original, powerful meaning. A more rigorous definition, at least for ecological economics, is thus required.

4.2 Defining Economic Resilience

According to Tierney (2003), resilience in human systems consists of four interrelated dimensions: technical, organizational, social and economic:

> The technical dimension of resilience refers to the ability of physical systems (e.g., structures, lifelines, other engineered systems) to perform to desired levels when subject to disaster forces. The organizational dimension of resilience refers to the capacity of organizations (e.g., emergency management organizations, utilities, hospitals, governmental organizations) to make decisions and take actions to reduce disaster vulnerability and impacts. The social dimension of resilience consists of factors that lessen the negative social or community consequences of disasters, while economic resilience refers to the capacity of firms and local, regional, and national economies to absorb, contain, or reduce both direct and indirect economic losses resulting from disasters.

Given how interlinked they are, both this thesis and ecological economics need to consider all four dimensions, but especially the last.

Homer-Dixon (2007 interview) agrees: "Resilience is definitely an economic issue". Economics is about the production and consumption of goods and services and the provision of well-being and welfare. Under either definition, resilience is certainly therefore "a critical concern of economics" (Homer-Dixon 2007 interview). Every time one makes a decision about resilience, one is also making an economic decision. There is potentially a cost to make technologies or institutions more resilient which may involve tradeoffs and opportunity costs.

To successfully incorporate resilience into ecological economics, what is needed then is a new definition for economic system resilience (the resilience of the human economy), as differentiated from ecosystem resilience (the resilience of nature's economy), or ecological resilience (the definition/type of resilience explained in the last chapter). The goal of a steady-state economy in Daly's vision of ecological economics might seem to favour an engineering definition of resilience yet the tendency in ecological economics to prefer ideas from ecology would suggest the ecological definition would be more favoured. Because of its complexity, debate over definitions also afflicts the resilience literature in general: "One paradox of this concept is that a more resilient system implies more flexibility and hence less tight controls, but resilient systems are also defined as those able to maintain their controls and structure" (Redman and Kinzig 2003, 5).

Offut (2005, 1) suggests the following narrow definition: “Economic resilience is the availability of substitutes in production and consumption”, but this fails to encompass more advanced understandings of system breakdown or adaptive change. Studying earthquake resilience, Rose (2004, 41) offers a better, though still not quite adequate definition for economic resilience: “the inherent and adaptive responses to hazards that enable individuals and communities to avoid some potential losses. It can take place at the level of the firm, household, market, or macroeconomy. In contrast to the pre-event character of mitigation, economic resilience emphasizes ingenuity and resourcefulness applied during and after the event”. Finally, Briguglio et al. (undated, 1) define economic resilience as the “nurtured ability of an economy to recover from or adjust to the effects of adverse shocks to which it may be inherently exposed”.

Returning to the basics from Chapter 3 for a moment, a useful general definition of the concept of resilience is provided by Redman and Kinzig (2003, 5): “the ability of a system to remain functionally stable in the face of stress and to recover following a disturbance.” Colding et al. (2002, 71) offer a similar definition, but this time narrowed to social systems: “Social Resilience – The ability of human communities to withstand external shocks or perturbations to their infrastructure, such as environmental variability or social, economic or political upheaval, and to recover from such perturbations”. With some modification these two definitions can be adapted for economics by incorporating one of the key economic measuring sticks for success: the maintenance and enhancement of utility, or more generally, welfare. Both of these essentially mean ‘happiness’.

This thesis will henceforth define economic resilience as: the capacity of an economy to endure, adapt to and successfully recover from shocks in order to maintain a base level of welfare for all people at least equal to that enjoyed before the shock occurred. It encompasses both preventing breakdowns from cascading into catastrophes, and avoiding collapse following a catastrophe, preferably while retaining or regenerating desired system characteristics and functions.

This definition shifts the focus of measuring resilience from the amount of stress a system is able to endure before essentially collapsing (ecological resilience) or the amount of time it takes to recover (engineering), to instead focus on the amount of welfare loss endured. Economic resilience is therefore about minimizing maximum losses so that the economy can continue to provide a baseline level of needs satisfaction to all the people depending on it. While this thesis focuses on resilience to large scale shocks and catastrophes, this definition does not exclude resilience to smaller scale economic perturbations as well.

4.3 Potential Principles of Resilience

Developing general principles of resilience is vitally important because we cannot predict with certainty the type, time or location of shocks that may befall us nor the exact way in which our system might break down. It is literally impossible for us to plan in detail for every possible emergency so we need more generic principles to help guide us. Resilience measures need to be flexible so they can be replaced, adjusted and scaled up and down easily. In pursuing principles of economic resilience, it is useful first to examine other general principles of resilience proposed by authors in the literature.

Tinch (1998) discusses different measures of the capacity of systems to absorb shock including: stability, persistence, resistance, non-vulnerability, stochastic return time and resilience. Lovins' and Lovins' (2001) many and varied principles include early detection of failure, functional redundancy, diversity, dispersion of components in space, simplicity, loose coupling of components and lengthening the time it takes a system to fail (make it more forgiving).

Tierney (2003) believes “Resilience can further be conceptualized as consisting of four dimensions: robustness, redundancy, resourcefulness, and rapidity”. Greer (2008, 170-71): discusses four features of a resilient technology: it must be durable, independent, replicable (if you have one, it does not take advanced technology to make another), and transparent (it's easy to work out how it functions just from the device itself). He suggests a slide ruler meets this criteria: compared to a calculator it is simple to construct and clearly shows the user how the relationship between numbers leads to an answer rather than having the answer hidden in the circuitry.

According to Berkes et al. (2003, 15), operationalizing resilience “means not pushing the system to its limits but maintaining diversity and variability, leaving some slack and flexibility, and not trying to optimize some parts of the system but maintaining redundancy. It also means learning how to maintain and enhance adaptability”. Hamel and Valikangas (2003, 12) recommend “strategic variety, wide-scale experimentation and rapid resource redeployment” to build business resilience. Janssen and Osnas (2005, 95), when answering what makes systems able to cope with change, identify three factors: redundancy, modularity and diversity. Hopkins (2008, 55) names diversity, modularity and tightness of feedback (in the sense of improved monitoring capability) as his three ingredients of a local resilient community.

Overall, a synthesis of the literature reveals the following six principles to be the most fundamental ones for determining the resilience of a system, in particular socioeconomic ones. These principles are not strict, nor absolutely defined, for to do so would entail trying to replicate the arcane laws of conventional mechanistic science which ecological economics is trying to diverge from. Fundamentally, each principle is intended to act as a circuit breaker or shock absorber to prevent synchronous failures from cascading (Kousky et al. 2009).

4.4 (Functional) Redundancy

"Two are better than one... For if one falls, the other will lift up their companion.
Woe to the solitary! For if they should fall, they have no one to lift them up."
Ecclesiastes 4:9

Functional redundancy refers to duplication of function or functional substitutability of one system element for another. The intention is that backup parts (of the same or different type) can take over the function of failed system components (Lovins and Lovins 2001, 196; Low et al. 2003, 97). Redundancy certainly exists in biological and ecological systems, for example duplicate genes in DNA. Many of us have come to think of redundancy as it relates to the space age, e.g. duplication of mechanical or engineering components to enable space craft to continue to function should one component break down: "In engineering systems, redundancy is designed in, typically as a risk-reduction strategy, for the sake of the whole system" (Low et al. 2003, 106). In technological systems lacking redundancy, "failed equipment entails a shutdown because the temporary substitution of other equipment is not possible" (Perrow 1999, 94).

Yet redundancy can also cover the duplication of industries, products, labour, techniques, data, knowledge, links, and management and governance structures in the economy. Redundancy as a component of resilience is basic: "In most studies, redundancy has been mentioned as a key factor for making systems cope with changes: redundancy of components, information, tasks, connections, etc. Redundancy enables a system to maintain its function when a component is lost, and the redundant component takes over the function" (Janssen and Osnas 2005, 95). In economic terms, this could include stockpiling a readily accessible reserve supply of a particular resource, part or skill.

Lovins and Lovins (2001, 193) identify functional redundancy as one of their various design principles for isolating breakdowns: "Individual modules, nodes, or links can fail without serious consequences if other components are available to take over their function right away. This requires redundant, substitutable units". Systems with redundancy make it possible for something to be done twice if not done correctly the first time (Perrow 1999, 94). Functional redundancy can also relate to ease of replication where a component or institution is designed so it can be reproduced with limited local resources and simple technology even under the most adverse conditions (Lovins and Lovins 2001, 206). A good example of this was the Russian PPS42 submachine gun designed and manufactured during the harsh siege of Leningrad in World War II. System components resulting from this design philosophy are typically quite robust and easily repaired as well.

While we are all too familiar with the consequences of failing to backup our computer data, functional redundancy should also encompass cultural information. Resilient economies must not only preserve the basic infrastructure necessary to survive in a modern, largely urban society, it must also be capable of preserving the cultural infrastructure (practical knowledge, philosophy, religion, art) "that enables us to understand our world and communicate across time and space" (Heinberg 2004, 141). Folke et al. (2003, 369) note that "institutional and social redundancy may serve functions similar to the overlapping functions of ecological redundancy for reorganization and renewal after disturbance, recognizing that redundancy implies similar but not identical functional roles".

The current global medical isotope shortage shows what can happen when an economic sector lack redundancy. Redundancy should ideally be built into the original design of a system. If added after problems are recognized, it can create "unanticipated interactions with distant parts of the system that designers would find it hard to anticipate" (Perrow 1999, 368).

4.5 Diversity

"Variety's the very spice of life"

William Cowper

Diversity refers to the degree of variance in the type and characteristics of components that make up a system. The greater variety, the higher the probability that at least some system parts will be resilient to any given shock: diversity helps prevent common-cause failures (Lovins and Lovins 2001, 195). Authors such as Levin et al. (1998, 229) and Holling et al. (2002, 397) note the significance of maintaining diversity to resilience. Even traditional neoclassical microeconomics recognizes that consuming too much of any one thing is not good because it leads to diminishing, and eventually negative, utility.

In nature, diversity is key to the resilience of ecosystems. A mix of genes and species is vital to "assimilating and/or permitting recovery from perturbations" (Gale 2000, 287). When an ecosystem is disturbed, the degree to which species loss affects critical processes depends on both the number of alternative species that can take over a particular function as well as the number of connections between the species (Perrings 1998, 514; Hopkins 2008, 55). Thus, "It is a serious error to assume that minor species are indeed 'passenger' species that can afford to be lost…The importance of such species may be detected only when they are needed, following a disruption" (Holling et al. 2002, 408).

Non-resilient economies and industries only have one way to reach production goals whereas diverse economies are flexible and can do it many ways, and interchange one process or resource for another (Perrow 1999, 94). In this respect there is some conceptual overlap with functional redundancy, however redundancy focuses on duplicating essentially the same function (the means to an end) whereas diversity implies substitutability in a much broader sense (achieving the same end but through various alternative means, allowing for more opportunity to deal with new stresses and/or take advantage of new opportunities). Both redundancy and diversity allow the part of a system that has been damaged to recover by drawing on undamaged parts (Homer-Dixon 2006, 290).

Historically in the Euphrates Valley civilization, Schwartz and Nichols (2006, 13) notes "the relatively marginal environment of the region gave its inhabitants an edge over people in 'core' areas in times of collapse, because the region's diversified subsistence economy allowed for flexibility and resilience". In contrast the Mayans and other built-up civilizations often lacked diversity in their crops and economy. Perhaps diversifying production may be able to help stave off the threat of decreasing returns on investing in complexity which Tainter (1988) blames for civilization collapse – in other words, economies should not invest too much in any one thing. New environmental, social and economic downsides of existing technologies and resource practices are being discovered all the time, so in order to distribute risk it would be wise for society to continually diversify the technologies, techniques and resources we depend on. Otherwise, we are likely to become locked into one increasingly unfeasible mode of operation such as our utter dependence on fossil fuels, to devastating results. On a smaller scale, the vulnerabilities introduced by trading nations becoming dependent on one specialized commodity export are well known (Hopkins 2008, 55).

Diversity can be applied not just to infrastructure and production decisions but also to culture, ideas, information and social organization: "Diversity of memories provides the potential for alternative ways to maintain functioning when faced with change. Diversity provides insurance to cope with change. It also provides the potential for reorganizing following change" (Folke et al. 2003, 376). In this sense we should diversify our knowledge, our worldview, and our experiences as much as possible to be better prepared for the shocks ahead. This will provide a diversity of potential responses to challenges (Hopkins 2008, 55). While they may not be popular at the moment, it is important that a wide diversity of intellectual ideas and value systems, like those advanced by ecological economists, always remain waiting in the wings for when society may need them most (Gunderson et al., 2002, 327).

4.6 Dispersity

Don't put all your eggs in one basket

While diversity encompasses variances in type, dispersity refers to the distribution of important system components and functions over space, scale, and time. When system parts are concentrated or centralized they function well together but are also highly vulnerable to disruption. Increasing the geographic, temporal or hierarchal separation between components (known as decentralization) can reduce the chance they will be affected by any single shock hitting at a particular place, time or scale.

“Geographic dispersion means that if a mishap occurs in a particular place, it is more likely that some units will be there but less likely that they will *all* be there. The greatest possible simultaneous loss is thus reduced” (Lovins and Lovins 2001, 198). Allenby and Fink (2005, 1035) note: “It is elementary that physical dispersion of assets makes them less subject to point attack or localized disaster such as a tornado or earthquake. A decentralized workforce is also more resilient against a number of other disruptions, including disease (employees who are able to work from home run less risk of infection and help reduce the velocity with which infectious diseases can spread)”. We should be especially careful not to make systems utterly dependent on central network hubs (e.g. supply points) that can be disrupted to the point where they bring the entire system down (Homer-Dixon 2006).

Dispersity can also refer to the distribution of administrative and economic decision making bodies, powers and processes between scales to improve their resilience and capacity to respond more effectively to breakdowns. Problem solving, especially in disaster situations, is often best done at more decentralized local scales that involve as many system actors as possible, except in those cases where entrenched local systems are part of the problem. In other cases, delegating some system functions to a higher scale can provide a backup in case there is a local breakdown. Embedding components across a dispersed hierarchy with rich interconnections can help buffer failures that afflict any single scale (Lovins and Lovins 2001, 210). An example is a food averaging system used by agricultural societies to provide smaller member regions with a fallback if they experience local crop failure.

Temporal dispersity involves lengthening the amount of time between the key events in a system’s operation so an interference occurring at a single time will disrupt as few major system functions as possible. Stretching out the time separating the phases of a system’s operation can allow more time for backups to come online and provide more opportunities for experimentation, repairs and course corrections in response to new feedback information. Safe-fail design criteria also suggests attempting to increase the time a component takes to fail so it will coast down more gradually rather than crashing suddenly, and thus provide more time for a soft landing to be prepared (Lovins and Lovins 2001, 201).

4.7 Autarky

"Can anything be so elegant as to have few wants, and to serve them one's self?"

Ralph Waldo Emerson

System components that are disperse may still rely heavily on other parts of the system for their functioning and these linkages can make them vulnerable. The term autarky is used mainly in economics and refers to a state of affairs where there is an absence of trade, and trading partners consume only what they themselves produce (Common and Stagl 2005, 263). In this paper it will be used to denote a general state of self-reliance in which a system component has the ability to survive or continue functioning even when cut off from other systems (to varying degrees). It can meet its needs even in the absence of travel (Hopkins 2008, 55). Autarky focuses special attention on shortening linkages and loosening the couplings and connectivity in systems so there is increased slack and flexibility. This will help reduce dependency on outside help and resources in a breakdown situation: "So as a rough and ready rule, boosting the ability of each part to take care of itself in a crisis boosts overall resilience" (Homer-Dixon 2006, 284).

The cost of neglecting autarky is that damages or shock in one part of a system can cascade to other parts, especially when links are short and tightly coupled. In economic systems, "Tightly coupled systems have more time-dependent processes: they cannot wait or stand by until attended to… Storage rooms may not be available, so products must move through continuously… In loosely coupled systems, delays are possible; processes can remain in standby mode; partially finished products will not change much while waiting" (Perrow 1999, 93). The sequence of steps is also more important in interconnected systems (A must be done before B) versus loose coupling where delays and interruptions are tolerable (Lovins and Lovins 2001, 200). Autarky means one can get by with fewer or lower quality supplies in the production line if necessary (Perrow 1999, 94).

Historically, Adams (1988, 21) believes "there was a degree of local autarky and geographic buffering throughout the millennia of our technically less-advanced past. Interdependencies were correspondingly less dominant, finely tuned, and disastrous in their consequences when allowed to slip out of balance". In the 20th century, Homer-Dixon (2006, 286) gives the example of the San Francisco Fire Department having its water cut off after the

1906 earthquake. In response, stand-alone cisterns were built at intersections across the city so each block would have its own water supply to fight fires.

High connectivity in systems typically arises as a result of the tendency in systems (both natural and human) to become specialized as they move up the growth curve of the figure-8 adaptive cycle, leading to increasing interdependencies. However, “This growing connectedness leads to increasing rigidity in its goal to retain control, and the system becomes ever more tightly bound together. This reduces resilience and the capacity of the system to absorb change, thus increasing the threat of abrupt change” (Holling 2004, 6). Low et al. (2003) contend that ecological systems must have some autarky built in, because if they were all very tightly coupled we would have seen greater ecological collapses by now.

On the other hand, the increasingly tight coupling within human socioeconomic systems means shocks and synchronous failures could spread much faster than at any previous time in history, increasing the risk of deep collapse (Homer-Dixon 2006, 231). Hopkins (2008, 56) writes that “the over-networked nature of modern, highly connected systems allow shock to travel rapidly through them, with potentially disastrous effects”. Indeed, “supply-chain disruptions can have a major impact upon advanced, industrialised economies” (Chapman et al. 2002, 61). Galtung (1986, 97) now believes the global economy is characterized by a “debilitating dependency: of peripheries on centres, of some countries on other countries, of people on ‘the system’”.

Almost all modern technologies are deeply interlinked and dependent on each other and will only function with a continuous supply of fossil fuel or electricity inputs. “Connectivity harbours other risks too. As we create links among the nodes of our technological and social networks, these networks sometimes developed unexpected patterns of connections that make breakdowns more likely” (Homer-Dixon 2006, 115). Hence Homer-Dixon (2006, 284) advises “loosening some of the coupling inside our economies and societies and among our technologies. For instance, we can promote the distributed supply of vital goods like energy and food”. Indeed the autarky principle would be better satisfied by technologies that are human or solar powered, have multiple interconnections between components, or are not so prone to synchronous failure.

Designing structures to be modular so they can continue working autonomously in isolation or until reconnected is another tactic to boost autarky (Orr 1992, 34). Modularity allows a system to more effectively self-organize following a shock, reducing its vulnerability to disruptions in wider networks (Hopkins 2008). Failures in turn can be isolated and corrected at the level at which they occur (Lovins and Lovins 2001). In loosely coupled systems, spur-of-the-moment recovery solutions can be found such as jury-rigging and patching that were not planned for ahead of time. In tightly coupled systems, recovery aids "are largely limited to deliberate, designed-in aids" (Perrow 1999, 95).

Yet as implied by the dispersity principle, there may also sometimes be benefits to greater connectivity: as long as the system linkages stay intact, they can "often make economies and societies more resilient to shock because they can respond faster and draw from their larger networks a wider range of skills, resources, capital, and goods and services" (Homer-Dixon 2006, 113). Likewise, some system interdependences simply cannot be avoided and trade remains desirable in many instances. This is why the term autarky was chosen for this principle rather than outright "self-sufficiency" or "autonomy"; an alternative term might be "self-reliance" (Galtung 1986, 102).

4.8 Adaptability

"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change."

Charles Darwin

Society may be vulnerable to various shocks but we are not entirely helpless once breakdown has occurred thanks to our marvellous ability to adapt to changing circumstances. Adaptability (or adaptive capacity) is one of the better defined concepts in the existing (largely ecologically focused) resilience literature. It is about building the capacity among parts of a system (in this case economic actors) to be flexible and effective at adapting to change: "Adaptive capacity is the ability of a social-ecological system to cope with novel situations without losing options for the future… Systems with high adaptive capacity are able to re-configure themselves without significant declines in crucial functions" (Colding et al. 2002, 17-18).

Holling et al. (2004, 7) note that "adaptability of the system is mainly a function of the social component—the individuals and groups acting to manage the system. Their actions influence resilience, either intentionally or unintentionally. Their collective capacity to manage resilience, intentionally, determines whether they can successfully avoid crossing into an undesirable system regime, or succeed in crossing back into a desirable one". Truly, since breakdowns are likely to disrupt our traditional coping mechanisms including technological change, social capital is key to adaptive capacity: "Much attention has been focused on the hardware of sustainability but relatively little on the software: on the kind of people necessary for the trials of building a sustainable global civilization" (Orr 1992, 139). Those societies that demonstrated adaptive capacity and hence were resilient in the face of environmental resource shocks include the Highland New Guinea, Tikopia and Tongan, Greenland Inuit and Icelandic societies (Wright 2004, Diamond 2005).

The International Panel on Climate Change defines adaptation as "actual adjustments, or changes in decision environments, which might ultimately enhance resilience or reduce vulnerability to observed or expected changes in climate" (Kousky et al. 2009, 11). They observe that "Adaptation options have previously been divided into *reactive adaptations*, which are undertaken in response to changes as they occur, and *anticipatory adaptations*, which are undertaken in advance of impacts" (Kousky et al. 2009, 11). Rose (2004, 52) also notes a post-breakdown aspect to adaptability: "*Adaptation* consists of two components: an active effect to reduce losses after an event has taken place (e.g., migration) and a passive absorption ('suffering') of the loss".

Certainly, adaptive capacity can be enhanced beforehand: "Resilience in social systems is different in one very important respect from that in ecosystems – i.e. the ability (adaptive capacity) of humans to imagine the future, the capacity for forward planning. The extent and elaboration of human forward-looking or anticipatory behaviour greatly exceeds anything found in the natural world" (Walker and Holling 2003, 2). Regarding preventative adaptive capacity, Redman and Kinzig (2003, 1) contend that "The key to enhancing system resilience is for individuals, their institutions, and society at large to develop ways to learn from past experiences, and to accept that some uncertainties must inevitably be faced". This can include plans at various levels of government to restore order and ration resources if necessary.

Indeed, an important part of resilience is being able to expect the unexpected and then absorb or withstand it (Folke et al. 2003, 362). To increase adaptive capacity, Homer-Dixon (2006) calls for society to have a "prospective mind", which means accepting that surprise and rapid change are an inevitable element of reality (i.e. "don't be surprised by surprise"). This demands prudence but not pessimism, denial or nostalgia: "To be resilient, an organization must dramatically reduce the time it takes to go from 'that can't be true' to 'we must face the world as it is'" (Hamel and Valikangas 2003, 3). Businesses and people in all sectors of the economy, not just in emergency management professions, need to better prepare themselves psychologically to deal with the full range of possible breakdown scenarios and eventualities we face in the coming century. Better education can help in this regard.

However, adaptability truly comes into play in the disorganization that follows a breakdown or catastrophe. In this sense, adaptive capacity "reflects a learning aspect of system behaviour in response to disturbance" (Walker and Holling 2003, 1). Economic actors need to become more knowledgeable about what is necessary for the survival of themselves and their communities in the face of disruption. For example, "Mass migration such as occurred after the devastation of Hurricane Katrina and Rita suggests that part of the natural adaptation to major change is to resettle in more hospitable locations" (Gilbert and Perl 2008, 284).

Furthermore, "Novelty is key to dealing with surprises or crises" (Gunderson 2003, 41). Among open-minded and creative people, innovation can flourish in breakdown situations since necessity is often the mother of invention (Tierney 2003). For example, the "Street Use" website documents how people have practically adapted commercial products and technologies for improvised uses entirely different from what their makers intended (Kelly 2011). Salvaging useful items from the detritus of industrial society may become a very important skill in a breakdown (Greer 2008, 160).

Altruism, trust and reciprocity are also key values given how important it is for citizens to share resources and knowledge such as survival skills with their neighbours (Levin et al. 1998, 231). Disasters historically have (at least initially) engendered high levels of cooperation among communities as conflicts and disagreements are suspended in the interest of meeting shared needs and coping with collective loss (Tierney 2003). Often the artificial divide between the public and private sectors of the economy has melted away for the common good.

Adaptability during a breakdown can be enhanced significantly by the leadership of great people, as exemplified by Winston Churchill (Holling 2004, 8). Institutions must also be prepared and able to rapidly mobilize and coordinate collective action in the face of shocks, sometimes at the expense of individual freedom (Adger et al 2005, 1038; King 1995, 979). An interesting question is whether a society that relies on central governance with great coordinating authority is more or less adaptable than one composed of many autonomous individuals, businesses, volunteer and neighbourhood organizations that is harder to coordinate but features greater autarky and thanks to its diversity has a lower chance of making a single large mistake (Davidson-Hunt and Berkes 2003, 66-7).

In terms of ecological economics, Daly and Farley (2004, 362) declare as one of their six policy design principles that "policies must be able to adapt to changed conditions" (i.e. adaptive management). However, they do not mention that the entire economy may need to be adaptable to change as well. This requires enhancing our capacity to recognize problems early and develop timely responses, such as by refining monitoring systems, institutional preparedness, and information feedback loops. It also entails developing preparedness measures such as fall-back options, resource reserves and established emergency procedures.

However with so few major disruptions, current generations in developed nations have had insufficient opportunities to practice adapting (Van der Leeuw and De Vries 2002, 240). The type of innovations generated by recurring small-scale disturbances may be insufficient for building adaptive capacity against major catastrophes (Carpenter et al., 2002, 192). An argument can therefore be made that "Small perturbations should be utilized to build resilience rather than be suppressed in order to reduce variability…. For instance, it is better to leave mild illnesses untreated so as to build immunity rather than ingest antibiotics at the mildest sneeze" (Lele 1998, 251). In natural systems the same thinking now applies to forest fire management. Resilient societies should consider incorporating non-linear negative feedback: when perturbations are small no action is taken, but when they are large and the system teeters on the edge of its stability domain, the response is overwhelming.

Thus, "In our communities, towns and cities we can use small-scale-experiments to see what kinds of technologies, organizations, and procedures work best under different breakdown scenarios" (Homer-Dixon 2006, 292). The potential for improvisation depends partly on the level of diversity in the economy: "In systems with low diversity, there is less chance of creating new ideas, components, or connections" (Janssen and Osnas 2005, 95). Similarly, if systems enjoy autarky, experimentations can be tested by one system component without affecting the others. For their part, redundancy and dispersity ensure more resources are available after breakdown to work with.

However, there always remains the possibility of maladaption (people are made worse off than if they had done nothing) (Kousky et al. 2009, 15). Jane Jacobs (2000, 84) notes that “emergency adaptations” like deficit financing by the government during depressions are often “damaging except in times of crisis” (Jacobs 2000, 116). Interestingly the British people voted Churchill out after their crisis was over, a decision which makes more sense in this light. Moreover, some adaptation measures “provide benefits under the circumstances for which they designed, but not if impacts are significantly different…. regulations and protection programs designed for more modest scale disasters can become at best ineffective and at worst counterproductive when addressing larger-scale events” (Kousky et al. 2009, 16). Likewise, people and institutions can adapt without necessarily learning how to be more sustainable so the next concept, transformability, is also needed.

4.9 Transformability

"Change your thoughts, and you change your world."

Norman Vincent Peale

Associated with adaptive capacity is the concept of transformability – the capacity of systems to use catastrophes as an opportunity to start over with new characteristics when existing conditions become untenable. Transformability is a different concept from adaptability because the latter is focused mainly on shorter term system survival and does not allow a system to shape its own basin of attraction. It is really only possible for a system to adapt back to the same basin of attraction as before, or a different one not of its choosing. As discussed in Chapter 3, adaptive capacity, and by extension resilience itself, is not always a good thing. Some undesirable system states “can be very resilient, and they can have high adaptive capacity in the sense of re-configuring to retain the same controls” (Walker and Holling 2003, 1).

Transformability however allows a system to evolve slightly or fundamentally in ways of its own choosing, purging existing characteristics that are undesirable in the process: “the aim of transition management is to achieve structural (socio-technical) transformations that improve performance in the desired sustainability functions. The aim is thus resilience with respect to these functions and those socio-technical structures that are judged best to deliver them – and emphatically not with the countervailing incumbent structures themselves” (Stirling and Smith 2008, 18). This means striving to shift the system into a more sustainable basin of attraction or proactively creating an entirely new stability landscape, possibly at a different scale (Holling et al. 2004, 5).

In terms of economic resilience this would imply changing in a way that has a net lasting increase of welfare for actors in the economy: "For any economy there are many possible states, each delivering different levels of welfare to society" (Brock et al. 2002, 270). Also, while adaptability matters most in the release phase of the adaptive cycle, transformability comes into play more in the later reorganization phase. Here innovation is the highest and novel system properties and interactions emerge that can be good or bad for the long term. Lawn (2007 interview) draws the analogy to biology where organisms can adapt to change in the short run, but actually mutate in response to change in the longer run.

As hinted above, transformability raises an interesting paradox which has yet to be resolved fully in the literature: if by definition a resilient system needs to be able to maintain its structure and function (not leave its basin of attraction), how then can transformability be a principle if it *requires* the ability to change shape and go to a new basin? Which functions should be kept from the old social system and which should be abandoned (Hanley 1998, 247)? To be considered resilient and transformative, a change in a system should probably meet some of the following criteria:

1) It should remove at least some of the conditions which created the breakdown in the first place (e.g. become more sustainable in resource use), and start society down at the bottom of a cycle. Shifting to a basin which requires greater resource consumption, or starting higher up the cycle, would be self-defeating.
2) It should be purposeful/deliberate/conscious change (ideally planned for somewhat before the shock) rather than the obvious changes that would naturally follow the complete breakdown of the existing economic or social order (e.g. the dissolution of the Roman Empire), such as disorganized and knee-jerk change in the panic following a shock.
3) It should be bottom-up change, agreed to by the majority of citizens rather than change imposed rigidly by the top-down on people who resist it. Some top-down guidance is undoubtedly necessary to regain order, but that may fall more under adaptability.

Transformability requires the vast majority of society to agree (at least in principle) on where they are going next.

The definition of economic resilience proposed at the start of this chapter incorporates the understanding that economic systems may need to change structure to adapt to breakdowns and catastrophes. Hence it focuses on maintaining the more flexible "function" of welfare (happiness) as its definition of resilience. Abel et al. (2006, 1) explain that "When the aim is to recover without changing the system fundamentally, the focus should be upon conserving or investing in the elements of capital critical for this. If the current system is not viable, it is necessary to invest in forms of capital that will enable fundamental change."

In both ecosystems and human societies experiencing catastrophic change, remnants or "memory" of the former system "supplies the experience of previous self-organizations and the ingredients for new self-organization embedded in a historical and evolutionary context" (Folke et al. 2003, 376). For example, "following a fire in a forested ecosystem, the reorganization phase draws upon the seed bank, physical structures, and surviving species that had accumulated during the previous cycle of growth of the forest, plus those from outside. Thus, renewal and reorganization are framed by the memory of the system" (Berkes et al. 2003, 19). Indeed, "change, renewal and variation by themselves will seldom lead to success and survival. To be effective, a context of experience, history, remembrance, and trust, to act within, is required" (Folke et al. 2003, 352). Social memory is represented by the diversity of knowledge, faiths, values and worldviews that can be drawn on, and since chaotic systems are inherently sensitive to initial conditions, it is also influenced by what institutions remain after the breakdown.

Therefore, we need to "Protect and preserve the accumulated experience on which change will be based" (Holling 2003, xx). Education is key, as is experimenting with alternatives ahead of time. Homer-Dixon (2006, 290) notes that "we need to lay down plans and organize ourselves so that we're prepared to take advantage of the opportunities that various types of breakdown might offer to build a better world. For instance, depending on the scenario, we might plan to aggressively disseminate information through the Internet, mass media, and various social networks to frame the rapidly changing situation". After a catastrophe, society must also act quickly to recover information in danger of being permanently lost, since lessons from the past are so key to our future transformability.

When it comes to socioeconomic transformability, “the influence of extraordinary leaders and other agents in the implementation of new institutions and ideologies should not be overlooked” (Schwartz and Nichols 2006, 12). However, “While the Great Depression gave Roosevelt the impetus and opportunity to reform American capitalism, it also gave Hitler the chance to establish one of history’s most evil regimes” (Homer-Dixon 2006, 24). Klein (2007) similarly contends that radical free market reformers have consistently exploited shocks to advance their ideological and personal profit interests. Homer-Dixon (2006, 292) hence cautions against letting extremists of any type hijack the agenda when people are scared, frustrated and angry following breakdown. Identifying “extremists” or “radicals” depends on one’s point of view (ecological economists are currently classified as such by some), but presumably this would mean those who believe in ideologies rather than evidence, or who are clouded by anger and fear and single out other people as enemies rather than undertake a rational appraisal of a situation.

Truly, “In the aftermath of disaster, the very legitimacy of government is at stake” (Vale and Campanella 2005, 340). Nothing is likely to motivate apathetic populaces to political action quite as quickly as the scarcity and ballooning prices of formerly plentiful commodity or the unexpected termination of basic services they have long taken for granted. Civil unrest on a scale unseen in the West for decades is to be expected, placing enormous pressure on existing, failing economic and governance systems to change or be discarded outright (Gallopin 2002, 373).

Heinberg (2004) notes that Cuba is a good example of a country that was able to survive being cut off from exports thanks to the success of its moral authority, the Communist Party, in coordinating necessary economic transformations. However, Heinberg (2004, 110) worries that in other modern nations like the United States, polls confirm that citizens largely distrust their political and corporate leaders: “when the crunch came Cubans pulled together and carried their nation through a painful economic transformation. But would another country have responded to similar circumstances so successfully? It is relatively easy to think of ones that have met economic challenges with cultural disintegration, deepening corruption or authoritarianism, or internal violence. Recall Germany in the 1920s, or Zimbabwe in recent years”.

Yet because deeply entrenched ideologies, values and paradigms will often only shift when they are shaken up by a jarring shock, the opportunities for new positive beginnings that open only in the aftermath of catastrophe should give us more reasons to be hopeful than afraid of the reorganization phase of the adaptive cycle: “Often the very ruptures of collapse generate new institutions, new social practices, and new forms of historical consciousness" (Kolata 2006, 219). For example it may be the only time when ecological economics has a chance to implement its ideas on the way to becoming the new mainstream economic paradigm. In Cuba, "a small group of agronomists had been advocating ecological agriculture for years previously, with no success; but when oil imports fell and the Cuban economy teetered, the nation's political leaders called on these marginalized ecological agronomists to redesign the country's food system. Something similar could happen globally in the years ahead" (Heinberg 2004, 184).

Transformation is like rebooting a computer after a system crash and starting over with some of the same components but the opportunity to make a fresh start. So we need to make sure that while we have the luxury to do so, we discuss and assess to the extent feasible a diversity of alternative models (economic, social, or otherwise) to bequeath to people in periods following breakdown. Funding and economic incentives for developing these long range economic models, theories and policy options for a post-catastrophe world would be very helpful.

Homer-Dixon (2006, 268) uses the term catagenesis to mean essentially the same thing as transformability – seizing the opportunity for "creative renewal of our technologies, institutions, and societies in the aftermath of breakdown". He equates this with Austrian economist Joseph Schumpter's idea of creative destruction. He notes that while breakdown is essential to long-run adaptation and renewal, it must be constrained so it is not too severe if catagenesis is to happen successfully (Homer-Dixon 2006, 23). This is in part why thinking about resilience long before catastrophes hit should be so important to ecological economists.

Chapter Conclusion

In summary, redundancy and adaptability refer to properties of the individual units or components within a system, while diversity, dispersity, autarky and transformability are largely properties of the entire system (i.e. it can be difficult to look at an individual component and judge it to be diverse or disperse). This is somewhat of an issue of semantics: when looking at the whole system, an argument could be made that adaptability and resilience are synonymous (Homer-Dixon 2007 interview). Some readers may also wonder why safe-fail was not one of the previous principles. In this author's view, safe-fail is more of a meta-concept encompassing all six principles: to achieve resilience or a safe-fail system (essentially the same thing), one needs redundancy, diversity and so on.

The first four of the principles discussed in this chapter (redundancy, diversity, dispersity and autarky) deal with the design of the physical economy while the latter two (adaptability and transformability) deal with the knowledge, attitudes and values of people making up the economy. Likewise the first four technically prevent the worst collapse of the system while the last two are more about people responding to and making the best of what remains:

> Hence there is a dynamic interplay between reducing the impacts of change and at the same time taking advantage of the opportunities created by change. Systems where change is not allowed will almost certainly generate surprise and crisis. Systems that allow too much change and novelty will suffer loss of memory… The dynamic process requires social-ecological memory with functional diversity (including redundancy) for turning disturbance into options for renewal and novelty. (Folke et al. 2003, 376)

Meeting one of these principles does not automatically mean satisfying the others. For example, a system could be redundant but centralized and hence lack dispersity, or a region could be geographically isolated (dispersed) from its neighbours and supplied with a diverse supply of goods from different trading partners but still be heavily dependent on outside linkages staying intact and so lack autarky (e.g. North America is separated from Asia by an ocean yet relies on it for most manufactured goods). It is possible that a socioeconomic system may adapt to a catastrophe and survive it without collapsing, yet lack the ability to transform and so just continue on with unsustainable practices, or worse be left in a shattered system state not of its choosing. Ideally, each of these six principles should be pursued simultaneously when building resilient economic systems, in order to minimize risk in case one or more principles proves ineffective in a particular case and since there are diminishing marginal returns to expenditures on each individual principle.

This thesis represents the first time that all six of these principles have been brought together into one framework to analyze what constitutes a resilient system (economic or otherwise). Certainly some authors have used one or more of these concepts together in the past, such as Colding et al. (2002, 19): "Diversity and an apparent redundancy of institutions (in the sense of overlapping functions) appears to play a central role in absorbing disturbances, spreading risks, creating novelty and reorganizing following disturbances". Low et al. (2003, 97) also note: "Systems with redundant and loosely connected subsystems… may change in many ways… yet persist relatively well". Likewise Holling et al. (2004, 6) observe that diversity of built, natural and human capital (in terms of education, expertise and occupations) are key to promoting adaptability and transformability. Yet overall the literature still grapples with any sort of unified framework of what properties make for resilient systems. Hopefully the above framework for identifying the core elements of economic resilience will help to advance the general understanding of resilience as consisting of *both* the technical aspects of how a system is designed as well as a theory of self-organizing social change.

Chapter 5: The Interplay between Primary Goals

The last chapter defined economic resilience and developed a theoretical six principle framework to allow us to finally apply this useful concept and theory to ecological economics proper to see what is revealed. There is no better place to start than a theoretical examination of how the pursuit of resilience compares as an objective to the other three existing ecological economic goals of sustainable scale, just distribution and efficient allocation. These three goals are a very logical and useful way for ecological economists to break down, simplify and analyze the major interrelated problems we face in the modern world, yet there is one critical attribute of the system they do not cover.

The evolutionary economist Underwood (1998) argues that human systems, like all other living systems, must solve two fundamental problems. The first is provisioning, the quest for the continuous supply of want-satisfying throughput. This is the primary focus of all economics. Underwood's second problem is adaptability, the requirement that solutions to the provisioning problem also be able to respond to unpredictable changes in the environment. This facet of the human story is essentially the problem of resilience.

In formulating their three policy objectives, ecological economists have likewise focused largely on the concerns associated with the first of Underwood's problems while neglecting the second (even in Underwood's article it is given short-shrift). The three existing goals of ecological economics are inarguably key to a sustainable society, yet they are based on the assumption that there is still time and the political willpower to stop major environmental resource shocks from occurring. Unfortunately, the modern human mindset is biased towards optimism and assumes that progress will continue indefinitely, unlike for example Dark Age European society which was concerned with simply preserving what remained of Greco-Roman culture and knowledge. So long as we wake every day surrounded by the social stability and reassuring comforts of civilization, most people simply cannot imagine anything worse than small isolated breakdowns (Perrow 1999, 389). But it is also becoming increasingly difficult to ignore the warning signs all around that we soon face a dangerous convergence of environmental challenges on a scale never before faced by civilization, and that it is high time for economic resilience to be given equal weight and consideration.

The key question remains however: would consideration of resilience in ecological economics be at odds with the three existing goals of scale, distribution and efficiency? How do they overlap or diverge and are these goals mutually reinforcing or irreconcilable? Does pursuing one goal necessitate a cost or tradeoff of another? Answering these questions will ultimately reveal the extent to which resilience is fundamentally compatible with the theory of ecological economics. This chapter will analyze each goal relative to the concept of resilience in individual subsections, and then compare how the goals fit into overall resilience theory in a single concluding section. Note that while ecological economics traditionally ranks scale first, distribution second and efficiency last in their hierarchy of policy action priority, it is more logical to discuss efficiency after scale in this chapter because resilience theory insights about efficiency follow directly from its analysis of the effects of growth. The relationship between resilience and distribution is more uncertain so it will be discussed last.

5.1 Resilience and Sustainable Scale

The ecological economic critique of economic growth is the primary factor separating it from all conventional economic disciplines, including environmental economics with which it is often confused. Ecological economists define economic growth as the physical (material and energy) expansion of the economy, as distinct from economic development, which is the qualitative expansion of economic welfare/wellbeing/potential that can be theoretically decoupled from material and energy use.

Ecological economists believe that because of environmental constraints there is a maximum sustainable scale of the global economy, and if we keep growing beyond this limit there will be in their own words “catastrophe” (Daly and Farley 2004, 20). However, many ecological economic diagrams depicting scale simply end at the point where maximum sustainable scale is exceeded, as though this automatically triggers the end of the world. It is time for ecological economists to explore the region beyond the point where maximum sustainable scale is exceeded, when economic resilience becomes most important. Simply crossing a line does not lead to society’s automatic collapse – instead there is a continuum of breakdown scenarios beyond this point, with complete collapse being the worst but far from the only outcome.

Since by definition, environmental resource shocks only occur if scale is exceeded, staying within sustainable scale is fundamentally all about preventing shocks by limiting economic production to the assimilative and regenerative carrying capacity of the global ecosystem. It is not about building economic resilience to breakdowns which only occur when scale has already been exceeded. However, as noted repeatedly in this paper, we have already exceeded the shrinking capacity of many local environments and likely the entire planet, putting gears into motion like global warming that are impossible to predict. Since we can no longer hope to prevent all shocks and breakdowns by constraining scale, consideration of economic resilience becomes extremely important as a policy goal distinct from scale. By and large proposals to address the scale issue attempt to manage natural and social systems and keep them from exceeding some parameters (Lawn 2007 interview). However it is profoundly difficult to run the economy within evolving limits that are contextual and interactive and so resilience is necessary as a safeguard (Anonymous interviewee 2007). The imperative of economic resilience explicitly recognizes that some breakdowns will inevitably occur, which is the most fundamental difference between it and the objective of sustainable scale. Some like Hanley (1998, 248) in turn wonder whether increasing socioeconomic scale harms or helps resilience.

5.1.1 Does the pursuit of sustainable scale enhance or undermine resilience?

As this thesis has previously pondered, it is debateable whether sustainable scale is even a feasible, attainable objective in the near future. Heinberg (2004, 10) writes: “we have already advanced so far in certain directions as to have foreclosed possibilities that we would all prefer were available. I take it as a given that we have already overshot Earth’s long-term carrying capacity for humans – and have drawn down essential resources – to such an extent that some form of societal collapse is now inevitable”.

Klein (2007, 513) agrees: “An economic system that requires constant growth, while bucking almost all serious attempts at environmental regulation, generates a steady stream of disasters all on its own, whether military, ecological, or financial”. While it simply may no longer be possible to attain a green utopia before the coming shocks hit perhaps sometime mid-century, efforts to control scale from getting even further out of hand can still pay dividends that enhance resilience.

The work of the Resilience Alliance has taught us that as a system grows it typically becomes less resilient. As natural systems approach their climax state/carrying capacity, they become accidents waiting to happen (Holling 1973). Likewise as societies "try to deal with their immediate problems, they develop inexorable momentum toward greater complexity, and this complexity brings with it long-term unintended costs" (Homer-Dixon 2006, 221). As we learned in Chapter 2, diminishing returns from complexity can increase a society's likelihood of collapse (Tainter 1988). Growth can directly cause loss of resilience because of increased brittleness, crowdedness and less natural resources per person in the economy available to fall back on. The complexity/organization of the global economy is in defiance of the law of entropy (the universe's progression towards disorder) and its current position far from its natural equilibrium demands constant inputs of high quality energy to maintain order (swimming upstream). In turn, "Complexity breeds weird failure modes which cannot be foreseen, understood even in hindsight, or fixed" (Lovins and Lovins 2001, 202).

Moreover, to increase scale often requires raising efficiency, another major driver of lower resilience: "The growth imperative worsens instability in other ways too. It tends to cause ever tighter connectivity among economies, financial institutions, corporations, and investors" (Homer-Dixon 2006, 200). A system that grows rapidly also does not have the chance to accumulate experience about how to respond to failure (Perrow 1999, 371). For all of these reasons, helping to keep scale in check through the ecological economic goal of sustainable scale also helps preserve system resilience.

Ecological economists similarly argue that increasing scale is subject to diminishing returns (increasing costs, decreasing benefits). Beyond a point, growth becomes uneconomic. This coincides nicely with the resilience critique of growth and Tainter's (1988) warning about diminishing returns from complexity. Ecological economists believe we should stop growing before we reach maximum sustainable scale at the point called optimum desirable scale, when the diminishing marginal utility of growth equals the increasing marginal harm each unit of growth causes through greater pollution and resource depletion. This is the point where the benefits of economic growth balance the environmental costs and where the happiness/utility of society is maximized.

In spite of these theoretical agreements, it is not clear cut whether increasing growth and complexity are always detrimental to economic resilience. The fact that the only modern examples of failed (collapsed) states are in the third world suggests that the technological advancement and wealth bestowed by growth, as well as the better relations with the international community and support network this provides, do confer up to a certain point some element of added resilience missing from the poorest nations of the world. However, it could very well be that the inequity that characterizes nations like Sudan and Somalia, and their historical lack of well established economic, legal, environmental and governance institutions, has as much to do with their vulnerability to shocks and lack of coping capacity as their relative lack of material growth compared to the current global mean. Examples such as Cuba show that a nation can be resilient even with below average wealth.

Indeed, civilizations like Egypt and China that persisted for millennia managed to do so without modern levels of economic growth or complexity. At the same time, civilizations like Rome that collapsed in Tainter's (1988) view due to overinvestment in complexity were actually much less technologically complex than our own global civilization, which has yet to collapse. This suggests that better technology can perhaps push back the boundaries of diminishing returns, although Tainter (1988, 215) warns: "Technological innovation and increasing productivity can forestall declining marginal returns only so long. A new energy subsidy will at some point be essential". This raises the question of whether long term sustainability is ever truly achievable.

Redman and Kinzig (2003, 6) wonder:

> has the long-term, worldwide growth of complex society come at a significant cost to the overall resilience of society? Although theoretical considerations would answer that question in the affirmative, 10,000 years of history say that increasing social and political complexity demonstrate the 'success,' or at least the popularity, of such a trajectory. Are our theoretical formulations incorrect? Can one substitute one reservoir of resilience (flexibility) for another (efficiency)? Or are we mistaking longevity for resilience?

Homer-Dixon (2010 Manion lecture) believes that complexity and diversity (and by extension resilience) can be positively linked: "Complexity is also often a source of innovation. Because a lot of innovation occurs when you bring together things that would not otherwise be combined. And you get novel combinations that are unexpected." The relationship between the complexity, diversity, stability and resilience of natural systems has long been a debate in ecology (Brock et al. 2002, 271). Underwood (1998, 521) writes that "Natural systems have evolved to provide stability through complexity. Complexity serves to provide redundancies so that perturbations are corrected by successive buffers”. This understanding seems to contradict Tainter’s correlation between over-investing in complexity and collapse in human systems.

The analogy of the climax forest (a highly complex system in the conservation phase of the adaptive cycle) provides evidence to support both hypotheses on the relationship between complexity and diversity. The dominant organisms, especially the trees themselves, are certainly no longer diverse in such complex systems: in a maple beech forest, two species have become skilled at using up most available energy and pushing out competitors. The lack of tree diversity has in turn left the whole ecosystem more vulnerable to a single disease, insect or fire. On the other hand, the proliferation of highly complex animals and plants at smaller scales of a climax ecosystem provide seeds of novelty and future diversity that the system can draw on later during its reorganization phase.

In the same way, the technological and information complexity of the modern world may provide a diversity of ideas that are important seeds for future economic transformation. Thus, Redman and Kinzig (2003) conclude that because systems are continually changing, resilience must include some capacity for learning and restructuring that requires increased organizational complexity. Yet, “This points to a second paradox, which is that resorting to increased social complexity to resolve problems seems to work in the short run while sometimes undermining the ability to solve them in the long term” (Redman and Kinzig 2003, 5). Since complexity is also a function of efficiency as well as scale, section 5.2.1 further discusses the relationship between resilience, complexity and diversity.

Some like Bjorn Lomborg who initially denied the severity of the problem of climate change and environmental limits are now using the more subtle argument that we cannot afford to scale back economic growth because we need as much wealth as possible to adapt to coming climate change. This would imply a tension between staying within sustainable scale and having the wealth available to build economic resilience. This line of reasoning is flawed however, because as scale increases, “it just keeps gettin’ hotter”. In other words there may be no point where we have unleashed as much climate change as possible – the more growth and consumption, the more severe the environmental resource stresses we may face. In fact, society may lack economic resilience not because of too little economic growth, but because of too much, leading to harmful forms of complexity, a lack of dispersity and autarky and depletion of scarce resources and environmental services.

"In general, the greater the number and severity of stresses affecting a society – and the more they combine synergistically – the greater the chance of social breakdown" (Homer-Dixon 2006, 111). Limiting the degree to which we overshoot maximum sustainable scale will thus aid resilience by limiting the number and magnitude of converging shocks we will face and simultaneously have to recover from. This is not about 100% prevention which is impossible, but instead minimizing the worst of the inevitable impacts we must adapt to: "complex systems are not confined to historical experience. Events of any size are possible, and limited only by the scale of the system itself. Since we have scaled the system to unprecedented size, we should expect catastrophes of unprecedented size as well" (Rickards 2008).

Likewise the longer breakdowns continue, the more society's resilience will degrade as resources run out and economic relationships and social norms fall apart: "A society overloaded with stresses breaks down" (Homer-Dixon 2006, 110). Indeed, "If the growth phase goes on for too long, 'deep collapse' – something like synchronous failure – eventually occurs. Collapse in this case is so catastrophic and cascades across so many physical and social boundaries that the system's ability to regenerate itself is lost" (Homer-Dixon 2006, 253). A system may even lose its memory and ability to transform.

We must therefore be wary of having the climate change agenda hijacked by adaptationists like Lomborg (2009), because "Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs" (IPCC 2007, 4). Lele (1998, 251) summarizes this relationship between scale and resilience:

> if the perturbation is anthropogenic (such as net CO2 emissions) and clearly of significant magnitude, then, regardless of the exact nature of the system and one's distance from equilibrium or the edge of the stability domain, reducing the perturbing force (stopping the burning of fossil fuels) is clearly one (and probably the best) means of reducing the chances of a disastrous domain shift (say in the climate system), even though this does not really constitute an increase in system resilience.

Even countries that have not exceeded their local maximum sustainable scale can increase their resilience by continuing to control their own scale because events like global climate change may put sudden pressures on the carrying capacity of their own environment such that they are suddenly at or exceeding maximum sustainable scale even though their economy has not grown. As ecological economists advocate, seeking to reduce human consumption and population will open up slack.

Heinberg (2003, 32) argues that a great deal of the earth's population growth in the modern era has been possible only because we have been unsustainably drawing down our fossil fuel supply, and that "When the flow of fuels begins to diminish, everyone might actually be worse off than they would have been had those fuels never been discovered because our pre-industrial survival skills will have been lost and there will be an intense competition for food and water among members of the now-unsupportable population". In this sense, ecological economists' desire to control population growth would help resilience by reducing the number of individual actors competing (possibly lethally) for limited resources during a breakdown situation. The downside is there would also be fewer minds available to think up innovative adaptation solutions and less hands to put them into practice.

Sustainable scale is also compatible with resilience insofar as preserving natural features can help provide redundant backups to human infrastructure. For example the depletion of wetlands around New Orleans reduced local capacity to buffer flooding. Protecting natural areas is also important to adaptability: Folke et al. (2003, 361) note the possibility of "Conserving patches in the landscape to serve as emergency resource supply in the face of change". The more resilience we have in some ecological systems, the more natural capital we will have to draw upon during a breakdown or catastrophe. More ecologically sound bioregions means greater availability of clean air, water, and soil to grow food locally if necessary, enhancing autarky and dispersity. Lastly, the quality of the natural environment can aid long term transformability: "if anthropogenic environmental degradation was a causal factor in collapse, then environmental recovery during periods of decentralization could also be instrumental to regeneration, given the reappearance of natural resources important for the reestablishment of societal complexity" (Schwartz and Nichols 2006, 11).

Interestingly, the actual tools that ecological economists recommend using to achieve optimum desirable scale may be somewhat theoretically inconsistent with resilience. Staying within scale based on traditional incremental management approaches to solving environmental problems inherently leads to greater complexity of institutions and technologies: "as the world economy expands relative to the size of the Earth's resource base and biosphere, we have to use resources and energy far more efficiently and manage our interactions with nature with ever greater care – and this means progressively more elaborate technologies, procedures, regulations, and institutions" (Homer-Dixon 2006, 251). Accordingly, otherwise excellent policies proposed by ecological economists to control scale, including efficient market-based cap and trade systems and Pigouvian taxes, may simply add another burdensome layer of complexity to an already brittle socioeconomic system (Tainter 1996). We should still go ahead with such measures because just as internalizing prices would help resolve the efficiency/resilience tension (see next section), efforts to make market prices reflect scale can help resolve the now common tradeoff between profit and environmental protection. We must just be aware there is also a hidden resilience cost to adding still further complexity to our system, even for legitimate environmental ends. Another implication is response options should be expanded beyond regulatory and market mechanisms to include a broader set of governance tools to engage more players and mobilize social change.

Likewise, pursuing sustainable scale too rigorously could cause problems for our civilization because of the way our economy is structurally reliant on growth: "For some human societies, stability (in the sense of peace and prosperity) is assured only by continued growth. Zero growth does not then represent a stable state, and negative growth can accelerate to disintegration" (Renfrew 1979, 489). This raises a troubling question: if our economy stops growing like Rome's did, will we too implode? Renfrew (1979, 489) suggests that "If a society is to adjust to zero growth after a prolonged period of positive growth, it must disconnect the positive feedback loops which made that growth possible". Otherwise, these same feedback loops can just as easily turn minor negative growth events into economic catastrophes. This entails decoupling material and energy growth from economic development.

Certainly economic growth can give us wealth and technological capacity that can help us to buffer change, but it also simultaneously makes us more vulnerable. This leads to an arms race where growth-oriented economies struggle to develop more elaborate and more effective knowledge and capital to deal with the increasing shocks and breakdowns that afflict such a society positioned far from thermodynamic equilibrium and high on the adaptive cycle. Past a certain point, diminishing returns from growth and complexity make it a losing long term strategy. Indeed, today "we find ourselves in a social system that knows only how to grow, and that would rather violently explode than deliberately contract" (Heinberg 2004, 171). Because we are entering a period of extreme, unfamiliar uncertainty where environmental resource shocks seem inevitable, we cannot prevent or manage them through scale alone, and so must start designing for economic resilience as well: "if we want to thrive, we need to move from a growth imperative to a resilience imperative" (Homer-Dixon 2006, 308). This leads to the next related question.

5.1.2 Does the pursuit of resilience enhance or undermine sustainable scale?

Again, the answer is complex, and depends on whether one is considering a pre-breakdown or post-breakdown world. On one hand, Homer-Dixon (2007 interview) thinks resilience comes more at the cost of scale than efficiency, implying we are going to have to purchase resilience at the cost of scale. This would hold true if resilience and efficiency are not compatible as well. To start building resilience principles such as redundancy and diversity into our economy will require new goods to be produced. This could have the net effect of increasing scale, paradoxically hastening the number and severity of environmental resource shocks we will face, unless we are willing to stop producing other, less resilient goods. This for example will mean manufacturing more basic durable goods like human powered hand tools and less luxury consumer goods like automobiles (Heinberg 2007, 177).

In this sense, pursuing economic resilience could undermine sustainable scale in that it either requires that scale be increased, or that a much greater proportion of society's existing scale be set aside for resilience measures. The latter would face significant political challenges, making ecological economist's goal of reducing scale on other fronts that much harder to achieve. Hence the aggressive pursuit of economic resilience will demand sacrifice in our traditional consumer lifestyle if we are to also meet the sustainable scale goal. The more resilience we want, the smaller scale we may be allowed for a given level of throughput based welfare. This is because having to build resilience principles such as redundancy into the economy would increase the marginal costs of all growth such that desirable/optimum scale (where marginal benefit equals marginal cost) would move even further to the left of maximum sustainable scale (i.e. at optimum scale we'd enjoy less benefit from consumption than if we had not tried to integrate resilience).

This raises the difficult question: if we are right now exceeding the planet's sustainable scale despite having little resilience built into our economy, is it better to exceed scale a lot and build in resilience, or should we try to stay within scale and forsake resilience? Or should we try to both stay within scale and build in significant resilience (asking major demands of the consumer public that may make such an approach politically unfeasible, despite increasing leverage as breakdowns get worse)? The third option seems like the most prudent approach: despite the political challenges, building in any amount of economic resilience would be preferable to almost no resilience, no matter the cost, especially since many shocks like global warming are now virtually inevitable anyway. Resilience measures that have low material or energy demands would be a good place to start.

The flip side of the question is whether building in resilience will be good for environmental sustainability in a post-breakdown world. The answer is most certainly yes. What would be the impact of breakdowns on sustainable scale in our society? On one hand they would dramatically alter our consumer lifestyle and business-as-usual energy habits which are destroying ecosystems around the world. An economic catastrophe could be good for the natural environment in many ways: pollution levels for example might dramatically fall (i.e. witness the clear skies seen on satellite imagery following great blackout of 2003). On the other hand, an unresilient economic system in breakdown mode could also be profoundly damaging to the earth's biosphere. Without electricity for example, many chemical factories would be unable to keep gases cooled in liquid form and tanks would start venting by the thousands into the environment (Weisman 2007).

A global economic crash would also wreck havoc on world ecosystems as billions of people try to sustain themselves on local fauna and refugees strip the countryside as they move (Anonymous interviewee 2007). Indeed, Heinberg (2003, 181) predicts that "As the global food system struggles to come to terms with the decline in available net energy for agriculture, transportation and food storage, people who have the capacity to fish or to hunt wild animals will be motivated to do so at increasing rates". What remains of conservation agencies would be hard-pressed to stop this, so "Endangered species will have fewer protections available and extinction rates will likely climb" (Heinberg 2003, 181). Freezing, starving people would likely burn anything to survive: from forests (releasing carbon and degrading ecosystems) to garbage dumps (releasing PCBs, dioxins and heavy metals). So preventing a complete societal breakdown is necessary if we want to preserve what's left of our wild environment.

Indeed Heinberg sees catastrophes as periods where sustainable scale is no longer necessarily maintained in systems: "While population levels among species in climax ecosystems are relatively balanced and stable, populations in disturbed or colonized ecosystems go through dramatic swings" (Heinberg 2003, 18). When considering the effect on human population growth of a breakdown, a power blackout might result in a spike in the conception of new children (people with nothing else to do resort to biological urges). So in this case, keeping the lights on through economic resilience can actually be good for the environment. Ultimately, in a post-catastrophe situation, society may need to scale down quickly in order for people to survive on the fewer remaining resources (i.e. rationing would need to be instituted), in which case pursuing the resilience and scale goals almost become one and the same.

Even smaller scale economic breakdowns can work against initiatives to control scale. In Australia, some of the federal government programs cut to help pay for cleanup of their 2011 earthquake were environmental initiatives for greener cars and carbon capture and storage. By reducing the economic costs from breakdowns, resilience can help ensure that funding for other important environmental programs is preserved.

Consideration of resilience could also help ecological economists win their academic and political battle against unrestrained economic growth by giving them a new argument in their arsenal. Not only can growth not continue forever due to environmental limits as ecological economics has long recognized, economic resilience adds the key insight that it cannot continue because it makes the system increasingly susceptible to destabilizing breakdowns. As we grow we generally lose redundancy, diversity, dispersity, autarky, adaptive capacity and transformability in favour of efficiency, homogeneity, centralization, interconnectivity, complacency, and undesirable rigidity (entrenched practices and beliefs that resist rational change). Resilience thus provides ecological economists with a fresh new complimentary critique of growth, and for this reason most of all it is compatible with the sustainable scale goal. Including economic resilience alongside sustainable scale in a joint unified explanation of why excessive growth is bad will strengthen the validity, and hopefully political impact, of the overall anti-growth argument.

Global society presently believes economic growth is the solution to nearly all of its problems, even environmental ones (i.e. the Kuznet's curve hypothesis). Our utter addiction to economic growth (exceeding our addiction to oil) is the main reason we find it so profoundly difficult to stay within sustainable scale and fight climate change: "As long as modern societies need economic growth in order to stave off collapse (as is clearly the case today, given existing debt-and-interest-based national currencies), we will continue to require ever more resources on a yearly basis from our already overtaxed earthly environment" (Heinberg 2004, 132).

However, if society could be persuaded to adopt resilience principles and use them as an alternative guide to confronting its imminent challenges, economic growth might cease to be so deathly important, making sustainable scale easier to achieve for ecological economists. Philosophically, adopting resilience provides an alternative frame of mind and direction for society that will help us to get over our obsession with growth: "Growth, even in already obscenely rich societies, is sacrosanct. This central value won't really change until it's discredited by some kind of major shock, which probably means some kind of system breakdown. Then, alternative values that are centred on the idea of resilience might flower, not just at the fringes of our societies, but also at their core" (Homer-Dixon 2006, 305).

One final dynamic worth noting is that unsustainable behaviours such as capitalism's pursuit of exponential growth and the consumption and production habits that underlie it, can themselves be resilient to change. In these instances of undesirable resilience we may actually wish for a catastrophe (hopefully only a political or moral one) to help flip attitudes, behaviours and industrial practices onto a new, more sustainable trajectory.

5.2 Resilience and Efficient Allocation

The potential tradeoffs implied by the relationship between resilience and efficiency is one of the key issues addressed in this paper. Ecological economists carry over the efficiency goal from conventional (neoclassical) economics. Herman Daly and others are often critical of the single-minded importance efficiency receives in that discipline and so for their purposes rank it third priority after scale and distribution. Nevertheless they still seek to achieve these other two goals in least cost ways – that is, ways that are least detrimental to allocative efficiency (Lawn 2007 interview). Market-based policies like cap and trade and Pigouvian environmental taxes are some ways this could be achieved.

What exactly do we mean by efficiency? Efficient means are assumed to lead to ends in which some or all are better off with no one being worse off, a state called Pareto optimality (Commons and Stagl 2005, 310). Efficiency is an umbrella term for several concepts which are not always clearly spelled out in economic literature. One type of efficiency is technical efficiency which is about maximizing the amount of physical output from a given amount of resource input, for example more efficient car engines (Perman et al. 2003, 3). The second major type is allocative (economic) efficiency, which strives to allocate society's resources so they maximize societal welfare (net benefits) as defined by their aggregated preferences. In other words, this means trying to meet society's preferences as accurately as possible by using the lowest cost methods, or redirecting resources from low value to high value uses (Daly 2003). This type of efficiency is the main concern of economists. Daly and Farley (2004) also include distribution efficiency, but this is not commonly recognized by other economists and so will be discussed in the just distribution section below.

5.2.1 Does the pursuit of efficient allocation enhance or undermine resilience?

Pursuing efficiency is more likely than not to undermine resilience, especially when resilience is absent as a criterion in economic decision making, as has been the case since the rise of modern economics. The great breakthrough of (neo)classical economics was in the use of semi-scientific methods to aggressively pursue allocative efficiency (the "best" way of doing things) and thereby cut away "wasteful" diversity, dispersity, redundancy and autarky: "During periods of gradual or incremental change, many important sources of resilience may be unrecognized or dismissed as inefficient or irrelevant. Typically, therefore, components of resilience are allowed to decline or are deliberately eliminated because their importance is not appreciated until a crisis occurs" (Adger et al. 2005, 1037). However, "What we're calling an efficient economy is one that is actually externalizing huge amounts of costs" (Homer-Dixon 2007 interview).

The first, perhaps most basic way that efficiency has been achieved since the dawn of civilization is through the geographic centralization of important economic and administrative functions: "When we build larger factories, we generally lower cost per unit of output, and when we concentrate expensive equipment and highly skilled people in one place, we can access and use them more easily and efficiently" (Homer-Dixon 2006, 120). This may lead to beneficial economies of scale and efficient centralized decision making and market exchange with a minimum of transaction costs. Homer-Dixon (2006) also warns, however, that putting so many critical economic components all in one place dramatically increases their vulnerability to a random or deliberate disruption as vividly demonstrated by the September 11 World Trade Center attack and other disasters. Centralization therefore undermines the dispersity principle of economic resilience.

Second, as an extension of centralization, efficiency promotes connectivity in every aspect of the economy as we demand that our systems function with ever greater speed and volume: "Markets are sensitive and highly coupled now that we have global twenty-four-hour trading, global product interdependency, and just-in-time supplies" (Perrow 1999, 403). Lovins and Lovins (2001, 201) note that "Many oil refineries are in fact very 'tightly coupled' because some narrow-minded accountant wants more 'efficiency' in keeping the oil moving, rather than letting it sit in storage between stages. But this greatly increases technical and financial vulnerability to any mishap."

Indeed our economy is now based on wringing out more and more efficiencies from a (supposedly) reliable and integrated system. This might not be so worrisome if we have time to adapt to changes. Greer (2008, 27) for example claims that "Gradual disintegration, not sudden catastrophic collapse, is the way civilizations end". Homer-Dixon however disagrees with Greer's (2008), Diamond's (2005) and Kunstler's (2006) "Long Emergency" type hypotheses: "by today's standards, almost everything happened far more slowly in Roman times…The underlying mechanisms may be the same – a combination of accumulated stresses, weakened resilience, and multiple shocks. But today our global social, technological, and ecological systems are so tightly linked together, and they now operate at such velocity, that the duration of any future breakdown or collapse is likely to be dramatically compressed" (2006, 124).

This tight coupling and interdependence, encouraged by free trade policies, has hollowed out local economies around the world and undermined the autarky of economic units within the system. Multiple parallel failures have been considered too remote and expensive to plan for, so production pressures are leading to systems being pushed harder and safety measures and slack removed (Perrow 1999, 379, 400). Thus, "as human societies' connectivity and speed increase, social breakdown, when it does happen, generally happens faster" (Homer-Dixon 2006, 127). Harmful feedback loops can reinforce instabilities, such as a stock market crash where fear leads to selling of shares, and even more fear. This is analogous to tightly connected food webs in climax ecosystems: if one species cannot adapt to environmental change it may drag all those dependent on it down with it.

Nevertheless, Homer-Dixon (2010 Manion Lecture) also believes there may in fact be a U-shaped relationship between connectivity and resilience: up to a certain point connectivity can improve resilience by enhancing the diversity of connections in an economy so it can fall back on external support when needed. Some degree of connectivity is also necessary for dispersity of scale. However, after a certain mid-range point, coupling starts degrading autarky by making systems too reliant on one another and allowing synchronous failures to spread. Lele (1998, 252) argues autarky may require some slack capacity that can remain unplugged and hence unaffected by shocks to the larger system, but that "Exploiting all opportunities for mutual gain may in fact reduce resilience by leaving no such slack".

Indeed, a third way efficiency is commonly achieved is through streamlining and cutting away supposedly unneeded redundancies. This means dispensing with duplication, stockpiles and reserves in favour of just-in-time production, and replacing expert personnel with computers and robots (Rochlin 1997, 183). The literature has much to say about this practice: "Of particular concern is the degree to which what is destroyed or discarded in the relentless pursuit of technical and operational efficiency is not waste or slop, but "slack," the human and material buffering capacity that allows organizations and social systems to absorb unpredicted, and often unpredictable, shocks" (Rochlin 1997, 213).

In fact, "Systems that are highly efficient are not necessarily also effective—they often reduce redundancies for purposes of cost savings, and as a consequence become brittle and unstable and may collapse when faced by unanticipated changes in their environment" (Ruth 2006, 337). Removal of redundancies has also extended to the merging of companies themselves. Homer-Dixon (2010 Manion Lecutre) observes: "Two companies make all large jet liners. Three companies make all jet engines. Four companies make 95% of microprocessors in the world. Three companies sell 60% of all tires. Two manufacturers in the world press 66% of all the world's glass bottles. One company in Germany produces the machines that are used to make 80% of the world's spark plugs." Unfortunately, "The drive towards more efficient supply networks during recent years has resulted in these networks becoming more vulnerable to disruption. In particular, there often tends to be very little inventory in the system to 'buffer' interruptions in supply and, therefore, any disruptions can have a rapid impact across the supply networks" (Chapman 2002, 59).

Lovins and Lovins (2001) argue that having buffer storage allows failures to occur gradually rather than abruptly. They observe that in the name of efficiency the British car industry holds such small buffer stocks of steel that it frequently suffers shut downs: "This is as false an economy as it would be for a hibernating bear to store exactly enough fat to see it through to the *average* date on which its spring food supply would become available" (Lovins and Lovins 2001, 201).

Christopher and Peck (2004, 16) believe there is a need for businesses to:

> Re-examine the 'efficiency vs. redundancy' trade off. Conventionally surplus capacity and inventory have been seen only as 'waste' and are therefore undesirable. However, the strategic disposition of additional capacity and/or inventory at potential 'pinch points' can be extremely beneficial in the creation of resilience within the supply chain. The trade-offs inevitably involve the judgemental balancing of the cost handicap involved in maintaining slack 'just-in-case', against the probability and likely impact of a negative event.

A fourth way to pursue economic efficiencies is through specialization, particularly of the labour supply: "It is the fact that agents are limited both in their physical and in their mental abilities that leads to the need for specialization: specialization in turn leads to the need for organization, that is, the co-ordination of agents' activities" (Magill and Quinzii 1996, 9). Indeed a high level of job specialization is the hallmark of a complex civilization. Built up social institutions like money allow for increasingly specialised occupations ranging from merchants to artisans to priests who are in turn entirely dependent on others for their essential livelihood. A civilization that comes to rely on the specialization of crops and labour is very effective at increasing yields and population under a small range of conditions, "but in the face of sustained changes it may simply collapse" because each family or village can no longer support itself (Renfrew 1979, 488).

Similarly, citizens in industrialized economies have certainly been able to attain a tremendous standard of living thanks to Adam Smith's idea of the efficient division of labour. Our economy is like an ecosystem in the sense that we, as specialized actors, have chosen to become dependent on one another because it bestows increased efficiency benefits for our own finances and for the overall economy (Heinberg 2003, 26). However, “At face value, there is at least a significant tension between the ecosystem principle of diversification and the economic principle of specialization” (Gale 2000, 289).

Because of our inextricable interdependency we have lost our individual autarky, the ability to look after ourselves at a fundamental level: “With a lifelong division of labour, many members of society became cut off from basic subsistence activities and processes; rather than enjoying a direct relationship with the natural world, they became, for their material existence, dependent upon the society’s economic distribution system” (Heinberg 2003, 27). Specialization in our increasingly service/information based economy has led to most people being trained only as white collar workers with no practical skills (carpentry etc.) needed for survival, which compromises both individual’s and society’s adaptive capacity.

Moreover, extreme specialization of entire societies, as particularly advocated for in economic theories about trade, also violates diversity by reducing the opportunity for each individual to become experienced in a wide variety of occupational activities. Nicolescu (1999, 5) therefore believes that “in our tumultuous world… any life which is frozen into one and the same occupation can be dangerous, because it risks leading to unemployment, to exclusion, to a debilitating alienation. Excessive specialization should be outlawed in a world that is in rapid change”.

Fifth, in part through the combined processes of centralization, connectivity, and specialization, efficiency is also an enabler and driver of complexity in civilizations. Tainter (1996) notes that investments in complexity require increasing the per capita supply of energy - either by increasing the physical supply of energy (scale) or technical, political and economic innovations that lower the energy cost of living (efficiency). Therefore, complexity is likely a function of both scale and efficiency. Redman and Kinzig (2003, 5) agree that:

> Efficient behaviors, such as specialization, reduction of redundancy, and streamlining of connectivity, allow a system to produce more at a lower cost of labor, materials, and energy and... allow a system to create and accumulate a surplus beyond its direct consumption needs and hence enable the concentration of power or the storage of capital... It is this ability to accumulate a productive surplus that is a necessary, although not always sufficient, condition for the emergence of complex society.

While at first, a storehouse of reserves can increase resilience, “As systems become more complex, they usually channel as much productivity as possible to current operation, minimizing inefficiencies or redundancies in the process. This requires the system to maximize power (energy) output to support the emergent complex organization, but it does so by giving up significant adaptive capacity in other aspects of the system" (Redman and Kinzig 2003, 6). Matutinovic (2001, 241) likewise observes that: "More complex societies necessarily imply higher per capita energy consumption than organically simpler societies, and consequently put more strain on resources and environmental sinks". This is partly because of the rebound effect (Jevon's paradox): efficiencies can actually encourage greater overall net consumption. As our technology becomes more complex, the odds of breakdown increase (Perrow 1999).

Lovins and Lovins (2001, 202) do hint that efficiency measures like streamlining can sometimes reduce complexity: "Some designs achieve 'forgivingness' through simplicity—the elegantly economical use of limited means". They note though that the downside of simplification through standardization is it "foregoes the benefits of diversity" (Lovins and Lovins 2001, 198). Thus while efficiency can reduce the complexity of one element in a system, the same measure may increase the complexity of the overall system. Indeed, while complexity can provide opportunities for diversity as discussed in section 5.1.1, it can also indirectly threaten it. Part of what compels complexity to exist in the first place in the economy is efficiency (e.g.. specialization increases the number of system interactions and dependencies), but as discussed efficiency also frequently tries to trim diversity in both human and natural systems (e.g. by homogenizing production methods). Therefore the evolution of efficiency, complexity and diversity in the modern economy seems a bit like a competitive game of rock, paper scissors where the final impact on resilience remains quite uncertain.

Finally, pursuing efficiency too far can weaken society's adaptive capacity and transformability. King (1995, 979) argues that "institutional analysis should not unduly emphasize efficiency as the criteria for institutional selection. Perhaps efficient institutions, like efficient species, may create critical instability, which in turn raises their vulnerability to destruction". In terms of their governance structures, "Complex societies are often characterized by overcentralization and organizational rigidity, which may render them vulnerable in times of social or environmental stress" (Schwartz and Nichols 2006, 11).

Efficiency can also hurt adaptive capacity by reducing intellectual creativity, as demonstrated by economists, business leaders and policymakers who stick too closely to orthodox theories, the current dominant paradigm, and the mantra of doing only what the book says is efficient: “Strict adherence to apparently optimal policies suppresses experimentation by preventing potentially informative probing” (Carpenter et al, 2002, 193). Indeed, “accumulated increases in wealth and efficiency also combine with an increased narrowness of view and a rigidity that make it difficult to agree on how to respond differently to new challenges” (Holling 2004, 6). This may explain the slow pace at which society has responded to our increasingly precarious environmental situation. Likewise rigid pursuit of efficiency can be bad for the diversity of ideas and cultures needed for future transformability after a catastrophe. In the name of homogenous efficiency, “The industrial interval has shredded traditional cultures and replaced them with a global consumer spectacle. Once the latter is gone, the survivors of its demise will run the risk of becoming cultureless wraiths condemned to subsist on decaying memories of what life was like before the great crash, but with few living traditions to guide them” (Heinberg 2004, 141).

Homer-Dixon (2006, 252) summarizes some of the primary hidden resilience costs of an efficiency-first agenda: “Capitalism’s constant pressure on companies to maximize efficiency tightens links between producers and suppliers; reduces slack, buffering, and redundancy; and so makes cascading failures more likely and damaging. As well, capitalism’s pressure on people to be more productive and efficient drives them to acquire hyperspecialized skills and knowledge, which means they becomes less autonomous, more dependent on other specialized people and technologies, and ultimately more vulnerable to shocks”. Rees (2007 interview) concludes that efficiency and resilience are “absolutely opposed”.

Yet, Redman and Kinzig (2003, 5) remind us that historically, “Individual cities, societies, and civilizations may have disappeared, but the longevity of the human experiment with efficiency, complexification, and stratification suggests that this is a strategy with significant staying power.” Indeed there is additional evidence that the drive for efficiency is not completely at odds with economic resilience. The key efficiency criteria of markets, their ability to self-adjust to change independent of information known to any single actors, helps to increase their dispersity and adaptive capacity relative to more centralized institutions like governments (Rose 2004, 52). At the firm level, improving efficiency by preventing an inefficient firm from persisting may improve overall economic resilience because it opens up new opportunities for transformation (i.e. Schumpter’s creative destruction) (Farley 2007 interview). Levin et al. (1998, 227) explain further:

> Companies that live in a very stable, protected environment will not have incentives to develop the flexibility and competitiveness that would be needed if a major shock were to hit the market. Companies that always have to fight for survival develop resilience much more fully, partly by the necessity to increase productivity. It is striking the degree to which such theories of economic resilience parallel concepts in evolutionary biology, in which similar tradeoffs have been deeply explored.

Likewise, cutting economic subsidies to certain sectors can be good for both efficiency and adaptive capacity: "The capacity to self-organize emerged from our studies as a critical source of resilience. Although rebuilding this capacity at times requires access to external resources, excessive subsidization can reduce the capacity to self-organize" (Abel et al, 2006, 1).

Technical efficiency is also certainly compatible with economic resilience: if we are more efficient with our natural resources, we will have more to work with (more natural capacity) when shocks hit. Technically efficient technologies like hybrid cars or more efficient microchips can be considered resilient so long as redundancies in the technology are not removed to achieve this efficiency. Technical and allocation efficiency can also provide us with more built capital giving us a greater material capacity to respond to breakdowns when they occur (Holling et al. 2004, 11). This is examined further in section 6.6 on the Emergency Response System. Of course more built capital also increases complexity, and during a breakdown situation the usefulness of built capital will degrade due to lack of maintenance. As explored in the scale section, efficient uses of nature's resources also helps to keep us within sustainable scale, either preventing or delaying shocks or limiting their severity.

Daly and Farley (2004) argue for a Comprehensive Efficiency Identity, which is the ratio of the psychic services (in other words, welfare) gained from human made capital to the services sacrificed from natural capital. Unfortunately economic resilience is incompatible with this definition of efficiency (and also with a definition focused on satisfying consumer preferences) if people do not get any perceived short term satisfaction (or even long term peace of mind) from added resilience. So long as the public remains ignorant about the need for economic resilience (and is unwilling to pay for it) and/or we define welfare narrowly over the short term, according to this criterion we would be sacrificing natural capital for no perceived increase in welfare. Of course, once a shock hits, the consumer public may change its mind very quickly about the benefits of resilience (all of a sudden, simply having a litre of potable water and a good meal will give high utility), but by then it may be too late to avoid catastrophe. To reconcile this tradeoff, people would need to start including the long term survival of their civilization in their daily level of psychic satisfaction/welfare so that it becomes efficient to build in resilience. Homer-Dixon's (2006) idea of developing a prospective mind might be of help here.

The most striking aspect of neoclassical economics is the degree to which it prioritizes a narrowly defined understanding of efficiency over all other goals. Tightly connected trade, streamlining, and specialization are all part and parcel of the creation of the modern consumer economy, with its focus on short term wealth maximization. Maximizing efficiency does not directly cause environmental resource shocks (exceeding sustainable scale is to blame for this), but efficiency may make any resulting breakdowns in our economy more severe. Renfrew (1979, 489) notes that when the strategy of efficiency and specialization seems to be failing in the face of change, human civilizations have tended to respond by working even more intensively at becoming efficient. This amounts to running on an out of control treadmill rather than attempting to get off. If we hope to have any resilience left in our economy, it is time to re-evaluate our understanding of the proper balance of efficiency with other goals.

Lovins and Lovins (2001, 183, 188) for example conclude that ecosystems:

> do not attain the absolute pinnacle of biological efficiency in capturing the energy available from their environment. But by avoiding the extreme specialization this would require, they also avoid the risk of reducing their margin of adaptability to environmental change… Imitating the strategy of successfully resilient ecosystems, then, may not wring out the last ounce of "efficiency" or attain the acme of specialization that might be optimal in a surprise-free world. But in a world of uncertainty, imperfect knowledge, and constant change, such 'efficiency,' with no slack for adaptations, can be deadly.

Similarly, in their modelling of ecosystems, Kristensen et al. (2003, 70) found that organisms in nature do not maximize their individual efficiency, but instead may sacrifice some to boost the resilience of the whole system.

Because of the complex dynamics inherent in systems, optimal management (i.e. for efficiency) is nearly impossible in any event (Colding et al. 2002, 17). Farley (2007 interview) believes "striving to 'optimize' for one objective is absurd". Likewise Ehrlich (2008, 5) writes: "In short, there is no reason to assume that economic plans should always attempt to maximize either efficiency or production as usually conceived. There is nothing wrong with the notion of maximization (or efficiency) per se, but the problem is that in practice too often critical variables such as resilience and externalities are omitted from the calculations". In the past when they could not rely on long-distance aid in times of crisis, “social groupings of any size or character had to give greater attention to preserving resilience and to keeping options open than to maximizing their advantages or well being at a given moment” (Adams 1988, 21).

Unfortunately, “Few organizations question the doctrine of optimization. But optimizing a business model that is slowly becoming irrelevant can’t secure a company’s future” (Hamel and Valikangas 2003, 3). In the same way, it does no good to optimize an economic system that is fundamentally unresilient because it ultimately has no long term future. Homer-Dixon (2006, 284) concludes: “in an increasingly uncertain and dangerous world, we should sometimes give up extra efficiency and productivity in order to gain resilience – especially to improve our ability to prevent foreshocks from triggering synchronous failure”. This ties in nicely with ecological economist’s inherent wariness of the neoclassical pursuit of growth at the expense of all other considerations.

Next we will examine the inverse question: is it possible to make an economy founded on specialization, trade, efficiency, and the removal of redundancy, resilient? If we start investing in economic resilience, will this begin reducing the beneficial efficiency we have achieved up to this point?

5.2.2 Does the pursuit of resilience enhance or undermine efficient allocation?

In short, it has the potential to do both, depending on whether efficiency is defined narrowly or more holistically: “The tradeoff between efficiency and resilience is not straightforward by any means” (Homer-Dixon 2007 interview). On one hand, building in redundancies reduces opportunities for streamlining, pursuing dispersity reduces opportunities for economies of scale, striving for autarky reduces opportunities for trade and pursuing diversity reduces opportunities for specialization. This implies less consumer utility derived per unit of natural resource. Since there is a potential cost to resilience, trying to build in resilience while maintaining current levels of consumption and associated utility would require the economy to scale up, hastening or increasing environmental resource shocks.

Indeed, markets themselves are a pillar of robustness in that our civilization has become totally dependent on them as the mechanism for distributing goods. We could not simply get rid of markets overnight, as some on the political Left used to favour, and expect our civilization not to crumble. Some environmental literature promotes diversity, resilience and localism in social systems with seemingly little consideration for the consequences of foregoing the benefits of efficiency and trade. For example, Jacobs (2000, 106) claims that Smith "led himself and others astray by declaring that economic specialization of regions and nations was more efficient than economic diversification". She believes specialization undermines the creation of co-development webs which lead to innovation.

And yet, if ecological economists could successfully internalize environmental costs into the prices of goods and services, it is possible that the market could take care of the economic resilience problem itself and the tradeoff between efficiency and resilience would effectively disappear. For example, increasing the price of oil would boost autarky by making long distance trade more expensive while also encouraging a diversification of alternative technologies. "If you get the prices right and the market clears efficiently in terms of supply and demand reaching some kind of equilibrium, you might be able to have your efficiency and your resilience at the same time" (Homer-Dixon 2007 interview).

Perrow (1999, 341) notes that high risks to society can rightly be thought of as an externality. The benefits conferred by economic resilience are therefore positive externalities and because it has non-rival and non-excludable characteristics, resilience is fundamentally a public good. This means the market will not naturally provide resilience without government intervention in some form. Therefore, perhaps "In our efforts to build resilience into the system, it looks like we're creating inefficiencies, but actually what we are doing is adjusting for external costs that haven't been incorporated into the prices of the goods and services" (Homer-Dixon 2007 interview). Intervening in the market to provide a positive externality like economic resilience thus increases the efficiency of the whole system.

However, the bureaucracy required to administer cost internalization programs represents a form of lost efficiency, as does the act of intervening in the market itself, just as government wealth redistribution efforts like the minimum wage are currently contrary to the neoclassical definition of efficiency. Also, following the internalization of resilience into prices, the economy would become less specialized, streamlined etc. than it might otherwise have been, so some amount of maximum *potential* economic efficiency (narrowly defined) is still lost. Some of these root efficiency tradeoffs would still exist, they would simply be obscured or overridden by prices that were also attempting to incorporate other market considerations. So while pursuing the internalization of economic resilience into prices is an excellent idea, it does not fully resolve all theoretical tensions.

Daly and Farley (2004, 360) also note that a basic principle of policy design in ecological economics is that “each independent policy goal requires an independent policy instrument”. They explain the price mechanism alone cannot increase efficiency, reduce poverty and curtail scale all at the same time. In the same way, it may be difficult or impossible to subsume resilience entirely under the mechanism of price so as to amalgamate four separate policy goals into one value.

There are still other instances where pursuing economic resilience is likely compatible with efficiency. The goals of diversity and economic efficiency (in terms of meeting societal preferences) are complementary insofar as both subscribe to the idea that pursuing the same thing over and over will eventually do more harm than good because of diminishing marginal returns/diminishing marginal utility. Diversification can thus increase utility. Homer-Dixon (2006) believes part of the reason economic growth is so important to our economy is because we need it to compensate for those disemployed by technological change and automation. If we applied the principle of diversity to the labour supply and despecialized, we might lose significant efficiency gains but greatly increase the demand for labour and thereby reduce the need for growth. Reducing dependence on technology would also help economic resilience since powered technology is often the first to fail in a breakdown.

Levin et al. (1998, 233) write that “resilience requires a competitive economy, effective government, and trust”. It is interesting they suggest that competition, and hence efficiency, is important for economic resilience. In turn, Low et al. (2003, 84) argue the traditional economic belief that redundancy in government is inefficient is incorrect: “empirical studies of redundancy in public services found that redundancy did not have the adverse consequences frequently attributed to it and that improvements (rather than reductions) in performance were frequently associated with redundant arrangements”.

Overall, Victor (2007 interview) argues that “Efficiency doesn’t make sense except in relation to ends. We can think of more or less efficient means for increasing resilience which illustrates the fact that they need not be in conflict at all”. Perhaps one way to proceed therefore is to create a new concept called “efficient resilience”. This would entail identifying and building resilience into the most critical infrastructure and systems needed for human and economic welfare. The focus would be on seeing where economic resilience could be enhanced the most at the least cost to traditional efficiency (as well as scale and distribution). One would not try to build resilience into goods where enormous effort and expenditure would only lead to marginal gains in resilience.

Consider for example building redundancy into the economy. A Boeing 777 has 150,000 subsystems but can still fly even when many become inoperative: "This redundancy is built in since the ability of the Boeing 777 to continue to function when modules fail is crucial. This might not be the case for products that have less of an effect on the lives of users during failures such as coffee machines, which can be developed more efficiently but with less robustness" (Janssen and Osnas 2005, 95). Low et al. (2003, 86) believes redundancy is "not always costly", nor is it always "absolutely required". There are potentially diminishing returns to redundancy in terms of conflicting with efficiency at an increasing rate and so we may need to find optimum levels (Low et al. 2003, 106). Often a single or double redundancy would be sufficient protection against breakdowns without pursuing redundancy to ridiculous ends.

Similarly, Homer-Dixon (2006, 286) argues for achieving a balance between autarky, dispersity and efficiency:

> When it comes to connectivity in its networks, a resilient system is a bit like Goldilock's favourite bowl of porridge: it has neither too much nor too little connectivity. In a resilient system, individual nodes – like people, companies, communities, and even whole countries – are able to draw on support and resources from elsewhere, but they're also self-sufficient enough to provide for their essential needs in an emergency. Yet in our drive to hyper-connect and globalize all the world's economic and technological networks, we've forgotten the last half of this injunction.

In this sense, dispersity (which recommends increasing distance and hierarchal connectivity) and autarky (which recommends shortening links and reducing connectivity) exhibit something of a Ying and Yang relationship (Lovins and Lovins 2001, 199, 213).

Homer-Dixon (2007 interview) also provides another way to view the problem: "When people say we're lowering the productivity of the economy by building resilience, we're only lowering the productivity of the economy because one of the important things we're producing, resilience, is not being priced because it's a public good and nobody can put a price on it". Looking at it this way, pursuing resilience might mean our economy becomes less efficient at producing some types of consumer goods and services but more efficient at producing resilience.

This has a certain logic to it, and may work in cases where resilience principles can be enhanced by manufacturing infrastructure, but does not resolve all the tradeoffs. You probably cannot "produce" your way out of the efficiency tradeoff between specialization and adaptive capacity. Homer-Dixon (2007 interview) agrees "there's no question that sometimes there's going to be a tradeoff". Real-life systems need to be examined on a case-by-case basis, looking at each individually and each component of each system individually, when deciding on resilience. There are not necessarily any easy overarching answers.

Looking to the past for guidance, Redman and Kinzig (2003, 5) explain that for hunter-gatherers and early agriculturalists, resilience was likely a much greater priority than efficiency:

> societies that maintained seemingly inefficient strategies were often highly resilient… the introduction of apparent short-term inefficiencies to mediate risk in the long-term, either consciously or unconsciously, was a widespread practice. Although our culture retains some of these attributes of resilience today, our activities and alliances have shifted, and are more subject to the demands of immediate return on investment, and less subject to considerations of how costs today should be borne to mediate risks that may not appear for several generations.

Thus, "some social adaptations or cultural traditions may appear inefficient or 'illogical' when viewed in the short term, but reduce risk and increase resilience in the long term" (Redman and Kinzig 4).

Farley (2007 interview) agrees: "This all depends on the time scale over which we define efficiency. Certainly there is an enormous tension between resilience and short run efficiency, but I also see an enormous tension between short run efficiency and long run efficiency. I would see system collapse (with no renewal, no resilience) as the least efficient outcome of all". Similarly, Lovins and Lovins (2001, 191) write: "It cannot be overemphasized that the property being sought when one designs a system for resilience is that it be able to survive unexpected stress: not that it achieve the greatest possible efficiency all the time, but that it achieve the deeper efficiency of avoiding failures so catastrophic that afterwards there is no function left to be efficient". Thus, long term efficiency (and in turn sustainability) may ultimately depend on the ability of the economy to endure catastrophes while preserving enough human welfare to ensure successful recovery. What can be said then is that efforts to build in resilience jeopardize efficiency less and less the more broadly efficiency is defined.

5.3 Resilience and Just Distribution

The majority of ecological economists, including founder Herman Daly, believe that the fair, equitable and just distribution of society's wealth should be one of the central objectives of ecological economics. Unlike other branches of economics, especially neoclassical economics and its sub-branch environmental economics, ecological economics holds that wealth distribution (i.e. who gets what and how much?) is a direct theoretical concern of economics and not something to be left solely to politicians to sort out. In this way ecological economics openly acknowledges the value system underlying its theory. Broader equity issues, such as distribution of power and opportunity, are normally less of a focus in ecological economics.

Ecological economists reason that since most wealth originally comes from nature, everyone is entitled as a citizen of earth to an equal share in that wealth. Individuals and corporations should not be able to capture solely for themselves the wealth that is created by nature or the rest of society (Daly and Farley 2004, 390). Another justification for having just distribution as a foundational goal of ecological economics is that wealth inequity is usually bad for the environment. Globally, the worst environmental damage is done by people and nations who are excessively poor (slash-and-burn agriculture) and excessively rich (massive overconsumption). If economic growth must eventually cease in a finite world, then it follows that we must tackle the issue of wealth distribution directly because once the economic pie becomes fixed we can no longer keep relying on growth (and the trickledown effect) alone to ameliorate poverty (Daly and Farley 2004).

In traditional economic literature, especially welfare economics, it is generally acknowledged that a trade-off can exist between equity and the narrow efficiencies recognized in conventional economic literature (Sagoff 1988, 60, Brock et al. 2002, 264). For example, efforts to rebalance wealth are seen as interfering with the operation of the market. Does such a tradeoff also exist between equity and economic resilience?

5.3.1 Does the pursuit of Just Distribution enhance or undermine resilience?

Wealth distribution is likely to most heavily impact the more people-centred principles of economic resilience: adaptive capacity and transformability. This is because the pre-existing economic order prior to a breakdown can greatly influence how actors behave and make decisions in the middle of a crisis situation. This aspect of adaptive capacity is not well explored in the literature. Economic equity is likely important to resilience because it pre-emptively builds community capacity to band together and persevere through adversity. People need to feel like they are valued by, and have a stake in, their community, but poverty and income disparity undermine this social fabric. Promoting just distribution therefore enhances the chance of a successful unified societal push to overcome crises.

Some civilizations like Egypt (which probably escaped being truly tested) could persist for thousands of years in spite of great wealth inequality and literal slavery. Yet inequitable social structures may have hastened the downfall of the sample civilizations from Chapter 2 that did face major catastrophes. This is because shocks and breakdowns often expose weaknesses and bring to the surface social grievances that have long been festering in a society. As a society breaks down, the claim by elites that the existing societal arrangement is "the best" is usually stripped of its authority. Most ancient governance structures depended on the people believing their ruler and the upper caste had a divine connection in order to justify large wealth inequities that existed. They often collapsed so suddenly because once the supreme ruler was exposed as lacking this connection, the people lost faith and their entire social model collapsed (Adams 1988, 37).

Historically, states and empires also maintained stability when their centre was supported by a periphery and the periphery regions believed the resources they provided to the centre were also returning a benefit to themselves (Eisenstadt 1969). This arrangement could break down if the centre pursued efficiency so rigorously that it neglected the fair distribution of resources: "A 'maximizing' strategy, in which the political center tends to channel resources and services for its own, rather than for societal, ends in which support and legitimation from the periphery are eroded, can lead to collapse" (Yoffee 1988, 13). Breakdowns are more likely to begin in peripheral regions and countries and then spread to the core as seen in the collapse of the Western Roman Empire. The lesson is that a happy periphery of poorer nations often makes for a happier more resilient core, and there is no reason to think this doesn't apply to nations in the modern global economy as well.

Unfortunately, "Without gigantic flows of high-quality energy – almost always coming from distant places – [today's] megacities won't stay peaceful. When these flows are constricted in the future, and when urban energy prices shoot skyward, we'll discover that the world's megacities, with their surging populations, are powder kegs" (Homer-Dixon 2006, 75). In this sense, otherwise beneficial urban intensification efforts that help scale by controlling sprawl may work against both distribution and resilience in a breakdown situation. Indeed Kunstler (2006, 300) believes that societal breakdown could lead to various economic and ethnic groups engaging in crime and clashing with each other and authorities in guerrilla warfare: "At their worst, the rap videos played on cable TV resemble the war chants of a conflict that has not yet been joined… In the disorders of the Long Emergency, when the poor become really poor by world standards, the urban ghettos may explode again".

If economic growth and employment greatly decline in a resource starved world, even the traditionally placid middle class may rebel if enough people decide they no longer have a chance under the present model to work their way to a higher standard of living. Given this worrying situation, just distribution within rich developed nations can be seen as complementary to economic resilience in that societies that are more equitable are likely to have fewer angry disenfranchised individuals and hence less debilitating civil disorder when a breakdown occurs (Rees 2007 interview). Stronger social capital can enhance capacity for cooperation and collective creativity and in turn adaptability.

Globally, "At the other end of the spectrum, we find societies – including many in sub-Saharan Africa and some in Asia and Latin America – that have much lower ability to manage or adapt, because of poverty, environmental damage, low education levels, chronic internal violence, and weak and corrupt governments. A few, like Somalia and Haiti, have completely succumbed to the stresses pounding away at them" (Homer-Dixon 2006, 111). From this perspective, redistributing income through international aid could also increase economic resilience by increasing the buffering capacity of poorer states.

Homer-Dixon also worries that disenfranchised people in poorer countries are more likely to become terrorists which of course does nothing to help world resilience. A report on climate change by retired US generals similarly argues for Western country to undertake self-interested generosity in the interests of preserving global order: "The U.S. should commit to global partnerships that help less developed nations build the capacity and resiliency to better manage climate impacts" (CNA Corporation 2007, 47). Ensuring that no nation is left behind will help reduce both the formation of rogue states that threaten international security and the frequency of wars over natural resource in the coming decades. In short, a more equitable world will mean fewer angry people and nations once breakdowns start occurring.

The relationship between equity and economic resilience in poorer nations is borne out by the example of Cuba where response to energy scarcity was made easier because of just distribution: “Because the Cuban economy was directly controlled by the state, and because there was little economic disparity in the country by this time, the shortages were shared more or less equally” (Heinberg 2004, 106). Redistribution could also help buffer economic downturns by making sure working people have enough money to buy the products being made so that aggregate demand in the economy is sustained. Thus, Farley (2007 interview) concludes: “I think inequitable systems are probably more prone to collapse, and I see little evidence that those with an inequitably large share of the resource base recover any better”.

All of this might suggest that an aggressive expansion of existing wealth distribution programs both within and between countries would be a solution to the world’s resilience problems. But things are never so simple. The positive relationship between global wealth redistribution and adaptive capacity is not entirely clear cut when comparing a wider array of countries and cultures. A Kalahari bushman or subsistence farmer in the third world can be considered quite resilient to shocks because of how strongly they embody the dispersity and autarky principles. Therefore lifting them out of their “poverty” and into urban areas could actually make their lives and their nation’s economy less resilient. This provides an alternative justification for Garret Hardin’s (1974) Lifeboat Ethics which warns about the ecological (scale) dangers of ill-considered foreign aid and unrestricted immigration. On the other hand, it could simply imply that poverty needs to be defined more broadly than low material throughput to take into consideration context.

This raises an even more provocative question: could the economic fundamentals of poorer nations actually be more resilient than those of richer ones? In general many “less developed” societies (excluding failed states such as Haiti/Somalia) may actually be more economically resilient in that they are less complex and have greater dispersity and autarky than rich developed nations, reducing their susceptibility to synchronous failures. Families in developing countries fortunate to still have an agrarian or indigenous lifestyle are probably much more economically resilient at a fundamental level than their counterparts in the West. Perhaps the richer countries are, the harder they fall: “the most technologically complex systems will be ones most subject to dysfunction and collapse – including national and state governments" (Kunstler 2006, 239).

Compared to developing nations, "America is already a highly developed and industrialized nation that is extremely dependent on automobiles, highways, shopping malls, and computers... Nor is the US in the same situation as Cuba: while the people of the latter nation have worked a half-century at building communal solidarity, America is an individualist society. Where Cuba has fostered a cooperative spirit among its populace, Americans are proudly competitive**"** (Heinberg 2004, 110). One only needs to contrast the effective communal response to disaster seen in countries hit by the 2004 Asian tsunami with the looting and rioting in New Orleans following Hurricane Katrina to see the effect that individualism and income and social inequity can have on the resilience of societies.

In many ways like barbarians invading Rome, Hurricane Katrina simply exposed the heart of an already rotting and unresilient social order: "the images of people stranded on New Orleans rooftops will not only be a glimpse of America's unresolved past of racial inequality but will also foreshadow a collective future of disaster apartheid in which survival is determined by who can afford to pay for escape… Perhaps part of the reason why so many of our elites, both political and corporate, are sanguine about climate change is they are confident they will be able to buy their way out of the worst of it" (Klein 2007, 504). If wealth is better distributed, more people around the world will be able to afford to make better preparations for shocks or alternatively escape them, and if the elites have less wealth relative to common people, they may start taking general societal resilience a little more seriously.

Another aspect of the distribution issue is the proper balance between public and private wealth. With the dominance of corporations in 21st century society, wealth is becoming concentrated in private hands to the detriment of goods and services provided by the government. Klein argues that the disaster of New Orleans was made far worse by relentless gutting of the public sphere in the name of neoliberal capitalism (2007, 492). Levees were never built and FEMA was understaffed and ill-equipped.

So within rich countries, particularly urban areas, just distribution helps economic resilience. Redistribution of wealth to (and within) less developed countries likewise helps resilience but those societies and the world community must be careful how this is achieved. Simply trying to transform developing nations into mirror images of Western industrial nations will mean replicating the same unresilient vulnerabilities that are set to give first world nations such great problems in the years ahead. Just as efforts are being made on the climate change prevention front to help poorer countries skip over the dirty industrialization phase and jump right to an efficient low carbon economy, these developing nations must make the direct jump to a resilient economy.

Around the world, increasing the education of the poor in desirable ways could enhance their adaptive capacity (ability to come up with innovative solutions to new problems) and transformability (ability to partake in the active reimagining of their society). Also, slowing the rate of productivity-enhancing technological change may improve employment and wealth distribution because people formally displaced by technology will need to be re-hired (Homer-Dixon 2006, 194). Such a policy could benefit economic resilience by reducing complexity, but as discussed in earlier sections, would also have consequences for efficiency and scale. Alternatively, taxing resources and pollution and redistributing the income may allow us to pursue scale, efficiency, resilience and distribution goals simultaneously.

Nevertheless it is not possible to create a resilient society solely through economic redistribution alone (i.e. as a nice bonus side effect of helping the poor). Heinberg (2007, 180) remarks that traditional left-wing ideology alone will not be enough to meet the challenges ahead – the problem of resilience is much bigger and requires a much greater diversity of solutions. Resilience must be designed for as a separate goal, which raises the counter-question of what impact a resilience-first agenda would have on distribution.

5.3.2 Does the pursuit of resilience enhance or undermine just distribution?

Catastrophic events have implications for welfare economics because changes in a system's state are likely to shift around costs and benefits between different present and future actors in a system (Brock et al. 2002, 272). It directly follows then that "the provision of resilience engages welfare issues" in economics (Homer-Dixon interview 2007).

Klein (2007, 497) notes that "Not so long ago, disasters were periods of social-levelling, rare moments when atomized communities put divisions aside and pulled together". Now, she says shocks are just as likely to accelerate the divisions between wealth classes. Indeed, when there is a shock to an unresilient system and it fails in some way, "the groups of people who are going to be hurt the most are those who are already weak and already disadvantaged" (Homer-Dixon 2007 interview). As illustrated so vividly by the New Orleans catastrophe, the costs of breakdowns are likely to be borne unequally (Rees 2002, 256). Many of the poorest people in the city were trapped in the disaster zone while the economically secure drove out of town, checked into hotels and called insurance companies (Klein 2007, 490).

It follows that designing a resilient, safe-fail economy can enhance equity by reducing the worst impacts of breakdowns, impacts that are likely to hit the poorest and most vulnerable the hardest. For example, many of the 30,000 who died in the 2003 European heat wave were elderly persons living alone without air conditioning. As well, the physically or mentally disadvantaged, single parent families and the sick may be cut off from state economic support and have to fend for themselves in the aftermath of an environmental resource shock. Therefore building resilience into the economy can certainly contribute to just distribution in society over the long run.

In terms of global wealth distribution, Homer-Dixon (2006, 286) observes that to avoid synchronous failure, we need resilience through the whole system including the weakest links, and so again equates building resilience with pursuing a pro-development agenda: "In practical terms today, this means we must focus our attention on boosting the resilience of the world's weakest societies – those with horribly damaged environments, endemic poverty, inadequate skills and education, and weak and corrupt governments". Already there is recognition that developing countries are likely to be hardest hit by climate change and thus work is beginning to enhance their ability to adapt as an extension of development assistance.

In Africa this has meant a shift to promoting traditional farming practices that are more resilient to drought and climate change. Chandler (2007) however argues that this new emphasis in international aid means abandoning development goals like modern agriculture and thus consigning people to perpetual poverty. He argues that traditional "development provides a better way of dealing with climate uncertainties than does concern with the individual lifestyles and survival strategies of the poor" (Chandler 2007). Again here is a tension between the need for growth and distribution on the one hand and resilience on the other – yet the argument could be made that a subsistence farming lifestyle is still preferable to outright starvation in the devastating wake of climate change. Climate change is also likely to force millions of people in the third world to try migrating to more developed nations, ironically meaning that a lack of resilience in their home country could actually result in a richer standard of living for those lucky enough to relocate successfully.

There is a particular potential for adaptations implemented hastily in the aftermath of breakdown to violate just distribution because confusion and the need for immediate action often prevents a careful consideration of who will be affected. Klein (2007) also warns of "disaster capitalism", where shocks are used as a pretext to force through ideologically driven economic policies that worsen distribution (among the examples she cites is the privatization of the New Orleans school system after Hurricane Katrina). Similarly, austerity programs currently being enacted in Eurozone countries to pay off government debt could be viewed as an adaptive response to the 2007 financial shock, however deep cuts to education and welfare will end up making the poor pay for the bailouts of the banks and financial elite. Whether such measures are truly resilient is questionable since they seem set to reduce the welfare of millions of people (violating our definition of economic resilience). If more resilient financial policies had been implemented earlier which impose efficiency costs on banks in good times but minimize maximum loses (see Chapter 6), the financial crisis could have been averted without harming income distribution. Again, preventing deep breakdowns is generally good for the poor and middle class since the current social order seems to be fond of making them pay to clean up the mistakes of the rich.

In a broader sense, resilience could also hurt wealth distribution if a society's ability to buffer change prevents it from shifting into a different stable state that is more equitable. This again raises the problem of undesirable resilience. A society that is effective at meeting sustainable scale and some resilience goals (narrowly defined without transformability), could still be very unequal in terms of wealth and power distribution, for example the feudal dictatorship of the Tokugawa Shogunate in 17th to 19th century Japan (Diamond 2005). The salient question then is how to take advantage of perturbations to help nudge a system toward more equitable distribution.

Daly and Farley (2004) advance the ecological economic idea of distributional efficiency, the notion that reallocating resources to poor people will generally lead to higher societal welfare since rich people have diminishing marginal utility of total consumption. As discussed, building in economic resilience probably reallocates societal resources to the net benefit of the poor since resilience is a public good that all can benefit from equally. But there may be a fine line given existing inequities in the world. Too much resilience and no shocks would harm the economy, preserving the status quo and its associated wealth inequities. Too little resilience and all of society breaks down, to the detriment of both rich and poor. Just enough resilience, and the status quo gets shaken up, hopefully leading to transformation to a new stable state with greater wealth equity. Overall then, a truly broad look at the relationship between distribution, resilience, scale, and efficiency requires consideration of how these objectives relate to the adaptive cycle.

5.4 Goals and the Adaptive Cycle

Now that the concept of resilience has been tested against scale, efficiency and distribution, this final section will consider the integration of these three ecological economic goals into the broader theory of resilience (the figure-8 adaptive cycle) in order to reveal further new insights. The relationship between the concept of economic resilience and the three other primary goals discussed in this chapter mirrors in many ways the relationship that is predicted and implied (though rarely directly stated) by resilience theory. Since the panarchy cycle is so rarely applied to economies, some adaptation is required.

Figure 3 shows this author's adaptation of Figure 1 (from Chapter 3) to ecological economics. Again, the box places the figure-8 in three dimensional space to allow the assignment of variables along the axes that illustrate the generalized changes in system dynamics that are believed to occur along the cycle. This cycle can apply to any sized economy through history but here we will discuss in a very generalized way its application to our modern global economy.

Like all economies, ours began humbly enough at the bottom of the figure-8 in the exploitation phase. Increasing growth and efficiency have been the single minded goals for centuries. As it proceeded to aggressively expand its scale and acquire more capital and wealth, the global economy moved rightwards and upwards along the front loop of the figure-8, becoming progressively more organized and efficient. However, it also started rapidly depleting its natural capital (unused resources), resilience and capacity for radical social innovation. Wealth inequality (not shown) often increased.

In the modern day, our global economy has become locked into the conservation phase (top right of the loop). It has become extremely large scale, efficient, orderly and interconnected but at the cost of its natural environment, resilience and ability to adapt or innovate at a fundamental level. Globally, wealth inequality is worsening. Gradually, staying within sustainable scale is becoming a major concern as decision makers begin to realize (too late) that their resource base can no longer support the demands they are placing on it for continued exponential growth.

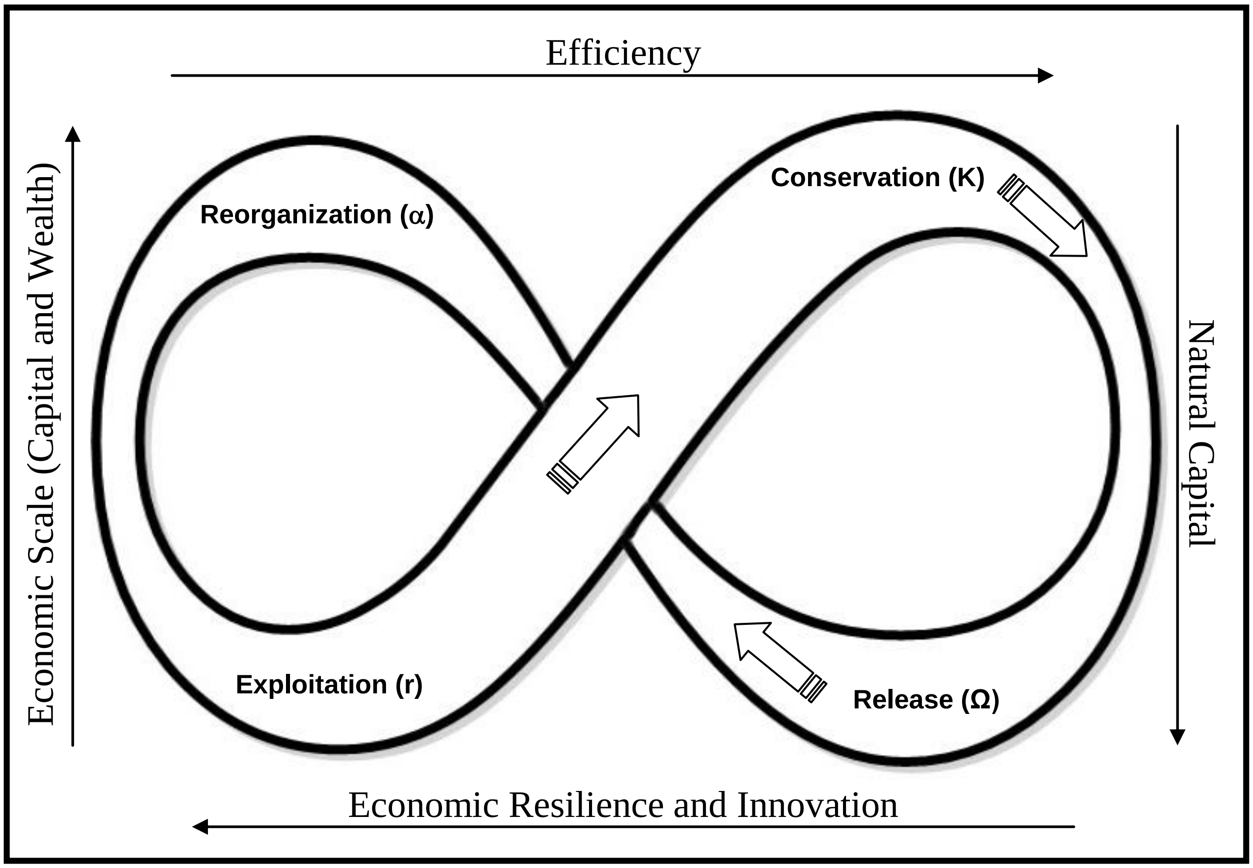

Figure 3: Figure-8 adaptive cycle applied to ecological economics

What follows is one likely scenario (though the future is impossible to predict). When hit with a large enough shock (or more likely, series of smaller converging shocks), these weaknesses will be exposed and the economy is likely to break down. Rapid contraction will lead to negative growth, decreased consumption and high unemployment. Traditional organizational structures will probably be abandoned and carefully nurtured economic efficiencies lost in the resulting panic.

If this should occur, the economy will move quickly rightwards and downwards through the release phase, resembling an out of control plane pitching over. The amount of resilience left in our economy will determine whether the plane continues on in free fall and crashes into the ground (terminal civilization collapse) or whether the crew in charge is able to regain control in time to pull up out of the catastrophe and enter the reorganization phase. Aiding this task are the resources, resilience and capacity for new innovations freed up (released) by the breakdown. The pilots of the economy hopefully regain their senses and discover their reserve fuel tank. They may remember emergency training they had almost forgotten and also dream up radical new solutions to problems that were never in any textbook. Eventually, once survival is assured, the economy is likely to begin this cycle all over again, but hopefully future generations will remember some of the lessons learned and build society within a more sustainable basin of attraction. This scenario is of course radically over-simplified but it is useful from time to time to consider our complex world as one global whole.

Nevertheless the real world dynamic interplay between goals does not perfectly mimic what would be expected in adaptive cycle theory, primarily because humans, unlike the actors in many other systems, can consciously design their economies for various ends which can lead to unexpected results in the relationships between resilience, growth and connectedness/efficiency. Therefore, the short answer to the research question of "Would adding consideration of economic resilience enhance or undermine the three main ecological economic goals of sustainable scale, just distribution and efficient allocation?" is that it depends. The question must almost be asked on a case-by case basis. But as discussed at length above, there do seem to be some general relationships.

Resilience theory as advanced by Holling predicts that if the scale and complexity of the economy rise, resilience inexorably declines. This implies that ecological economist's goal of controlling growth is very much mutually compatible with resilience theory. In ecological economic terms, moving up the growth side of the adaptive cycle means moving further away from thermodynamic equilibrium. Maintaining this position requires more and more inputs of increasingly scarce high-quality (low entropy) energy to prevent breakdowns (Homer-Dixon (2006, 233). The adaptive cycle shows us that a system can never continue growing forever, and that growth is always followed by a breakdown of some form which is when resilience becomes especially important. Even the outward growth of the universe is starting to slow, and it is predicted to eventually collapse back on itself.

Attempting to extend the conservation phase too far only makes the fall that much worse: "The longer people sustain a social, economic, or ecological system in its growth phase, the sharper, harder, and more destructive its ultimate breakdown will be" (Homer-Dixon 2006, 232). Because earth has finite resources, gaining each additional unit of scale when moving up the cycle requires greater and greater efficiency and hence the loss of more and more resilience (there is usually increasing marginal costs to resilience of increasing scale). In this way the growth curve along which society travels looks similar to the marginal disutility of growth curve used in ecological economic texts (see Daly and Farley 2004, 20). Both curves warn of the danger of too much growth, showing the intriguing theoretical similarity between the sustainable scale and resilience goals even though they have approached the problem of scale from very different angles.

However, if the growth is occurring due to societal efforts to enhance economic resilience (such as by building in redundancies or amassing stockpiles), then sometimes resilience and scale can both rise together. This follows from the fact that building anything, whether it is cars or solar panels, will require nature's inputs. Thus scale and resilience can be both positively and negatively linked: reducing scale usually leads to increased resilience, however, some efforts to increase economic resilience can also counter-intuitively increase scale. Whether a given economic investment that increases scale will hurt or help resilience depends largely on whether the goods being produced have resilient characteristics themselves or will be used to achieve resilient ends.

Is there a point along the growth curve where scale and resilience are both optimized? Or is this impossible and we are fated to go through the adaptive cycle forever? The answer is probably the latter, but wise use of nature's inputs for more resilient ends (as well as a switch in focus to qualitative economic *development*) can make the down slope of the cycle much less severe. Ultimately, given that economies are dynamic systems, perpetually moving along the adaptive cycle and between basins of attraction, Daly's idea that an economy could even be held in a "steady-state" is in some ways theoretically incompatible with resilience theory. For example, Redman and Kinzig (2003, 1) explain that while stabilizing phases in the adaptive cycle are important to maintain "productivity, fixed capital, and social memory", destabilizing forces are likewise needed to maintain diversity, flexibility, and opportunity.

Several ecological economists have in fact disagreed with the simplicity of the steady-state idea, including Daly's mentor Nicholas Georgescu-Roegen (Rosser 1991, 269; Anonymous interview 2007). But what Daly's idea lacks in theoretical rigour, it makes up for in practical usefulness in terms of communicating to policymakers the need to keep the economy within carrying capacity given our limited knowledge of the ecosystems on which it depends. Perhaps "zero growth economy" would be a slightly more accurate name, though that too is contestable given that economies like ecosystems are continually mutating and evolving. What is steady should not be the state of the economy itself, but instead the fact we are keeping within carrying capacity even as our economy remains otherwise dynamic: "The complexity, dynamics, and nonlinear nature of these interdependent systems imply that the notion of 'sustainability' as a steady-state equilibrium is not realistic. Forces of change, such as technological, geopolitical or climactic shifts will inevitably disrupt the cycles of material and energy flows. Therefore, achieving sustainability will arguably require the development of resilient, adaptive industrial and societal systems that mirror the dynamic attributes of ecological systems" (Fiksel 2006, 16).

The ecological economic goal of efficient allocation at first seems to violate resilience according to panarchy theory. As economic systems gain efficiency and progress along the adaptive cycle, they forsake resilient principles including redundancy, diversity, dispersity and autarky in favour of streamlining, monoculture, centralization and interdependence leading to "efficiency-based competition" in the conservation phase (King 1995, 965). Philips (1979) also explains that emerging states and civilizations (in the exploitation phase) have not yet developed complex institutions and so use their resource base in low return ways. Over time as they expand (move into the conservation phase) and learn how to use their resources more fully and efficiently (defined as high output or return per unit of investment), they use most freely available resources in support of complex social and political institutions. Their complexity and efficiency leaves them with no reserves or flexibility to reallocate resources in emergencies, making them vulnerable to disruptions that an emerging state would be able to control.

However as discussed, the relationship between efficiency and economic resilience is not so clear cut: "The common perception that there's a tradeoff is something that holds more at the level of the macro-economy than at the level of individual producing units" (Homer-Dixon 2007 interview). The answer depends largely on how efficiencies are achieved and indeed how efficiency itself is defined. Internalizing environmental costs into the market would go a long way toward ensuring that the efficiency, scale and resilience goals are pulling in the same direction. Some initiatives that could greatly improve efficiency may have little impact on economic resilience and vice versa. Yet for now our society's focus on one particular type of efficiency, and the complete neglect of scale, distribution and resilience, has led to the fact that "The 'winners' in recent decades have been corporations that could enjoy the economies of scale conferred by gigantism… The 'losers' can be summarized generally as the future and its inhabitants. They stand to lose not only future wealth, but also their civilization" (Kunstler 2006, 240).

Indeed modern society dedicates its resources heavily to technological innovation, however the adaptive cycle reveals that these sorts of efficiencies which occur in the growth/conservation phase are in fact not really innovative at all: because each new technology locks us more and more into the current way of doing things and the need for more growth and more resource inputs. True innovation, in terms of radical social or spiritual transformation, often occurs only in the backloop after breakdown. This is in part why we suffer an "ingenuity gap" in coming up with real systemic solutions to today's fundamental problems, and inventing any number of glitzy new high-tech gadgets will not help this.

Truly, on one hand efficiency is a very positive attribute that can not only make society vastly wealthier but also allow us to do more with less, helping to control the speed that we move up the growth curve and in turn delaying environmental resource shocks caused by exceeding scale. For this reason efficiency is one of the three main objectives of ecological economics. Yet, an analogy can be drawn between current economic efforts to prevent shocks through rigorous efficiency measures and failed efforts to prevent wildfires in heavily forested areas even as flammable debris pile up. Both efforts may serve only to overextend the cycle's front loop and its associated growth and connectedness so the inevitable breakdown is worse than it needs to be: "Put simply, efforts to regulate the system – efforts undertaken apparently without much understanding of how they affected the system's resilience – produced the conditions for catastrophe" (Homer-Dixon 2006, 233).

In the same way, efforts to make our economy fail-safe and prevent breakdowns through efficiencies and technologies may simply be overextending our own growth phase and making the breakdowns that much worse when they do occur. Ecological economists are already cognoscente of the limitations of conventional efficiency as a solution to all environmental problems, and so would not necessarily disagree with this analysis. Beyond this, what may be needed is a reconsideration of what efficiency initiatives ought to serve and, consequently, how they should be defined and measured.

Just distribution is the most difficult ecological economic goal to fit into resilience theory. Equity cannot be directly predicted by a society's progress along the adaptive cycle curve because it is so heavily influenced by human morals. As scale increases, equity can in turn become better or worse within and between countries depending on political choices. Historically, civilizations tended to become more and more unequal as they moved up the adaptive cycle, culminating in deepening class divisions and the concentration of capital in a few self-indulgent hands during the conservation phase (Adams 1988, 25). Seeking a less complex society might therefore reduce the ability of certain groups and individuals to amass wealth and associated power. Yet in the mid 20th century Western society was managing to close the distributional gap in spite of rapid economic and technological growth thanks to the formal creation of the welfare state and the spread of international aid agencies – only to have the gap open up again following a shift in political ideology and the spread of Reagan-style economics and globalization. While a perfectly equitable society is likely to have much more economic resilience, it may still suffer from fundamental resilience deficits associated with too much interconnectedness, specialization and unrealistic demands placed on the natural environment.

Similarly, an economic breakdown (release phase) could either level the playing field and bring people from all walks of life together as social classes dissolve in the anarchy following a societal shake up (Landau and Saul 2004, 305), or lead to gated communities which make equity far worse. Poor societies that have not moved as far up the adaptive cycle may not have as long a way to fall in the release phase, mitigating the severity of their decline somewhat relative to the hard fall that rich nations seem headed for. However, Homer-Dixon (2007 interview) points out that poorer societies can be considered more resilient only by default, not because of anything special they have done to make themselves resilient. Neither poor nor rich nations in today's world are foundationally resilient – both are travelling through the panarchy cycle but neither have explicitly incorporated recognition of it into the design of their economies. Both remain obsessed with economic growth and aspire to stay in the growth phase of the front loop indefinitely which is simply not possible.

The end effect on resilience of pursuing a more egalitarian society may depend on how it is achieved. Trying to raise the poor of the world up to the consumption lifestyle of the rich is destined to move the global economy dramatically higher on the adaptive cycle with a corresponding decline in resilience and environmental quality. This underscores the need to redistribute from rich to poor rather than just trying to raise all boats by expanding the ocean of economic growth. If the bottom of the social pyramid was raised at the expense of say the richest 10% in the world, redistribution goals could be met without moving the global economy to an even more dangerous scale. Most importantly, poorer nations should be sure to follow their own unique development path and be careful not to repeat the various unresilient design flaws that Western economies have taken on while moving up the adaptive growth cycle.

Chapter Conclusion

In the end, all four societal objectives are in theory compatible at some level – certainly none are perpetually, diametrically opposed to any other. Relating the principles of economic resilience to the three goals is perhaps easiest to understand by thinking of three periods in a breakdown scenario: before, when you try to prevent or soften it (through scale and efficiency initiatives); during, when you try to weather it (when redundancy, diversity, dispersity, autarky and adaptability are especially important), and after, when you try to recover from it (transformability and possibly just distribution come into their own). All of these principles need to be simultaneously planned for, yet the point on the adaptive cycle when each is most critical to society is different. To ignore some of these principles because they seem superfluous or unimportant at a particular point in time is to show a grave lack of foresight. It is critical that we start adopting a much longer term view of the history and current position of our economy on the adaptive cycle, recognizing that we must start preparing for tomorrow's inevitable challenges today.

The adaptive cycle thus provides a very useful way of synthesizing the framework of economic resilience from Chapter 4 with ecological economics. Placing the three existing goals of ecological economics within the broader theory of social change provided by the figure-8 cycle of resilience theory can shed new light on their interrelationship. It reveals that these three policy objectives are in part a response to challenges that naturally arise as our system, like all those in the universe, progresses through an evolutionary cycle. The fact we are saddled with today's complex problems was probably made inevitable the day our ancestors started down the path of civilization. Traditional hunter-gatherer societies were not large enough to be civilizations precisely because they did not have the efficiency (in terms of specialization) to allow them to be. When humans signed on to the project of civilization they not only got its well understood hallmarks like increasing growth, efficiency and organization, but also hidden costs including declining economic resilience, environmental quality and distributional equity. We can use the adaptive cycle as a chart for plotting the progress of civilization and clarifying the positive and negative relationships between our multiple, sometimes competing objectives.

Clearly then we see four major dynamic forces in play in the evolution of any economy: scale, efficiency, distribution and resilience. In these challenging times, these four objectives provide a valuable framework for analyzing the tradeoffs potentially inherent in complex decisions affecting the environment, the economy and society and a fascinating glimpse at the difficult balancing act that policymakers increasingly face. By thinking through these issues ahead of time, ecological economists will be better equipped to help decision makers meet the challenge posed by looming environmental resource shocks and thereby enhance the credibility and relevance of ecological economics. Ultimately these goals are all valuable and interrelated: a great challenge for future researchers will be actively seeking out those areas where the goals are complementary so that initiatives can be undertaken that lead to mutually reinforcing gains.

Chapter 6: The Challenge of Economic Resilience in Practice

From the last chapter, we have seen that economic resilience is an important concept missing from ecological economics, yet one that is extremely useful for the theoretical insights it provides, warranting further examination. Resilience and ecological economics clearly complement each other overall as a way of evaluating the design and structure of socioeconomic systems in a comprehensive manner. This chapter will apply this framework to analyze some vital real life sectors in the economy in order to see what we learn about both the potential effectiveness of the framework (testing its usefulness) and what insights we can gain about how the resilience of these sectors can be improved, barring possible tradeoffs with other policy goals.

Batabyal (1998, 504) notes that "most policy makers are not interested in resilience per se, but in what this concept means for policy". This chapter therefore deals with the challenge of designing for resilience in practice, and the policy implications that follow. Recognizing that past literature has analyzed the resilience of largely natural ecological systems, the focus here will be on systems in the human built environment, systems which most immediately affect human economic welfare and over which we have the most control. Since this is primarily a theoretical economic paper it is most concerned with system linkages related to the allocation of society's scare resources.

6.1 Choosing Key Economic Systems

In the Region of Waterloo, Ontario where this author lives, regional government releases an annual list of potential environmental resource shocks as part of its emergency preparedness week. These include a smog event, power blackout, heat wave, water contamination, chemical outbreak, ice storm/blizzard, infectious disease and flood (Region of Waterloo, 2006). In part due to climate change, other potential shocks confronting populated regions include drought and crop failure (Russia in 2010), giant dust storms (Beijing in 2006), super wildfires (Australia in 2009), landslides (Indonesia in 2008 and Venezuela and Colombia in 2010) and fuel shortages.

The concern is not that a single shock will cause every system to fail, but that critical systems might just be among those that do (Perrow 1999, 403). Homer-Dixon (2006, 284) argues that "A prudent way to cope with invisible but inevitable dangers… is to build resilience into all systems critical to our well-being". Yet around the world, "infrastructure systems face pressures from growing demand, and difficulties in expanding capacity. Strained during normal conditions, their ability to deliver services during extreme events is limited, and systems may fail" (Chang et al. 2006, 35). For example, super storms may damage systems, mass migration caused by climate change may strain their capacity and shortages of key resource inputs may jeopardize their operations. Even if infrastructure is left physically intact, systems can break down if the people running them simply stop going to work (i.e. trained power station or medical staff). Comfort (2005, 5) notes that "aging infrastructure and growing populations moving into risky areas have increased the vulnerability of US cities to natural and technological hazards. The losses from Katrina alone, now estimated at over $250 billion, underscore the importance of maintaining rigorous planning and preparedness activities".

An analysis of how to build resilience into key economic systems is largely missing from the literature, however. One of the earliest works to apply the concept of resilience to a real-world infrastructure problem is Lovins' and Lovins' 1982 Pentagon-commissioned study, *Brittle Power* (republished in 2001). Their book, more from a technical/engineering perspective than an economic one, examined the implications of resilience for energy policy: "Few engineers deliberately design for resilience as an end in itself. If they achieve it, they do so by accident while pursuing other ends….In designing an energy system for the decades ahead, that is no longer tolerable" (Lovins and Lovins 2001, 208). Indeed, "Conventional thinking about disasters in the developed world revolves around seeing that people are prepared as individuals to survive for the short time it takes the authorities to respond to the emergency situation and restore normality. Almost no thought is given to changing the models for systems to make them substantially less brittle and more resilient" (Steffen 2006). The focus of economic resilience should be on weathering the storm and recovering from the damage rather than trying to prevent what cannot be predicted. Zeckhauser (2009, 13) calls for the identification of contingency circuit breakers that can prevent synchronous failure but does not identify any specifically save for “extremely large stockpiles of basic food, water and shelter that could be dispatched quickly if a series of smaller disasters threatened to slide into larger-scale catastrophe”.

To extend the previously raised notion of efficient resilience, we should probably focus first on building resilience into the most critical systems where it can do the most good. Public Safety and Emergency Preparedness Canada (PSEPC 2008) have identified critical infrastructure sectors, which they define as: “those physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of Canadians or the effective functioning of governments in Canada”. According to them, Canada’s critical national infrastructure consists of ten sectors: Energy and utilities, Communications and information technology, Finance, Health care, Food, Water, Transportation, Safety, Government and Manufacturing. Homer-Dixon (2006) likewise recommends identifying the highly connected central hubs of our energy, food, information, transportation and financial networks and redesigning, removing or replicating them to enhance dispersity and redundancy.

Due to space constraints this chapter will focus on a) the money supply, b) electricity and energy utilities, c) the water supply, d) the transportation network, e) the communication and information system and f) the emergency response system, concluding with implications of general urban system interrelationships. These sectors/subsystems have been chosen because they are critical for the basic functioning of any economy (and hence among the most important sectors to begin incorporating resilience). An environmental resource shock could potentially put all of them under stress that leaves them vulnerable: “Vulnerability is the flip side of resilience: when a social or ecological system loses resilience it becomes vulnerable to change that previously could be absorbed” (Colding et al. 2002, 13). Additionally, each shows evidence of the aforementioned tensions between economic resilience, sustainable scale just distribution and efficient allocation. These systems will be examined at different scales (local, national and global) and the resulting analysis will usually remain broad enough that it can be generalized to many different economies worldwide.

Ultimately some of the micro-scale issues related to building in resilience are better handled by engineers (the detailed design of infrastructure, technology and building standards), disaster management specialists or sociologists (controlling public panic). However, some examples from these disciplines are included to help ground this thesis and show the practical applications of the resilience concept on the ground.

6.2 The Money Supply

Money functions as a unit of exchange and store of value in the economy (Daly and Farley 2004). The supply of money in turn encompasses the creation and administration of currencies and banking. Money greases the gears of the global economy, and so the root cause of most financial crises is the freezing up of monetary liquidity in the system. This can occur if a large number of people default on their loans, causing lenders to be more cautious and the availability of credit to dry up. Without easy credit the system can no longer function properly or grow (as required by capitalism), and the whole fabric of economic relationships and hierarchies starts to disintegrate.

Presently banks still have low reserve requirements, allowing them to loan out currency they do not actually own and thereby create most of the new money in the economy: “the trend for two hundred years, since the times of John Law, had been to set credit free of its limiting association with bags of gold in a cellar” (Kunstler 2006, 207). This permits the money supply to remain liquid, efficiently expanding and contracting based on fluctuations in demand (Miller 2004). Access to cheap credit has become unofficial government policy in Western countries, in part to compensate for worsening income inequalities (Rajan 2010). Consequently global industrial capitalism has come to be fuelled by the ever increasing debt of developed nations. Because almost all money created through loans is IOU debt that must be repaid, liquidity in our monetary system is structurally dependent on economic growth.

Yet this so-called fractional reserve system may not be particularly resilient. As seen with the subprime mortgage crisis, when global credit dries up the whole system can grind to a halt. Moreover, if a shock prompts a run on the bank, a lack of physical reserves to back up virtual wealth may lead to panic. If psychological faith is lost in the monetary system, rapid devaluation and economic ruin are the likely result (Yasutomi 1995). The Roaring Twenties and subsequent Great Depression demonstrated that the greater the disconnect between bank reserves representing real wealth and the creation and lending of pseudo-money through loans, the more efficient and liquid the monetary system can be in good times but the less resilient and harder a fall it will suffer if things break down. During the Great Depression, "the loss of faith in various forms of credit represented by abstract instruments of finance translated into a persistent lack of money – that is, a means of exchange – and the institutions devised to create it stood in disrepute" (Kunstler 2006, 208). Deflation occurred in part because money loaned into existence disappeared when the loans were not paid back. As growth slowed, the ability to pay interest on credit did as well, compromising the entire banking system.

Within ecological economics, there is a body of literature critiquing our present system of handling money, primarily because a fractional reserve system seems at odds with the goal of sustainable scale. In order to control growth of the money supply and thereby help reign in the scale of the economy, a number of ecological economists (e.g. Daly and Farley 2004) advocate that banks be required to hold higher reserve requirements. Other ecological economists challenge the basic idea of a fractional reserve system, arguing it is the fiscal embodiment of the neoclassical economic belief in unending growth (Heinberg 2007, 40). Because a debt based monetary system requires the money supply and the entire economy to continually grow just to pay back interest on existing loans, it violates thermodynamic principles that no system can grow in perpetuity. As a result, these ecological economists propose radical alternatives such as a negative interest rate to simulate entropy and force people to spend money instead of hoarding it.

The ecological economic critique of the fractional reserve system because of the issue of scale flows nicely into a critique of the same system from the perspective of economic resilience. Bank reserves are akin to an inventory issue (Homer-Dixon 2007 interview), so a fractional reserve system that allows banks to make commitments far in access of their buffer inventory is in fundamental violation of the redundancy principle. Banks deplete overall economic system resilience by having thin capital reserves underlying their loans. Resilience thus should become a guiding principle of monetary policy. This would start with unified international regulation of the multinational banking sector to make sure bank loans are backed up by sufficient cash in the vault (Kuntz 2010), a policy that is compatible with existing ecological economic recommendations. If such redundancy were in place it would have helped lessen the blow of the current recession. Stronger banking regulations could improve just distribution as well.

A debt based money system lacks resilience at a deeper level as well. During breakdowns, not only can there be a run on banks by consumers who have lost confidence in the system, but if the demand for luxury consumer goods and services dries up, the demand for more money (created through loans) does as well, causing investors to lose confidence in the entire system (Heinberg 2003, 171). A monetary system that encourages everyone to constantly be in debt to one another means individuals, businesses and governments have very little financial autarky and thus the potential for synchronous failures is magnified. When viewed from the perspective of resilience theory, the fractional reserve system intrinsically extends the growth loop in the money supply too far, leading to financial bubbles. The money supply is revealed to lack resilience when that growth cycle is interrupted by shocks. High bank reserves would therefore greatly increase monetary resilience not only because they lessen the chance of currency collapse if people run on the bank, but also because they help make sure the growth of the money supply is kept in line with the relative strength of economic fundamentals.

Pursuing these resilience measures however conflicts with Miller's (2004) ecological economic analysis that the money supply should be left free to evolve so it can be liquid and efficient. Again the tension between efficiency and resilience arises. Some still argue that an unregulated money supply can be resilient as well; though perhaps discredited by recent events, Alan Greenspan argued that "Enhanced flexibility provides the advantage of allowing the economy to adjust automatically, reducing the reliance on the actions of monetary and other policymakers, which have often come too late or been misguided" (Offut 2005, 1). Rose (2004) also has faith in the dispersity attributes of markets: "Prices act as the 'invisible hand' that can guide resources to their best allocation even in the aftermath of a disaster".

In a bid to prevent future financial breakdowns, world authorities met in Basel Switzerland in 2010 and agreed to make banks start holding 2% more capital in reserve, but for the time being these measures are largely voluntary on a country by country basis and are likely to be challenged later if the economy seems to improve. Following the meeting, Bank of Canada Governor Mark Carney explicitly drew attention to the above tradeoff when deciding on capital requirements: "The point is not to pile up so much capital in our institutions that they are never heard from again, either as a source of instability or of growth. The challenge is to get the balance between resiliency and efficiency right" (McKenna 2010, B4). The lesson remains though that banks should never be allowed to accumulate liabilities greater than their reserves, or at least the capacity of governments to bail them out.

Speaking of which, central banks have traditionally provided the first line of resilience in the money supply. Historically, the catastrophes of the San Francisco fire of 1906 and financial crisis of 1907 provided the original impetus for the creation of the US Central banking system in order to help build future resilience to shocks into the monetary system. The Federal Reserve was created to act as a lender of last resort that could bail out banks who do not have sufficient liquidity, guaranteeing all existing bank deposits and debts. It also reduced dependency on foreign funds, increasing system autarky (Homer-Dixon 2006). During an economic downturn, central banks need to keep pumping liquidity into the system because private banks cannot. In these ways, central banks around the world are fixtures of monetary resilience and calls by some political Libertarians to disband them betray a foolish ignorance of the history and rationale for their creation.

This is not to say there are not legitimately debateable aspects of the current central banking institution: for example the recent massive bank bailouts ended up simply transferring private debt to public debt with little provision for paying governments back, greatly setting back just distribution. Likewise, the first response of central bankers to a global economic breakdown is to slash interest rates in order to reignite economic growth, but this can provide a perverse incentive for people to take on additional debt that may eventually make the system even less resilient. Low interest rates can also lead to dangerous inflation which perpetuates paranoia over a currency's perceived lack of value.

By way of historical example, Rome in the 3rd century AD had runaway inflation because it tried to pay for its army by debasing the currency used for payrolls (Tainter 1988, 143; Wright 2004, 93). This inflation "devastated the economy" as the last Roman emperors churned out coins and taxed the peasants in order to double the size of the Roman army and public bureaucracy in a vain effort to contain the chaos (Tainter 1996). Thus the usual preoccupation of the central bank with controlling inflation may actually make sense during a prolonged breakdown when employers and the government are in no place to raise wages or pensions commensurately. Even though a downturn should logically lead to deflation because there is no demand for money, a prolonged breakdown can often paradoxically lead to runaway inflation (e.g. Weimar Germany) if the government tries to raise the economy out of stagnation by printing more money, a strategy that history has proven rarely works. It will be interesting whether current quantitative easing schemes in the United States are successful at boosting exports or just lead to a depreciated dollar that depresses aggregate demand.

This interdependence of the global monetary system has also reduced its autarky and made addressing global economic problems that much more complex and difficult. Experts have emphasized the necessity of joint coordinated global action in addressing the financial crisis because any country failing to act, or working out of sync with its trading partners, could actually make the problem worse. Unified international currencies such as the Euro which are very beneficial and efficient when things are going well may violate the principles of autarky, diversity and dispersity. It is more resilient for each country and region to have their own currency so they retain the flexibility to respond to breakdowns in ways most suited to their own economic conditions, such as inflating their way out of the debt problem as Argentina did.

Certainly, "national currencies are subject to inflation, deflation, and collapse as well as to manipulations and panics beyond the community's control. One solution is the promotion of local barter systems; another is the creation of a local currency. Both are legal (if operated within certain guidelines) and have long histories of success" (Heinberg 2003, 216). Local community currencies (ITHICA dollars etc.) are interest and debt-free, and their diversity, dispersity and autarky make them resilient if the larger system breaks down (Hopkins 2008, 62), but this is less efficient than having one unified national or international medium of exchange. Nevertheless, a breakdown of national currencies following a particularly severe environmental resource shock could force the creation of local currencies as an adaptive response the world over. To help build their adaptive capacity, communities could begin pre-emptively laying the groundwork for adopting a local currency if the situation ever demands.

It may also be very efficient to move to a cashless society based on electronic payments using debit and credit cards, and it would also be good for the environment by saving plant material and minerals. However, card readers, ATMs and even cash registers will cease to function if the electricity fails in a deep breakdown, creating major problems for both retailers and consumers. Electronic payment methods can also cease to function if server connections are interrupted (Stein 2000).

Indeed, any capital in the form of currency, be it paper or electronic, is of questionable usefulness in a crisis situation. Yasutomi (1995) and Kunstler (2006, 234) highlight the fundamentally arbitrary nature of money, the tenuous and abstract relations between this asset and what it is supposed to represent, and the ease with which it can fail as a unit of exchange during a breakdown. Put simply, when things get truly difficult people become far less willing to accept money and instead turn to bartering real tangible goods needed for immediate survival (Heinberg 2007, 177). Those expecting retirement checks, dividends, or paychecks may have a long time to wait in the aftermath of a breakdown (Perrow 1999, 398). Even gold is completely arbitrary and only holds the value that humans attach to it, though it still might not be a bad idea for individuals to own a little silver or gold they could at least try to trade for necessities in an emergency, since these may be one of the few currencies still accepted (Lele 1998, 252).

Ultimately, the resilience of the money supply hinges on little more than psychological faith in the social contract it represents (Greer 2008, 94). During the Great Depression, FDR reminded the shaken public about this during one of his fireside chats: "there is an element in the readjustment of our financial system more important than currency, more important than gold, and that is the confidence of the people themselves… You people must have faith; you must not be stampeded by rumours or guesses. Let us unite in banishing fear" (Roosevelt 1933, 8). The key then to ultimate resilience in the money supply is improving people's adaptive capacity, in the face of breakdowns, to maintain their belief that their currency still holds value and that it is safe left in the bank. Adopting Homer-Dixon's (2006) prospective mind could help in this regard. Because of looming environmental resource shocks that will impose very real physical hardship, a future collapse of public confidence in money and the financial system "could easily be worse than that of the Great Depression because we will not be living in 'want amidst plenty', as FDR put it, but in hardship among scarcity" (Kunstler 2006, 234).

6.3 Electricity and Energy Utilities

Energy is our master resource (Homer-Dixon 2006). Human societies "are open systems that depend upon the flow of energy and matter to create temporary islands of order" (Heinberg 2003, 11). Without a constant supply, human civilizations quickly break down, but with enough energy, they can surmount nearly any difficulty. A 100% resilient energy system would have to be able to guarantee that society had access to all the energy it needed to respond to, mitigate and rebuild any breakdowns in the other sub-sectors in this chapter. But as ecological economists know, there is only a finite supply of low entropy energy available on planet earth. We will never have as much energy during good or bad times as we would like. So rather than pursuing the impossible goal of perfect resilience in all of our energy sources, this section will focus on two of the most important for basic survival at the household level in the developed world: energy for heating buildings and electricity (which in a warming world is increasingly used to cool them).

Perrow (1999, 404) explains our electricity supply is unique among major industries and systems in three ways that are important to its resilience, or lack thereof:

> It is the lifeblood of our modern society; without it, most things we depend upon would fail. The second unique aspect of power systems is that electricity is the original and ultimate example of the 'just-in-time' system we have introduced intro manufacturing, increasing its tight coupling. Electricity cannot be stockpiled in large quantities to tide us over until we get the system fixed. A third unique feature is that the electric systems in North America are tightly interconnected within and between four major electrical interconnections known as 'grids'.

Indeed electricity is among the most fundamental resources upon which all sectors of our technological economy depend (Lovelock 2006, 153). If this flow is disrupted, chaos ensues: "Experience data from recent disasters indicates that while virtually all infrastructure sectors are disrupted by electric power outage, the most significant and frequent impacts occur from disruptions to building support, water, food storage, hospitals, public health, and road transportation" (Chang et al., 2006, 33).

Since the 1950's, electricity has been cheap, reliable and largely taken for granted (Patterson 1999, 136). Yet, "in today's energy system, the great reliability of supply most of the time makes designers less likely to take precautions against rare, catastrophic failures which they have not experienced and hence do not consider credible" (Lovins and Lovins 2001, 185). However it is surprisingly easy for outages to cascade through the electricity system in a classic synchronous failure:

> The national electric grid is fragile and can be easily disrupted. Witness the Northeast Blackout of 2003, which was caused by trees falling onto power lines in Ohio. It affected 50 million people in eight states and Canada, took days to restore, and caused a financial loss in the United States estimated to be between $4 billion and $10 billion. People lost water supplies, transportation systems, and communications systems (including Internet and cell phones). Factories shut down, and looting occurred. As extreme weather events becomes more common, so do the threats to our national electricity supply. (CNA Corporation 2007, 38)

This has been painfully demonstrated by the repeated storm outages in British Columbia in the last few years. Perhaps most worrisome, the 1998 Quebec ice storm demonstrated that a prolonged winter in northern climates without access to traditional electricity or heat sources could potentially kill millions of people.

Each major type of electrical generating technology has positive and negative resilience characteristics. Jurisdictions like Ontario will need to weigh these as they decide which supply sources to pursue in the coming decades. Again, the apparent tradeoff between resilience and efficiency appears. On one hand, there may be significant economy-of-scale and efficiency benefits to a continued reliance on centralized generation (nuclear, coal, natural gas, deep geothermal and hydro) and interconnected electricity production and distribution systems (Patterson 1999, 79). On the other hand, as the great North American blackout of summer 2003 demonstrated, a centralized system may be less resilient than one based on many small local renewable sources. Centralized generation is entirely dependent on the integrity of the network and the Quebec ice storm abundantly showed the vulnerability of power lines (Patterson 1999, 17). Moreover, since the 1980s the privatization of electricity has introduced difficulties in coordinating central system stability (Patterson 1999, 167).

The autarky principle of economic resilience mandates that we reduce the proportion of our power dependent on a steady stream of fuel inputs (fossil fuels and fissionable materials). It also means decreasing the distance between power sources and end-users, and increasingly shifting to more flexible decentralized generation to enhance the dispersity of our power grid (Lovins and Lovins 2001). As Homer-Dixon (2006, 284) notes, "the more power we produce with solar panels on our rooftops, the less vulnerable we'll be to power disruptions far away". Wind and especially solar power are indeed the most self-sufficient electricity sources available, particularly if installed at the household level. Because of their passive nature, renewables can keep providing power with no one around to operate them. Getting the prices right on carbon and ending subsidies to non-renewable resource extraction are measures that can greatly encourage this shift and simultaneously enhance economic efficiency (Heinberg 2003, 222).

The redundancy principle of economic resilience suggests that at the cost of some efficiency, we should build extra transmission lines, transformer substations and gas pipelines in case some are damaged. Likewise we need redundancy in the manufacturing plants needed to repair power system components. Proposals to build small natural gas plants in Ontario communities that only operate a few hundred hours a year to handle peak demand would have the side benefit of enhancing redundancy year-round (Swayze 2008). Furthermore they would be meeting the dispersity principle: "The geographic distribution of the so-called "peaker" plants also provide greater flexibility to the transmission system when there is a major accident, such as a fire at a transmission station" (McCarthy 2010). Despite their other resilient characteristics, the fact that solar and wind power can be interrupted by changing weather conditions renders them unable to meet the redundancy principle.

Therefore, to ensure the resilience of our overall electricity supply we should diversify our energy sources as much as possible, which means supporting a mix of both small-scale renewables of all kinds and centralized generation. Ideally a city should have enough disperse, decentralized power sources to allow most essential utilities to operate if centralized grids fail (Patterson 1999, 166). Yet because of their own inefficient drawbacks like cost, dependence on conditions and the large land area taken up relative to their small energy output, renewables alone will probably never be able to meet all our daily energy needs. Nuclear and coal have higher fixed costs but lower operating costs, allowing them to more efficiently operate 24/7 to meet base load demand (Patterson 1999, 79). Environmentalists would do well to keep in mind the need for diversity when they lobby for the complete phase-out of nuclear power. In Ontario at least, nuclear is especially attractive because it is largely "free of emissions and independent of imports from what will be a disturbed world" (Lovelock 2006, 153).

Expansion of coal power relying on carbon capture and storage, on the other hand, would likely discourage diversification of our electricity supply. If the massive investment in complexity in carbon capture infrastructure is made, supporting coal plants will invariably be constructed around it to make up for the significant energy lost in the sequestration process. Just like the Romans, this would mean locking ourselves into an inflexible system with declining thermodynamic returns. Nevertheless, due to the world's plentiful remaining supplies, coal still has a place as an energy option of last resort. As it hopefully proceeds to decommission its remaining coal plants, Ontario should not completely dismantle them, but instead pay just enough to keep them in operational condition for an emergency.

Cogeneration power plants are more resilient and efficient because they vent heat where it can be used productively, remove some dependence on water inputs along with the need for solid waste removal, and can be situated within urban areas (Patterson 1999, 114). Drought shocks induced by climate change may deprive traditional power plants and hydro dams of the water they need to power and cool themselves. Likewise, unlike fossil fuel and nuclear generators, incineration plants do not require low entropy fuel inputs and can just keep burning fuel of all shapes and sizes. When people are cold, the range of things they are willing to burn as garbage quickly multiplies.

It should be noted that centralized generation sources tend to be less safe-fail than smaller disperse renewables (the repercussions of their failure are more severe) (Perrow 1999, 335). If society breaks down or power authorities desert their posts, there may be a heightened chance of a burst hydroelectric dam or nuclear meltdown which can threaten large numbers of people (Weisman 2007). The lack of redundant safety systems in Japan's Fukushima nuclear plants was clearly demonstrated following the March 2011 tsunami. Fortunately, Canada's Candu nuclear technology is designed more with safe-fail than robustness in mind: by locking down if something goes wrong it ceases to produce power (still detrimental in times of emergency), but also ceases to be at risk of exploding. Of greater concern are waste fuel facilities, where spent rods remain at risk of overheating (releasing radioactive clouds) for several years if cut off from the fossil fuel needed to cool them (Weisman 2007). However, the fact that the majority of the world's reactors, including those in Japan, were built using 30-40 year old technology provides hope that with renewed funding for nuclear research, new reactor types incorporating more resilient design principles (such as redundant arrays of battery powered cooling generators) and using fuel like thorium and depleted uranium could be developed to reduce these risks. For its part carbon capture and storage has the worrisome potential for gas leakages (either into the atmosphere or surrounding populated areas with deadly results) if not constantly monitored. Similarly deep geothermal power can potentially trigger earthquakes.

The more complex a system, the more energy it requires to maintain its order far from thermodynamic equilibrium in a universe governed by entropy. Therefore reducing energy use can reduce complexity and improve resilience. When it comes to the electricity supply system, Lovins and Lovins (2001) argue that encouraging demand-side efficiency is key to the overall resilience of the grid. This makes common sense – reducing electricity demand means less dependency on the grid, so people will be less affected if it breaks down – a safe-fail approach. Here then is another case where efficiency is compatible with resilience. Demand side conservation can be achieved through a combination of more efficient technologies and changes in consumption behaviour achieved through education and especially higher electricity prices.

Limiting our dependence on imported fossil fuels is also necessary to enhance the resilience of home heating systems. Homer-Dixon (2007 interview) believes governments should be “providing incentives for people to install ground-heat pump systems to heat their houses”. He suggests legislation to bind subsequent owners of a house to paying for the initial installation of these systems to amortize the cost. Moreover, buildings incorporating green architectural features that naturally absorb or disperse energy from the sun and retain heat through insulation can forgo traditional electrical and heating systems yet remain liveable in a variety of climates (Steffen 2006). Incentives could also be provided for citizens to purchase portable generators (especially hand-operated ones) and stockpile batteries, candles and firewood as fall-back energy sources during a power failure (Homer-Dixon 2007 interview; EMO 2006). Larger backup generators may also be need to power critical appliances like refrigerators and sump pumps, however these tend to be inefficient and polluting. Finally, skyscrapers make efficient use of our land area which helps sustainable scale but if the electricity required by elevators and pump water fails, upper storeys will quickly become unliveable (Kunstler 2006, 253). Given this, cities may want to consider bylaws to limit the number of storeys allowed in future development.

The necessary actions to enhance electricity and energy resilience are summarized in a report commissioned by the US Department of Defence (CNA Corporation 2007, 38), which explains that it can improve the energy resilience of its facilities by a threefold strategy of deploying more efficient technologies, renewable energy sources, and “islanding” installations from the national grid. Yet Homer-Dixon (2007 interview) notes there are not only economic but institutional impediments against heat pumps and all forms of small-scale local generation. Societal leaders are not thinking in these terms, and the civil engineering culture assumes energy must be centrally provided. Tainter (1996) argues that ultimately energy simplicity will be achieved in the future either through a collapse marked by violence, starvation and population loss, or a ‘soft-landing’ made possible by the voluntary shift to solar power, green fuels, energy efficient technologies and less consumption. But this “will come about only if severe, prolonged hardship in industrial nations makes it attractive, and if economic growth and consumerism can be removed from the realm of ideology” (Tainter 1996). Heinberg (2003, 222) declares that “even at this late date, a truly heroic national effort toward developing renewables could succeed in substantially reducing social chaos and human suffering in the decades ahead”.

6.4 The Water Supply

Historically rivers were the lifeblood of civilizations. The availability of water remains critical for economies and is among the systems most dependent on the proper functioning of natural systems and in turn ecosystem resilience. Humanity has compromised this resilience by consuming water much faster than it can be recharged. Due to factors such as climate change, water systems are becoming increasingly vulnerable. Droughts now plague the south-eastern United States, southern Europe, parts of Africa and Pakistan where tension over water threatens to spiral into armed conflict with India (Dyer 2008, 121). In Australia the call has gone out to develop a "resilience framework" for addressing the water needs of Australia's cities, agriculture and ecosystems (Cawood 2007, 48).

Over the last few years British Columbia Canada has been hit with a succession of mild water shocks. The Town of Tofino experienced a water shortage caused by lack of rain that heavily disrupted the local economy. Water was limited to residential use and many businesses were forced to close while bottled water was trucked in from outside. Similarly, Vancouver's water supply was disrupted by turbidity in local dams and two million people were told to boil water or drink bottled water for a week. Indeed, more population centres globally are becoming heavily dependent on the trucking in of bottled water as the most sought after commodity on earth becomes increasingly privatized. Yet this violates the autarky principle of economic resilience: a community cannot rely on outside water always being available because pumping, bottling and trucking systems can all be interrupted, especially as water scarcity begins to hit every community simultaneously in regions like western Canada and the southern United States.

Additionally, even municipal water supplies can be interrupted: "water availability is influenced by the survival of the electric power and transportation systems. Electric power may be needed to drive pumps that enable the water system to function; transportation disruption can impede the ability of the water utility to make repairs in a timely manner" (Miles and Chang 2003, 141). However, "few communities are prepared to meet energy-based challenges to their ability to supply clean water to citizens" (Heinberg 2003, 216). If treatment plants cease operating human sewage may back up into rivers and lakes, contaminating natural water supplies (Weisman 2007).

Building autarky and redundancy into water infrastructure, both natural and man-made, is thus of paramount importance (Gunderson 2003, 45). Measures to preserve and restore water recharge areas like wetlands and moraines benefit both the resilience and scale imperatives and are the first line of defence in guaranteeing uninterrupted access to the water that human and animal populations need to survive. Authorities also need to begin identifying emergency water supplies in non-traditional areas in case droughts force mass migrations. Technical solutions like desalinization plants (e.g. San Diego) and cloud seeding may provide supplemental autarky but carry their own fail-safe risks.

For short-term water emergencies households can maintain a stockpile of bottled tap water (EMO 2006). To ensure medium-term resilience they could purchase mechanical purification devices (available at most camping stores) which can be used over and over again: if society breaks down the threat of water supplies becoming contaminated by chemicals and disease is very high (Perrow 1999). Households can also own rain barrels to collect rainwater in emergencies, which the Region of Waterloo provides free-of-charge to reduce water demand, a scale issue (Steffen 2006). Indeed, key to achieving water resilience is controlling its scale of use (reducing dependency on the system). For example, rather than having a sewage system based on water, every home and business could be refitted with biomass toilets that will continue to work without water.

6.5 Transportation Networks

Maintaining a steady flow of goods and services is necessary for the operation of all the previous subsystems, especially trade. If transportation networks break down during a catastrophe, all levels of the economy will be cut off from key inputs (i.e. goods and supplies) and the ability to remove harmful outputs (i.e. garbage and hazardous waste) (Heinberg 2003, 181). Heinberg (2003, 175) notes that "serious consequences of reduced transportation will be felt in disruptions in the distribution of goods. In the 1980s and '90s, increased global trade resulted in the moving of products and raw materials ever further distances from source to end user". Tight coupling among modern firms (Homer-Dixon 2006, 400) means transportation disruptions can be devastating.

Modern transportation systems depend critically on internal combustion engine vehicles: "More than 80 percent of everything ever built in America was built after World War II, and most of it was designed solely to be used in connection with cars" (Kunstler 2006, 26). There are certainly efficiency benefits to specializing in one interlinked mode of transportation (roads and the automobile). However, this system's resilience has been greatly reduced by its rapid growth up the adaptive cycle and extreme specialization.

Unlike other subsystems, it is fairly easy to predict what shock will bring down present-day transportation systems: a shortage of its key input, oil. The availability of fuel in turn is dependent on enough vehicles being available at the right place and time to transport it long distances from source to markets. Yet every indication is that the oil upon which so much of our present transportation system depends will become increasingly scarce and expensive in the decades ahead due to the well documented peak of world oil production (Gilbert and Perl 2008). Beyond the actual geological scarcity of cheap oil, supply interruptions may be caused by climate change or political strife in an era of environmental flux.

Cheap oil has led to a dependence on overlong supply chains (both within nations and on a global scale) that will likely break down when oil becomes more expensive. Most urban centres are dependent on only a few arterial highways (e.g. 401) to provide their vital goods, and so are gambling with their resilience in the event of a shock like a road blockage or oil shortage. Supermarkets we assume will always be magically full of food actually carry only a few day's worth of stock and can be easily cut off from incoming produce, leading to chaos (Kunstler 2006, 244). Similarly gas stations can be cut off from fuel and if electricity shuts off, gas pumps will not work (Stein 2000). A tanker truck bringing relief to a cut-off population is consuming the very energy it carries. Such breakdowns also have implications for health, including the transportation of sick and wounded and the distribution of drugs and vaccines.

Conceptually, the easiest way to increase the resilience of our transportation system is to increase the redundancy of existing infrastructure by building more of it. In the Toronto area, highways are already at maximum capacity during rush hour, meaning in a breakdown situation they will quickly become gridlocked by evacuees. Locally in Waterloo Region, there are only two bridges over the Grand River – if those were cut off, our main supply lines would be as well. But building more bridges would require growth that compromises scale, unless we sacrifice other construction projects, possibly at the cost of efficiency. Furthermore, redundancy of traditional transportation can only go so far: for example, in the absence of continual maintenance in a situation of societal breakdown, pavement will rapidly degrade, especially in northern climates (Kunstler 2006, 264). We should consider whether we wish to continue expanding a highway system we may no longer have the societal resources to maintain (Gilbert and Perl 2008, 281).

Deeper resilience thus requires us to heavily diversify our transportation system and stop policies that lock us into traditional transportation modes that presume infinite supplies of cheap oil (Gilbert ant Perl 2008, 238). This could mean simply changing the engine that powers our cars by rapidly investing in the expansion of electric battery infrastructure for automobiles and scooters (Gilbert and Perl 2008, 273). The economic shock that has hit the automotive industry has provided political leaders with an ideal opportunity to transform North America into a global leader in electric car manufacture, but so far this opportunity has been ignored in favour of bailouts for the status quo. More futuristic options include shifting to PRTs (personal rapid transporters), which are fully automated 1-6 person vehicles on reserved guideways (Gilbert and Perl 2008, 157)

But economic resilience also requires diversifying away from the personal vehicle and towards public/mass transit. A key to this will be rebuilding North America's decrepit passenger rail service, which is decades behind Europe and Asia (Gilbert and Perl 2008). Kunstler (2006, 268) believes this task is as monumental as originally building the highway system, yet its cost (mainly land re-acquisition) may be small compared to the challenge of trying to maintain the existing highway system in a societal breakdown.

Electrified trains (passenger and even freight) are likely better for scale and resilience than diesel trains or buses because electricity can be generated closer to the citizens who use it rather than having to import fossil fuel from far away deposits (Gilbert and Perl 2008, 286). Most existing US rail infrastructure is already at maximum capacity hauling freight, making sharing lines with new passenger trains impractical, so dedicated high-speed rail lines between cities would enhance redundancy. This is another case where building resilience would benefit economic efficiency as well, since high speed trains can move commuters far faster than highways. We may even need to start preparing for the return of steam locomotives by studying the lost art of manufacturing condensed steam boilers because they are simple and cheap to make and can burn almost anything as fuel.

Within urban areas, major investment in urban light rail, trolley bus and tram transit could be undertaken (Gilbert and Perl 2008, 273; Heinberg 2003, 232). These rail lines would preferably stay above ground – without electricity to power pumps, water will flood subway systems (Weisman 2007). Municipalities could reclaim inter-urban rail lines from hiking trails and also start laying light rail lines along existing right-of-ways of roads for electric trolleys and streetcars. If things become truly desperate these could even be pulled by draft animals (Kunstler 2006, 269). When considering efficiency implications, urban mass transit is certainly more efficient with fuel and moving people in crowded areas, but not as efficient in terms of flexibility or convenience as personal vehicles, again suggesting the resilience/efficiency tradeoff.

Public and private sector investment in mass transit could be made economically viable by including the costs of environmental pollution and road infrastructure in gasoline taxes and license fees (Curtis 2003, 91; Gilbert and Perl 2008, 283). All of this would have implications for distribution –for example, it could at least temporarily put many auto workers and truckers out of work. Yet better public transit would improve distribution in the net because our current automobile based system is biased against lower income people who cannot afford cars (Gilbert and Perl 2008, 233). As an aging population increasingly migrates from the suburbs back to the inner city in the face of higher fuel prices, the demand for effective public transportation will only increase.

As long as fuel was inexpensive, air travel could be considered highly beneficial for economic efficiency because of its speed. However, its heavy contribution to greenhouse gasses and oil depletion are at odds with the scale principle and it is not a particularly resilient form of transport because large planes are entirely dependent on high grade fossil fuel and well maintained runways. The 2010 volcanic ash cloud over Iceland illustrated how dependent we have become on airplanes for intercontinental travel with no redundant backup available, and dust storms arising from climate change may create similar situations. Taking resilience into account would suggest we stop subsidizing the expansion of the airline industry (including airports) (Gilbert and Perl 2008, 281). Propeller driven aircraft and perhaps even solar powered airships could be required by authorities to make up a greater percentage of commercial fleets to reduce emissions and prepare for the day when oil becomes truly scarce (Gilbert and Perl 2008, 274).

As the price of airfare rises due to compounding shocks, it may increasingly become an option only for the rich in spite of taxpayer subsidies, hurting distribution (Kunstler 2006, 270). We may therefore see a return to ocean liners as the main means of global passenger transportation, but perhaps with more of the luxuries found on modern cruise ships (Gilbert and Perl 2008, 294). Kunstler (2006) also calls for the reactivation of waterfronts and canals (including on the Great Lakes) so that maritime shipping can once again become a major source of trade. In the 20th century, many wharfs and warehouses were dismantled in favour of parks and condo development, which are efficient land uses only so long as there is no disruption in the road network. Ships could also be mandated to carry sails in case of oil shortages (Gilbert and Perl 2008, 1).

Because most vehicles would still be dependent on the electrical grid, ultimately the best principle when it comes to transportation is autarky: encouraging self-sufficiency so people do not depend on far away products and do not need to travel long distances to acquire critical supplies: "Communities which have been designed to be walked and biked rather than driven can better withstand a disruption in the supply of gas" (Steffen 2006). Unfortunately in the last decades the trend has been in the opposite direction. Kunstler (2006, 233) believes the rush to suburbia after WW2 represents the greatest misallocation of resources in human history – it was efficient only so long as cheap energy prices held, and now we are stuck with a system that violates diversity and autarky principles (e.g. far from food).

Walmart may have brought the efficiencies of standardization and economies of scale, however it has led to communities that are pedestrian and mass transit unfriendly. Heinberg (2003, 216) worries: "Once a local economy has been destroyed by dependence on the "big box", the chain frequently pulls out, forcing members of the community to drive tens of miles to the nearest larger town for basic consumer needs." Cuba, which was forced to adapt after being cut-off from Soviet oil, provides an interesting contrast and a possible glimpse of the future: "Today there are few cars on Cuban roads, but nearly every vehicle is filled with passengers due to an official policy that systematically encourages hitchhiking. Bicycles are common, and animals (especially oxen) are often used both for human transport and for traction in agriculture" (Heinberg 2004, 107).

In terms of autarky versus efficiency, stopping urban sprawl (e.g.. by municipally taxing land rather than properties) and placing less dependence on the car in urban planning (e.g. by raising national fuel taxes) are policies which can be said to be both resilient and efficient (Heinberg 2003, 218). Gilbert and Perl (2008, 286) believe we need to start transforming our transportation system sooner rather than later, and that the massive scope of the necessary overhaul will require diverting resources from other sectors of the economy. Yet it is not without precedent: in 1942, the United States forced its industry to stop making all cars and light trucks and within months had switched 75% of its machinery to war equipment in spite of claims by auto company executives that this goal was impossible to achieve (Gilbert and Perl 2008, 22).

6.6 Communication and Information Systems

The virtual information sector is now among the most important to 21st century economies. Allenby and Fink (2005, 1035) note that in response to globalization, "Institutional structures are shifting from rigid to more fluid and responsive network-centric organizational patterns", which helps them absorb, manage and respond to information quicker and thereby improve their efficiency and adaptive capacity. Yet the increasing dependency of firms and individuals on interconnected information networks also has the potential to reduce overall societal resilience: "Information and communication networks can all too easily be obstructed by a disruption at some key node" (Vale and Campanella 2005, 350).

As communications technologies continuously evolve they open up new benefits and vulnerabilities. Compared to landline telephones, cell phones provide greater efficiency through mobility but in turn require more electricity to keep their batteries charged and receiver antennas operational. Similarly, as recent school shooting incidents in North America have demonstrated, cell phone frequencies can quickly become overloaded in a crisis. Unlike cell phones, landlines will continue to function for a number of days in a power blackout thanks to emergency batteries in central telephone exchange rooms. To greatly increase landline resilience, these batteries could be charged by solar panels. Alternatively, hand-cranked dynamos could be installed on every telephone: this technology from the last century allowed telephone networks to be set up in rural areas before electrification.

However, Vale and Campanella (2005, 35) have faith that because it is a distributed network, the internet can provide the resilient communication system modern society needs. The internet certainly has the potential to profoundly transform the structure of our economy. Allenby and Fink (2005, 1035) explain how a shift to telecommuting motivated by improvements in broadband infrastructure and higher fuel costs could simultaneously benefit resilience, scale, distribution and efficiency. First, the shift to working out of the home could enhance economic resilience by decentralizing the workforce so it is less vulnerable to a single shock (e.g. blizzards, bad air quality days or transportation disruptions). In the event of a sudden breakdown more people would be at home where they are most needed rather than stuck in workplaces. Second, fuel savings and the reduced demand for new road and highway infrastructure could substantially help sustainable scale. Third, by offering the flexibility of non-placed based work and temporary hours, telecommuting could improve just distribution by allowing more people, including women, the elderly and the disabled to participate actively in the economy: "if properly managed, a network-centric society might well be more equitable, more productive, and therefore perhaps less fragile in the face of challenge" (Allenby and Fink 2005, 1036). Likewise, a better sense of community and security could result from more people working in their own neighbourhoods. Finally, telecommunicating could improve efficiency by reducing time spent travelling, freeing up time for more productive pursuits and reducing traffic congestion. The internet could also allow for a greater shift to just-in-time manufacturing and even a preorder economy, which have incredible efficiency benefits, allowing society to produce higher-valued goods yet reduce the scale of the economy by dispensing with unwanted products and unnecessary packaging and inventory (Stanley 2006).

Clearly, computers and interconnected data networks have provided extraordinary benefits to economies, not just by improving the flow of information but by better coordinating the allocation of capital and labour. The internet also allows information to be spread digitally around the world at little cost to environmental scale or dependency on fossil fuel based transport. Yet like most efficient technologies in this chapter, information systems are tremendously beneficial so long as the system is functioning smoothly, but can immediately turn into liabilities when things start to break down.

Our mass interconnected, interdependent computer network in many ways fundamentally violates the autarky principle. The great database of human knowledge and experience is increasingly tied up in and only accessible through computers and the internet which Heinberg (2003, 185) ominously warns are "directly dependent on regional electrical grids. These grids are complex, costly to maintain, and highly vulnerable to interruptions in the supply of basic energy resources…. unless an alternative renewables-based electrical infrastructure is already in place, the information infrastructure of industrial societies will collapse and virtually all electronically coded data will become permanently irretrievable”. Even computers with batteries like laptops and servers that have auxiliary generators can only last a short while off the grid.

Online encyclopedias like Wikipedia are putting print ones out of business, and for the last 10 years many university libraries have stopped carrying print journals. It is efficient and saves paper to keep information on easily searchable centralized computer servers rather than for every home or university to have a copy, yet it is not disperse or redundant, for if the power fails people will instantly lose access to information. Holling (2008 personal communication) agrees that the shift to internet journals leaves our knowledge base vulnerable, but also points out that the open-source nature of online journals like *Ecology and Society* are better than print ones at helping to foster the creativity needed for the adaptability and transformability principles of economic resilience.

Indeed copyright protection, patents and digital rights management that aid economic efficiency can serve as a barrier to making redundant copies of information. Peer to peer file sharing (e.g. bit torrent) perhaps better satisfies the dispersity principle than traditional central servers. Notorious website The Pirate Bay calls itself "The world's most resilient bittorent site" after resisting repeated attempts by copyright holders to have it shut down to prevent illegal file sharing, and even if they are successful the peer to peer connections it established will remain.

The new trend toward cloud computing (storing data remotely on centralized servers) in the name of convenience (i.e. efficiency) can also enhance dispersity by providing an optional backup in another geographic location and at a higher system scale. Yet full cloud computing that does away entirely with local on-site data storage jeopardizes autarky because access to information becomes completely dependent on the internet staying up. Allenby and Fink (2005, 1034) explain that the internet is a largely scale-free network, which makes it “highly resistant to random failures, in that a substantial number of links can fail and still not affect the performance of the network as a whole. But such architectures are very vulnerable to a deliberate attack directed against the major hubs”. They therefore recommend that information networks be designed with geographically separate hubs (dispersity principle), the duplication of critical ones (redundancy), and sensitive network security systems (adaptability).

Indeed, "Ensuring that data and information are not located only in one area, but duplicated in facilities that would not be affected by the same local event, similarly helps protect against catastrophic loss" (Allenby and Fink 2005, 1035). This was made abundantly clear in the wake of the September 11 attack, where firms like Lehman Brothers and Cantor Fitzgerald that had backup data facilities were able to resume operations immediately whereas both the main and backup offices of the Bank of New York were caught in the cordoned off zone (Homer-Dixon 2006, 399). Nevertheless, lessons from 9/11 have probably helped to make global computer facilities more disperse and redundant.

Overall, digitization and networking have reduced the autarky of many key systems: "Whether these systems be military or industrial, financial or bureaucratic, the increased tightness of coupling, lack of redundancy, and speed of response, will make human intervention or control difficult at best when something goes wrong – particularly for those systems whose means and mechanisms of operation are so deeply embedded in the computers that operate them that no human being fully understands them" (Rochlin 1997, 215). Indeed, since few people know how their computers actually operate, if a breakdown upsets manufacturing, people could lose the ability to build or repair their computers and within a generation the knowledge they contain would be lost.

Allenby and Fink (2005, 1034) claim that unlike telephone networks, internet-based networks "are being designed to continuously monitor and tune their own performance; adapt to unpredictable conditions (making them resilient and not just engineered for redundancy); predict, prevent, and gracefully recover from failure". But Rochlin (1997) warns that computers can only do what they were programmed to do, and so are inherently much worse than humans at responding to situations out of the ordinary. Therefore, improving the adaptive capacity of information systems is not only about designing better technology, but also preparing people "to make decisions on the basis of partial knowledge and partial information" (Rochlin 1997, 190).

This also has implications for governance structures. Since some of the most critical information necessary for adaptive capacity is communicated by municipal governments, in metropolitan areas there is an advantage to having separate municipalities able to make decisions rather than mega-cities. The latter bring the efficiency of amalgamation but the former have greater dispersity and autarky (they are closer to the affected populace making it easier to transmit instructions that are most relevant to local needs). Every home should be encouraged to purchase a hand-cranked radio to listen to emergency information (EMO 2006). One of the most resilient ways to pass on this and other information during breakdowns is through old fashioned word of mouth, yet neighbourhood social webs have unfortunately deteriorated in many modern suburbs.

Rochlin (1997, 215) also worries that in this age of digital specialization where information can be looked up rather than memorized, we have lost vital experience and know-how: “the computerization and automation of complex and risky systems not only prevents humans from gaining expertise, but interferes with their learning how to respond at all without computer aid”. One way to overcome this problem is by setting up modern academies to teach a proportion of the population endangered but vital skills from earlier times (like how to build and operate a steam engine or hand-spin wool). Because these skills are of little use as long as our technologically advanced system runs smoothly, we would have to pay people to learn them just like we do with army reservists. There is an efficiency cost to training these ‘resilience reservists’ but it may be worth it. More broadly, our education systems should actively seek to develop Homer-Dixon’s (2006) prospective mind in all young citizens so they will be better ready to adapt to whatever lies ahead.

Since even acid-laden paper may disintegrate after a few hundred years, a prolonged breakdown in society could threaten most of the knowledge we have accumulated since the dawn of history (Heinberg 2007, 183). Both Lovelock (2006) and Heinberg (2004, 155) therefore believe strongly in the need to create dedicated cultural preservation centres to act as redundant repositories of the knowledge, tools and technologies that are as important to the resilience of economies as genetic information is to the resilience of ecosystems. Those in charge of running these institutions would be like ‘new monks’, ready to emerge following a catastrophe to help the world adapt and transform: “The monasteries carried through that earlier Dark Age the hard-won knowledge of the Greek and Roman civilizations, and perhaps these present-day guardians could do the same for us” (Lovelock 2006, 155). Like the seed bank, these centres could also house the genetic information of every known plant and animal species on earth, effectively creating modern-day Noah’s Arks.

Finally, because of the difficulty in picking out easily understood, useful and impartial information from the debris of civilization, Lovelock (2006, 156) suggests that “One thing we can do to lessen the consequences of catastrophes is to write a guidebook for our survivors to help them rebuild civilization without repeating too many of our mistakes…an accurate record of all we know about the present and past environments”. It must be written on durable paper with long-lasting print, not on any medium that needs electricity to read it. It would preserve and present the most vital accumulated knowledge of human civilization, including astronomy, chemistry, known fuel and mineral reserves, ecosystem dynamics, forms of government, farming skills, how to stop the spread of infectious diseases, and the necessity of never again overstepping ecological limits. Lovelock believes if the book was splendid enough, it would be found in every home, school and library (dispersity and redundancy in practice) so some copies would invariably survive the fires.

6.7 Emergency Response Systems

Speaking of fires, while the minutiae of disaster response procedures and equipment is not the domain of this paper, the proportion of society’s scarce resources that should be allocated to these services is an important economic decision affecting a society’s resilience, especially its adaptive capacity. The damage done by recent natural and human caused shocks suggests that as a civilization we have likely been under-investing in emergency response capability. According to Comfort (2005, 5), “the sequence of events that followed Hurricane Katrina illustrates that the present US emergency response system is grossly inadequate for managing large-scale catastrophic events, let alone multiple incidents in different locations simultaneously”.

Environmental resource shocks like Hurricane Katrina and the massive wildfires (linked to climate change) in British Columbia, Australia, California, Greece and Israel in recent years have consistently overwhelmed local response crews. They could only be brought under control by bringing in significant emergency help from other areas of a country and even other countries (in the case of the 2007 fires, from across North America and the European Union). The future promises to bring environmental resource shocks that are not only bigger, but occur in multiple regions and countries simultaneously. This “may overwhelm the capacity of local authorities to respond, and may even overtax national militaries, requiring a larger international response” (CNA Corporation 2007, 47). Yet the autarky principle suggests that even international non-governmental relief organizations like the Red Cross cannot be relied upon because they would likely be quickly overtaxed if breakdowns affected multiple countries at once.

Again the efficiency/resilience tradeoff appears. It is efficient for jurisdictions (regions, provinces and countries) to share emergency resources (fire trucks, ambulances, helicopters, medical ships, water bombers and engineering equipment) rather than each having stockpiles of their own. However, if a crisis hits multiple areas simultaneously each local area will be overwhelmed without proper redundancy. Therefore, training more emergency workers and building more response vehicles, stations, coordination centres and medical/mortuary facilities (to handle a spike in injuries and deaths and control disease outbreaks) can all be very valuable for enhancing redundancy and adaptive capacity. But all come with a financial and environmental price. Since many redundant assets will stand idle until a large enough shock hits, and no one can predict with certainty when or where they will be called upon, they cannot be justified on efficiency grounds alone. If they come at the expense of consumer goods, they will reduce economic efficiency so long as the economy is functioning normally. If instead they are bought by expanding economic growth, this of course comes at the cost of environmental degradation.

Depending on the tax structure in a society, these increasingly expensive government services could be disproportionately funded by the poor and middle class. But a more worrisome trend undermining just distribution is the privatization of emergency response capability. Klein (2007, 455) argues Hurricane Katrina and the Iraq War have forged “a new paradigm” for the way human catastrophes are responded to. She describes the rise of the “disaster capitalism complex”: companies like Lockheed and Carlyle that provide for-profit response and rebuilding services. These companies benefit from disasters to such a degree, they may actually lobby for them to occur, as is theorized to have occurred with the Iraq war (Klein 2007, 372). More generally, rich corporations that have hands in both the resource extraction and engineering sectors stand to profit from the very environmental resource shocks they have helped to create. Meanwhile the poor of the world, those who have contributed least to creating the conditions for environmental resource shocks, will be most adversely affected by them and often forced to bear the costs of cleanup. Therefore, we must be vigilant that in the process of advocating and designing for economic resilience, a powerful industry does not develop which actively desires disasters because they benefit its bottom line.

Yet a more resilient emergency system can also mutually benefit other ecological economic goals. A better public medical system with redundant capacity enhances both economic resilience and just distribution because all citizens benefit equally in good times and bad. Poor countries definitely lack in emergency response capability, and so supporting their development is an imperative for both resilience and equity. Allenby and Fink (2005, 1035) discuss the benefits of new technologies that "aggregate and display complex information patterns at the urban systems level, such as the immersive Decision Theatre at Arizona State University. Such technologies not only facilitate coordinated emergency management and systemic responses to disasters, but enable better routine management of increasingly complex urban systems and can serve as important educational tools for city managers and the public. They are thus good examples of dual-use technology", that enhance scale, efficiency, and resilience goals. On the topic of urban planning, again interesting relationships arise between ecological economic goals: suburban neighbourhoods, otherwise the arch-nemesis of sustainable scale, are nevertheless robust against the spread of fires thanks to the geographic dispersity between houses. If fire departments should fail, fires will quickly devastate the dense centres of modern mega-cities. Constructing buildings out of less flammable materials would be helpful.

The proportion of time and funds allocated to emergency capital and training must be made not only by nations and regions, but households as well. Individuals and families should be educated and encouraged to develop emergency survival plans to enhance adaptive capacity. Yet, "It is difficult to plan for personal survival in the context of unpredictable social chaos. If I have a garden but my neighbors are hungry, I must either defend my land with deadly force or watch my crops disappear. But what if someone else has more guns, or comes when I am asleep? Ultimately, personal survival will depend on community survival" (Heinberg 2004, 140).

To begin with, it would be helpful for societies to refine emergency and evacuation plans and systems for every populated area, at every scale, including the provision for mass alternative shelter. This should not only be a top-down bureaucratic exercise: for redundancy reasons, power should be pre-invested in local people outside of traditional authority structures who can be ready to lead and respond by themselves. This ensures true community level autarky, dispersity and adaptive capacity in the emergency response system. The model to avoid is New Orleans, where most response work was done by outside contractors who were unfamiliar with the local area, distrusted by the community and prone to keeping surplus money rather than investing it in community rebuilding (Klein 2007, 559). Sterling (2007), drawing on firsthand experience of the California wildfires, advises local governments to help neighbourhoods set up pre-selected emergency meeting locations designated by signs. There neighbourhood collectives can be formed to pool and store resources. Households must know to send a representative there during a breakdown to share want lists and get in contact with emergency personnel. Ultimately, fostering habits of mutual aid would help make people less dependent on the emergency response system (increasing their autarky) and building social capital would be valuable even in the absence of breakdown.

In terms of governance more broadly during breakdowns, Daly and Farley (2004, 361) paint a grim picture of what may be required to prevent anarchy in the aftermath of breakdown: “Our historical experience with small life-support systems operating close to capacity – namely spaceships, or even ordinary ships or submarines – has thus far not permitted democracy. Military levels of order and discipline are required”. This is only more true in the aftermath of a societal breakdown. Therefore, nations may wish to ensure that sufficiently large police, army or national guard reserve forces are located near all major urban areas, ready to act if called upon to prevent looting and violence. CNA Corporation (2007, 46) agrees that “The U.S. should evaluate the capacity of the military and other institutions to respond to the consequences of climate change. All levels of government—federal, state, and local—will need to be involved in these efforts to provide capacity and resiliency to respond and adapt”. The Canadian army, for its part, was very helpful during the 1998 ice storm.

While enhancing the law and order aspect of resilience, such a force does carry costs and risks. Governments may be tempted to use a larger standing army for other purposes that could affect world equity, positively if they are used as peacekeepers or negatively if they are used to seize foreign resources. For example, the Louisiana and Mississippi national guard, which should have been available to help after Hurricane Katrina, was unable to do so because it was deployed overseas in Iraq. Instead the US Government turned to Blackwater Corporation to restore law and order, a private mercenary force that lacked the oversight built into the regular military.

In the interests of the social equity goal of ecological economics, having a well funded public police and military force available to help in a post breakdown situation is preferable to defaulting control to either private security companies hired by the rich, survivalist militia groups, or roving criminal gangs (regarding the former see Klein 2007, 505). A public security force is the lesser of evils so long as strong safeguards are put in place to ensure it cannot be turned on its own citizens to prop up inequitable government policies or protect the interests of select elites as chaos descends. Having a sufficiently redundant domestic military force also removes the justification for bilateral agreements such as the Canada/US "Civil Assistance Plan". This worrisome accord, signed in secret by generals without the debate or consent of the US Senate or Canadian parliament, provides American troops with the authority to freely occupy Canadian territory (or vice versa) in the event of a domestic crisis (see Canada Command 2008).

Any emergency response system will mainly be reactive to shocks after they occur: "Any suggestion that better technology for forecasting could reduce the danger of oncoming storms through earlier evacuations was certainly exposed as myth by the tragedy of Hurricane Katrina" (Ward 2007, 186). Likewise the 1984 Bhopal disaster showed the lack of resilience in emergency response systems: workers and people living nearby were told the gas was not dangerous, and "Emergency vehicles for evacuating the public were not used" (Perrow 1999, 356). Indeed, the above are all necessary but short term responses and more of a band-aid than a cure. If the only thing a society has is a good emergency response system, it is not resilient. If other economic systems are not resilient, then even the best emergency response system will fall prey to the same disruptions as the rest of civilian society: transportation systems break down so emergency crews cannot get where they are needed, trade interruptions mean they will not have the fuel and materials required to operate over a large range or for any extended time, and jurisdictional silos and communications failures mean they will not even know where they are needed. All of these factors affected FEMA's heavily criticized response to Hurricane Katrina.

6.8 Appreciating Urban System Interrelationships

For want of a nail… the Kingdom was lost.

John Gower, 1390

If we do nothing to build resilience into these and other sectors, they have the potential to be profoundly shaken by coming environmental resource shocks, jeopardizing their ability to meet our economic needs: "Even businesses that incur no physical damage are likely to have to curtail their production if they are cut off from their electricity, natural gas, water, or communication links. Moreover, such disruptions will set off a chain reaction of further production cutbacks among successive rounds of customers and suppliers spreading through the entire regional economy" (Liao and Rose 2005, 76). If these systems should fail entirely, there will essentially be no economy left to worry about.

All of this leads to an important question: which of these economic sectors is most important? Should governments seeking to build economic resilience focus on one subsystem first and foremost? Because of scarce resources, there is an impetus to rank these systems by priority. In terms of highest priority systems for allocating society's resources, Allenby and Fink (2005) think information and communication are most important in the information age. Anonymous interviewee (2007) agrees and thinks financial systems and reducing trade linkages are next most important. According to Farley (2007 interview), "The most important systems and linkages are those that are essential and have no substitutes". He ranks food/water first, followed by electricity, communication/information, transportation/trade, and money last. Rees (2007 interview) shares Farley's #1 and 2 ranking. Kunstler (2006, 239) also agrees that in a future economy plagued by shocks, "All other activities will be secondary to food production". Perrow (1999, 404) believes "a failure of electricity is the most fearsome possibility". Patterson (1999, 130) likewise observes that the electricity system is not only uniquely vital, but uniquely complex and vulnerable:

> a synchronized AC network differs profoundly from the other networks that criss-cross a modern industrial society, including not only road and rail but waterways, natural gas grids, telecommunications and water pipes. A traffic jam near San Francisco, for example, has no effect on traffic flow around Los Angeles or Sacramento. On a synchronized AC system, by contrast, a major disturbance anywhere on the network can spread over a thousand kilometres almost instantaneously.

On the other hand, Martinez-Alier (2007 interview) and Victor (2007 interview) believe all subsystems are of equal importance and that system interconnections are what we need to focus on most. Perrow (1999, 351) argues that the way a system is configured is often more important than its components, necessitating the need to be aware of hidden interactions. Indeed, "Because of infrastructure interdependencies, increasing risk in one system has ripple effects in other systems" (Chang et al. 2006, 35).

Nowhere is the potential for synchronous failure greater than in cities, which currently house 50% of the world's population, projected to rise to 60% by 2030 (Allenby and Fink 2005, 1034). In cities, "Failures in one infrastructure system often cause chain reactions, compounding losses and leading to catastrophe" (Chang et al. 2006, 33). For example, there is a rapidly accelerating "reliance on information infrastructures by other critical networks, such as transportation, financial, and corporate systems" (Allenby and Fink 2005, 1034). Mitchell and Townsend (2005, 317) explain:

> Since different types of networks are often functionally interdependent, failure of one type can produce failure of another. Telecommunication and electrical supply networks are particularly closely intertwined. Telecommunication devices require electric power, and increasingly, power grids are managed by means of sophisticated telecommunication systems. Similarly, if the power grid goes out, the traffic lights cease to function, and the traffic network rapidly snarls up. And, where pumps power water and air supply networks, power failures quickly render buildings uninhabitable.

Another example of synchronous failure would be a breakdown in the financial system immediately affecting trade by destabilizing international currencies required for transactions (Heinberg 2007, 177). Likewise, the money system depends entirely on people having strong trust in its vitality and so is uniquely vulnerable to even mild shocks that shake another sector of the economy. Perrow (1999, 399) worries: "It is not inconceivable that we could have *at the same time* a run on banks, a closing of stores because registers will not work and supplies cannot arrive, grid lock in traffic because of failed lights and stalled cars, unheated buildings with freezing pipes and no security alarms to prevent looting, contaminated water supplies because of filtration pump problems, equipment failures in hospitals and spoiled medicines, and so on".

Clearly, it is very difficult to prioritize these systems since they are so fundamentally interlinked. Rees (2007 interview) reminds us of Liebig's Law of the Minimum – in any complex system with many inputs, what matters most is the one limiting factor, meaning a modern economy cannot afford to lose any subsystem if it wishes to function properly.

Various real life examples illustrate interrelated failure of urban systems resulting from overinvestment in complexity. Following the August 2003 blackout that rippled across Ontario and parts of the Northeastern and Midwestern United States including New York, sewage systems and many water pumps including those in high-rise buildings stopped working; subway, rail and flight transportation was disrupted; cell phone communications and cash machines went offline; there was an accidental release of vinyl chloride; nuclear plants and gas stations shut down and millions were under a boil water advisory for days afterwards. The 2003 SARS outbreak in Toronto similarly illustrated the profound economic ripple effect of a disease outbreak in a crowded urban centre. While the Y2K disaster did not come to pass, it was an early reminder of the potential vulnerability introduced by making major societal systems so connected and interdependent on computers that a tiny failure (in lines of code) could in theory chaotically build into a serious, large scale one (Perrow 1999, 399).

New Orleans is one of the most vivid examples of misplaced confidence in robust fail-safe measures that did not take system linkages into account: “Catastrophe models had predicted—before Katrina—that even with a major hurricane, there would not be significant flooding in the city because levees would remain intact and, importantly, the city’s pumping system would be operating. The storm took out power, however, which prevented the pumps from working, and the forced evacuation meant there were not people to man the systems anyway” (Kousky et al. 2009, 13). In other words, the dike and pumping system lacked redundancy and autarky, power sources lacked diversity and dispersity, and emergency responders were not prepared to adapt.

In their effort to standardize and increase efficiency, policymakers failed to consider the unique circumstances of New Orleans and instead treated it like any other cookie cutter urban centre. The subsequent partial collapse of New Orleans, according to Comfort (2005, 4):

> illustrates the vulnerability that is built into the infrastructure systems of any major city or metropolitan region…. flood waters shut down the electrical power system, which in turn shut down traffic lights, communications systems, water, gas, and sewage distribution systems. The dependencies among these critical infrastructures left the city without essential services, making it uninhabitable and escalating the disaster into a major catastrophe for the city. The collapse of these operating systems, especially the connecting systems of communication and transportation that allow individuals and organizations to mobilize response efforts to assist stranded or displaced persons, represented the threshold point of failure for the entire city.

Westrum (2006) elaborates further:

> What was not so evident previous to the flood is that many of the key resilience facilities would also be damaged or submerged, and thus put out of order. These included most police facilities, (such as the armoury and the morgue), the National Guard barracks (whose rescue boats were also submerged), hospitals, power and communication centers. This meant that the city would not only lose power, but also much of its landline communications (mobile communications, such as cellphones, had been lost when the hurricane knocked down the cellphone transmission towers). Power for the hospitals would become a major problem, leading to patient deaths. Getting around in the submerged city would require boats.

> All of these problems were inter-related, and so, when the electricity failed, so did most of the city's ability to respond.

The current reorganization and rebuilding phase in New Orleans presents the city with the perfect opportunity for a transformation into a greener, better city (Costanza et al, 2006, 317). Unfortunately, the continued neglect of health care and education services seems set to recreate the same old conditions of poverty (Brown 2005, 7). Indeed, both just distribution and economic resilience can be compromised by the efficiency optimization logic that we should have "just enough" essential services with little redundancies. Klein (2007, 499) places the blame for the poor resilience of many urban areas on the spread of laissez-faire economic ideology: "It's easy to imagine a future in which growing numbers of cities have their frail and long-neglected [public] infrastructures knocked out by disasters and then are left to rot, their core services never repaired or rehabilitated. The well-off, meanwhile, will withdraw into gated communities, their needs met by privatized providers".

Chapter Conclusion

This chapter has hopefully illustrated both the need for and the difficulty of balancing ecological economic goals because every decision or indecision has very real practical benefits and costs to the economy, to the environment, to social justice, and to the ability of society to weather breakdowns and catastrophes. Ultimately, "Urban systems provide ideal laboratories for understanding resiliency and for developing dual-use technologies, practices, and systems that provide value even if no negative events occur." (Allenby and Fink 2005, 1034). Ecological economics has a golden opportunity to be at the forefront of this research, enhancing its own real world policy relevance by improving our understanding of how best to safeguard vital systems necessary for our collective survival.

Chapter 7: Conclusions

The last chapter demonstrated that applying a resilience framework to ecological economics theory can reveal a variety of insights about traditional economic systems, helping us to look at them in a whole new way. Let us now review what has been accomplished over the course of this thesis and evaluate what it has contributed to the literature.

7.1 Answering the Research Question

How can the concept and theory of resilience be incorporated into the study of ecological economics in order to improve society's capacity to endure, adapt to and recover from impending environmental resource shocks and catastrophes?

This paper explores the idea of incorporating resilience into ecological economics at a fundamental level and more importantly how this could possibly be done and the implications of doing so. In order to understand the need for resilience, it was necessary to establish that systems behave in non-linear, unpredictable ways (Chapter 1), that many civilizations before ours have eventually collapsed and there is no reason to think ours should be immune (Chapter 2), and that in other disciplines, especially ecology, resilience is now a very well developed concept and theory of change (Chapter 3).

To help answer the 'how' question, this thesis developed a conceptual framework (Chapter 4) by defining a new concept: economic resilience, and then identifying and unifying a set of six major guiding principles of resilience applicable to all systems, but especially economies. It then applied this framework to ecological economics to consider how resilience relates to all three existing major goals of ecological economics: scale, distribution and efficiency, leading to the next question:

Would adding consideration of economic resilience enhance or undermine the three main ecological economic goals of sustainable scale, just distribution and efficient allocation?

This thesis concluded it has the potential to do both, depending on the goal, the particular economic issue (case by case), the value system used to prioritize decisions, and a host of other factors. There was no definitive overall answer, but the relationships between the goals were explored in depth (Chapter 5). In many cases the goals are complementary, however in some cases building desirable resilience into the economy will come with a cost of increasing scale or reducing efficiency. These profound interrelations warrant much further research, especially how the complementary aspects can be enhanced and the conflicts minimized.

What are some practical implications for human economies?

Implications for various economic subsystems and policies were discussed in Chapter 6. While this analysis was generalized, it was valuable in generating new insights and revealing various practical implications of applying the framework in real world contexts.

The last remaining overarching research question left to answer is: *How* specifically should resilience be incorporated into the theory of ecological economics? Should resilience stay as a niche concept or become a guiding principle or even a fourth policy goal?

7.2 Implications for Ecological Economic Theory: Time for a Fourth Goal

Ecological economics has been called "the science of sustainability". But fundamentally, to be considered effective and sustainable, a system must be resilient in the face of disturbance: "sustainability requires the ability to cope with, adapt to, and shape change without losing options for future adaptability" (Folke et al. 2003, 353). It is unfortunate then that ecological economics has so far paid insufficient attention to the problem of economic resilience.

Hopefully this paper has encouraged ecological economists to focus not just on preventing environmental resource shocks but also the processes by which we can survive them and use them as springboards to transform us out of the fossil fuel age. Folke et al. (2003, 378) explain that:

> Learning to live with change and uncertainty and nurturing diversity for reorganization and renewal are an ongoing dynamic process of sustaining development. But they require a fundamental shift in thinking and perspective from assuming the world is in a steady state and can be preserved as it is, by focusing on preventing and controlling change, to a recognition of change being the rule rather

> than the exception, and thereby concentrating on managing the capacity in complex adaptive-ecological systems to live with change and shape change.

In this sense it is time for ecological economics to supplement Daly's useful but rather simplistic idea of the "steady-state economy" with a deeper model of system change. Daly's conceptualization of ecological economics is somewhat lacking when it comes to incorporating ecological dynamics or evolutionary phenomenon (Anonymous Interviewee 2007). Adding consideration of economic resilience would make a significant step toward correcting this, and could, together with other theoretical improvements, raise the relevance and stature of the field by improving its ability to tackle tomorrow's problems. Farley (2007 interview) notes that ecological economics' three existing goals of scale, distribution and efficiency "are necessary but not sufficient objectives. Arguably the higher level end we should focus on is to provide a high quality of life for this and future generations" (Farley 2007 interview). Insofar as maintaining long term welfare is one of the key criterion of this paper's definition of economic resilience, incorporating economic resilience into ecological economics would go some way toward meeting Farley's high level goal.

7.2.1 Can resilience be subsumed under an existing goal?

The complex interrelationships between resilience, scale, distribution and efficiency have been discussed at length in this paper. One larger question that arises from these relationships is whether there is potential for resilience to be successfully incorporated under the umbrella of one of these three existing goals. If this was possible, it might be the easiest way to start going about adding resilience into ecological economics because it would be the least disruptive to the theoretical status quo.

Ecosystem resilience arguably can be subsumed. Resilience of natural environmental systems (forests, wetlands) cannot be directly designed for by humans. In fact, historically most human attempts to manage ecosystems for a desired (usually what we consider efficient) state has led to the steady erosion of their resilience. Efforts to specialize natural systems or increase their yields in the interests of economic export have led to monocultures with depleted diversity (Gale 2000). Indeed, "The simpler, more uniform landscapes created by human activity have put thousands of species under threat of extinction, affecting both the resilience of natural services and less tangible spiritual or cultural values" (MEA 2005). In the pursuit of growth and efficiency, we have taken most global ecosystems to the edge of their capacity and magnified their susceptibility to catastrophes: "The paradox is that the processes of economic diversification, liberalization, and globalization ultimately depend on nature's subsidies, on diversity and resilience of ecosystems, but tend to create increasingly fragile ecosystems, as witnessed in modern food, fiber, and timber production systems" (Folke et al. 2003, 382).

Therefore, ecosystem resilience is perhaps best achieved by ensuring nature is protected and left alone so it can manage its own resilience. Kristensen et al. (2003, 70) note that nature seems to be able to build its resilience in concert with other objectives like increasing biomass. Controlling the scale of our economic activity is therefore the most important thing we can do to help build nature's resilience. This entails safeguarding large tracts of wilderness from development, overuse and other harmful activities that disrupt natural systems (Kousky et al. 2009, 13). Protecting unique bioregions of the earth along with the genetic diversity of wildlife is also fundamental to preserving the ecological memory required by these systems and species to transform and adapt to a rapidly changing planet (Folke et al. 2003). In that regard, holding the pace of climate change to a manageable level will be key to minimizing the number and severity of stresses that global ecosystems will face this century.

Humans should not try to manage ecological resources to optimize a single attribute or tightly control spatial and temporal variation. Rather, a diverse use of resources that controls the scale of impacts would be more resilient (King 1995, 965, 976). Martinez-Alier (2007, interview) believes: "Resilience and Scale clearly may be considered together. For instance, the collapse of a fishery will come from increased effort in fishing. Whether the fishery will recover (i.e. whether it is resilient) might depend on biological and economic factors". Therefore, ecosystem resilience can probably continue to be successfully subsumed for now under the existing sustainable scale goal, a framework ecological economists are already using to consider various ecological issues in their research and publications.

As discussed, controlling scale is also compatible in many ways with efforts to boost economic resilience. A society with abundant natural capital is significantly more resilient than one with degraded ecosystems and undergoing frequent environmental resource shocks. Given this positive relationship, some (e.g. Rees, Lawn and Farley 2007 interviews) have wondered whether the goal of economic resilience could likewise simply be captured under sustainable scale. Would not controlling scale, the argument goes, also ensure that resilience is not depleted? The problem is, economic activity can increase within set scale limits by raising efficiency, which often increases connectedness, centralization, specialization and monoculture at the expense of autarky, dispersity, redundancy, diversity, and thus resilience. Simply subsuming resilience under scale does not capture this critical relationship between efficiency and resilience to say nothing of resilience and distribution.

On that note, given that distribution is a bit of a wildcard in terms of its relationship to economic resilience, opportunities for subsuming resilience under the just distribution goal seem slim. Improving equity is positively linked to building adaptive capacity and transformability (except if it increases scale), but the moral foundation of the just distribution goal makes it less well suited for incorporating the other more quantitative technical principles of economic resilience.

As discussed earlier in Chapter 5, one possible way of reconciling the resilience/efficiency tradeoff is to try and internalize environmental and resilience externalities into prices so the market can resolve these problems itself. This suggests the possibility of subsuming economic resilience under efficiency. However, Daly (2003) argues that "If we use relative prices to solve the allocation problem, we cannot simultaneously use prices to solve the scale problem (or the distribution problem)". Or, more than likely, the resilience problem. Indeed, resilience must be designed into the economy at a system-wide level, which implies that a significant degree of planning oversight is required to ensure systemic resilience is achieved rather than simply adjusting prices and leaving it up to the market in the hope that resilience built in piecemeal at the individual level will be sufficient.

Indeed we have to be careful about what policy tool we use to internalize resilience into prices – using a single tax to try and subsume all elements of resilience under efficiency might further confuse the scale/efficiency/resilience relationships. One of the arguments in favour of cap and trade policy is that it provides more certain results than environmental taxes because the level (scale) of pollution is decided on by the government before market trading is allowed to take place for efficiency reasons. In the same way, some sort of guaranteed level of resilience would need to be planned for (as a separate policy goal) before leaving it to the vagaries of the market. To summarize, subsuming resilience entirely under efficiency would be like mixing three (or four) ingredients together in one cauldron and then hoping it is still possible to taste each one, in the exact proportions added, after bringing the brew to a boil. This is why Daly and Farley (2004, 360) stress that every separate policy goal requires a separate instrument, and is also in part why ecological economists believe scale and efficiency must be separate goals. Internalizing desirable resilience into prices is an idea worth pursuing, but first a level of resilience must be designed from outside of the market domain.

Overall the potential of subsuming economic resilience under an existing goal starts to run up against real theoretical problems the more we think through all the dimensions. Neoclassical economists already argue that ecological economist's most cherished goal of scale could be subsumed under long run and even short run efficiency as well if we could make all prices reflect true costs. The fact that most ecological economists have come to the conclusion these two goals must be separate in turn lends strong weight to a similar separation of resilience in light of its well demonstrated tensions with the other goals that are described throughout this paper. Economic resilience is influenced by, but not addressed within, the other three goals.

7.2.2 Resilient Design as a new fourth policy pillar

Given that economic resilience clearly cannot be adequately subsumed under any of the existing goals, the only logical conclusion is that resilience must become its own distinct theoretical pillar within ecological economics, perhaps by creating a new fourth policy goal called Resilient Design. Resilient Design would encompass the concept and principles of economic resilience described in this paper along with consideration of the implications of adaptive cycle theory. It could also incorporate the study of natural ecosystem resilience and management rather than leaving it subsumed under scale. The word design denotes the idea that resilience must be planned for ahead of time, and also consciously and intelligently built in rather than being left for the market alone to build (or not). More broadly, examining the design of complex systems is key when trying to formulate theories such as ecological economics that seek to describe their fundamental characteristics (Carlson and Doyle 2002, 2545). Victor (2007 interview) prefers the term "resilient structure" but the idea is similar enough.

Making resilience into a goal of equal stature to the others highlights the possible tradeoffs which may have to be made between goals in some cases, or at the very least the need to pay attention to these relationships. Just as Daly chose not to subsume scale or distribution under efficiency (though other economists have said this is possible), so too does resilience deserve to stand alone. Only if the theory of ecological economics contains such counter-balances can one argue, for example, that a redundancy may be inefficient, but it is still justifiable because it serves the equal, competing goal of resilience: "It's not that optimization is wrong; it's that it so seldom has to defend itself against an equally muscular rival [i.e. resilience]" (Hamel and Valikangas 2003, 11). Because resilience has its own unique principles, new and separate analytical and policy tools may need to be created to address it, and so adding resilience is not something that can be accomplished over night.

Martinez-Alier (2007 interview) states: "I think that the insistence on Resilience as a central concept (by Perrings, Folke) beyond the simple idea of carrying capacity, and also the insistence on Uncertainty and Ignorance in the work of Funtowicz and Ravetz (as opposed to quantifiable probabilistic risk), are very much part of Ecological Economics. Post-normal Science has its best audience among ecological economists". Integrating resilience into ecological economics will provide it with new tools that make it much better equipped than its peers to be effective in this new post normal world likely characterized by unpredictable shocks. Insofar as efficiency and to a lesser degree distribution were the only goals of conventional 20^{th} century economics and policymakers, scale and resilience are brand new post-modern 21^{st} century goals.

Incorporating resilience as a fourth goal could even strengthen the usefulness and appeal of the existing ecological economic goals by making them a more coherent unified package for evaluating the overarching goals of sustainability and in turn a more comprehensive vision for our economy and society than is found in almost any other discipline. The broader environmental movement, for example, would finally gain a more persuasive theoretical economic argument for "small is beautiful" type localism to balance the efficiency arguments of neoclassical globalization and free trade theory.

A revised goal statement of ecological economics might therefore read: *our economy should be sustainable, equitable, efficient, and resilient, and this can be achieved by striving for sustainable scale, just distribution, efficient allocation, and resilient design.*

7.2.3 Prioritizing the fourth goal

We cannot add resilience as a new goal without in some way affecting the three other goals and/or some other economic variable: “The biologist Garrett Hardin once pointed to a disarmingly simple lesson of systems analysis that has powerful implications: ‘We can never do merely one thing’. His point was that good intentions are virtually irrelevant in determining the result of altering a large, complex system” (Tainter 1988, 207).

This calls into question: in cases where tradeoffs are unavoidable, what priority order should the four goals be assigned in ecological economics? Following the lead of Daly, ecological economists traditionally rank scale as most important, followed by distribution and then efficiency last. While several of the ecological economists interviewed for this paper did not necessarily believe in fixed ranking when so many factors are interactive and critically important, they were still willing to share their thoughts. Farley (2007 interview) reasons: “I would subsume resilience under scale, then rank them as scale, distribution, efficiency. If I did not subsume resilience under scale, then resilience would rank first”. Lawn similarly ranks scale first (resilience subsumed), than distribution, and efficiency last. Rees ranks scale first, followed by resilience, distribution and lastly efficiency as defined by mainstream economists. Martinez-Alier puts equity at the top of the list but thinks resilience is important too, and the Anonymous interviewee places efficiency at the bottom of the list. Taking these comments together, it would seem only scale could be argued to take priority over resilience.

Victor (2007 interview) adds an additional insight: “Daly and Farley’s ‘logical’ ordering (scale, equity, efficiency) has some appeal. Which should be prioritized depends on the issue under consideration. I rather like dealing with resilience as a separate characteristic worthy of attention”. In effect, scale determines how much ‘stuff’ gets made in total, efficiency determines exactly what gets made based on this constraint, and distribution determines who gets what and how much. However, as discussed in this paper, Resilient Design would need to encompass all of these elements in order to take into account all six principles of economic resilience. Perhaps then, as Victor suggests, resilience is a meta goal that must be considered at all times alongside the other three goals – it can neither supersede nor be subsumed or delegated in priority to any other goal. Moving forward, the most effective approach would be to consider the goals as an inseparable package and seek out policies and activities that work toward all four simultaneously.

7.2.4 Conclusions for ecological economics

Whether or not a fourth goal is created, if ecological economics wishes to stay current with our constantly changing world, it is time to begin considering the implications of economic resilience both as a concept (incorporating the six principle economic resilience framework of this thesis) and as a theory (incorporating insights from the adaptive cycle). Discussion of resilience moves emphasis of analysis in economics from simple models of static equilibrium to a more complex understanding of dynamic change (Davidson-Hunt and Berkes 2003, 76). A serious investigation needs to begin not just in ecological economics, but throughout the entire economic community to evaluate how the issue of resilience has been forsaken (along with the natural environment) in the quest for growth and efficiency. In applying this recipe too far, we have followed the human tendency through history to develop a logic for economic success and then extend that solution to all parts of an operation without due consideration for long-term consequences (Hurst 1995, 125). If the increasingly recognized limits to environmental scale are the driver calling into question the wisdom of unlimited economic growth, then the need for societal resilience is the driver challenging the orthodoxy that more efficiency is always a good thing.

By establishing the usefulness of the concept of economic resilience and its associated principles, this thesis has hopefully shown the value of integrating resilience at a deep level into ecological economic theory, possibly by creating a new fourth policy goal. In the process, it has demonstrated the striking complementarities that exist between the theory of ecological economics and the Resilience Alliance's theory of resilience, in particular their shared conceptual understanding of the world as a complex system, their critiques of growth and efficiency, and their transdisciplinary approach. It is fascinating that these two theories developed independently among two silos of scholars; the fact they have nevertheless reached similar conclusions lends weight to the validity of their findings. All things considered, some of the Resilience Alliance members could easily be thought of as honourary ecological economists. This thesis has provided a link toward bridging the gap between these transdisciplines and thereby forging of a unified theory of how civilizations can be made sustainable, equitable, efficient and resilient. The usefulness of such a theory for charting the future course of civilization should not be underestimated.

7.3 Areas for Future Research

This thesis could spawn an almost infinite set of follow-up questions. However, the following are seven salient issues (not necessarily specific to ecological economics) that the literature would do well to examine in the future, the first being more technical and the latter relating more to philosophical/world system issues:

1) As noted, the Resilience Alliance's figure-8 theory charting the loss of resilience due to growth also meshes readily with ecological economist's critique of the environmental costs of growth, even though both theories developed separately. There is thus a tremendous opportunity and need for *dialogue and collaboration* between these two distinct groups of scholars. If they could incorporate one another's research and synthesize their ideas, a new unified theory could potentially be created that would greatly enhance our understanding of how global socioeconomic and environmental systems interrelate. More broadly, it would be valuable for researchers to begin investigating how resilience ideas could be incorporated more fully into all existing branches of economics in order to have the greatest effect on real life policy creation.

2) There is a need to propose alternative *definitions and principles* of economic resilience (other than the ones suggested in this thesis), to study them, and to accept or invalidate them. The validity of various resilience ideas is not something that can be easily proven or disproven because our civilization represents a sample size of one: by the time we test all alternative hypotheses, we may already have collapsed. Nevertheless, the quality of thinking and understanding would be enhanced by open discussion among many informed participants. There are bound to be conflicting interpretations of how resilience can or should be built-in, and these need to be given due attention and debate: "there is a lot that needs to be done to create a broadly useful resilience economics" (Peterson 2007). An important consideration that bridges the various definitions of resilience may be whether the policies and activities needed to maintain

function in the face of breakdowns are different from the ones needed to enhance capacity to recover from catastrophes and successfully transform system states.

3) The next step will be to come up with useful *indicators* of a given economy's resilience, or lack thereof: "If we agree that resilience is a useful concept even in the context of socioeconomic systems, then we must be able to answer the question 'How resilient is a given socioeconomic system?' There is no way to answer this question without measuring resilience; hence the salience of this measurement issue" (Batabyal 1998, 236). Rose (2004) and Briguglio et al. (2003) have attempted to create resilience indicator indexes but only according to very narrowly defined definitions of resilience.

4) Another question when it comes to quantification is: *How much* resilience in an economy is enough? What marginal benefit is provided by incorporating resilience versus other possible resource allocations, and how should they be prioritized? Yorque et al. (2002, 436) ask: "How much societal redundancy is required to sustain the capacity to adapt in a flexible way to unpredictable change?" Petak (2002, 1) note the difficult in this area of research: "when the occurrence of a disturbance and the consequences of its impact are highly uncertain, it is necessary to view system resilience and system sustainability probabilistically. This adds a difficult dimension to the process of determining what the acceptable level of resilience or sustainability… ought to be" (Petak 2002, 1).

5) By extension, there is a need for developing suitable approaches for assessing *where* resilience is and is not desirable. This involves collectively agreeing as a society which system characteristics and functions are (and are not) worth preserving and regenerating in the wake of a catastrophe that alters our system's equilibrium state: "The important point is to recognize both the designed and self-organizing components of a SES and to study how they interact... Socio-ecological systems are never fully designed or controllable, nor are they amenable to the definition of one simple, easily measurable performance index, such as output value minus input costs" (Anderies et al. 2004, 2). Similar approaches are needed for assessing where efficiencies are and are not desirable.

6) Beyond theory, modelling, and philosophy, a much more in-depth examination is needed of how to *operationalize* economic resilience on the ground, on a city by city, country by country and sector by sector basis, and across international institutions and systems. The few existing books on enhancing the resilience of cities (such as Chernick 2005 and Vale and Campanella 2005) are incomplete and only look at the engineering definition of resilience (time to return to normal). Furthermore, the communication of resilience ideas by scholars to those outside academia needs significant improvement: "Critical scientific and economic conclusions about resilience need to be made available to decision-makers and the public at large in a way that aids understanding" (Levin et al. 1998, 233).

7) There is a need to identify further opportunities for *enhancing the complementarities* between scale, distribution, efficiency and resilience while minimizing their conflicts. Insofar as unavoidable tensions remain, suitable processes and criteria are needed for assessing them and making difficult tradeoff decisions. In particular, the tension between resilience and efficiency remains unresolved and certainly requires further attention because of the profound implications. For example, is the otherwise positive trend toward an internet based, streamlined, environmentally efficient just-in-time economy better at handling sudden change or is it setting up our economy for disaster by stripping out redundancies and autarky? Could reducing the overproduction of goods that are not wanted in the first place (see Stanley 2006) be a way of achieving efficiency without resilience draining specialization? The impact on economic resilience becomes a question of how important a reserve of resources, built capital and manufactured goods are in an emergency. Could government legislate for redundancy and autarky in critical components while still allowing a just-in-time type economy for luxury goods? In all cases, the objective should be seeking ways to realize mutually reinforcing and lasting benefits.

8) Gallopin (2002) asks an important meta question: if the figure-8 adaptive cycle is applicable to the global human system, does that mean our civilization must alternate forever between phases that maximize production and accumulation and phases of decline and reinvention? In other words, will civilization always inevitably collapse (to some degree) no matter what we do? Certainly civilization is a complex system like any other, yet most would agree human behaviour is not predictable or set in stone. What is our precise location on the adaptive cycle and how

much time do we have left before the catastrophic release phase? Gallopin (2002, 392) goes on to ponder: “is there a healthy strategy to maintain an advanced level of civilization while keeping adaptive fitness?” Might it be possible to freeze our current position on the cycle and maintain our current level of complexity by fixing the scale of the economy (i.e. finally achieving sustainable scale)?

7.4 Final Thoughts on Our Common Future

The great modern myth of perpetual progress is a relatively recent phenomenon dating from the 15^{th} century on; prior to this people were more concerned with preserving what was left over from the previous golden age of the Roman empire. In some ways we are both blessed and cursed to be living during a new golden age of immense global economic complexity. We are witnessing the pinnacle of many human material pursuits, yet it is an age that may not last much longer. In this time of great technological advancement, the human species is also on the cusp of environmental change more profound than any it has experienced in recorded history, including a sixth great mass extinction and irreversible changes in our planet’s atmosphere and oceans. Scientifically, socially and conceptually, we are entering unexplored territory: perhaps the only certainty is that everything is about to change.

Lovelock (2006, 155) warns that we are “unprepared for a catastrophe such as a global event that is wholly unexpected and unpredicted… something that could throw us into a new dark age”. Diamond (2005, 7), whose twelve environmental challenges introduced this paper, believes: “Much more likely than a doomsday scenario involving human extinction or an apocalyptic collapse of industrial civilization would be ‘just’ a future of significantly lower living standards, chronically higher risks, and the undermining of what we now consider some of our key values. Such a collapse could assume various forms, such as the worldwide spread of diseases or else of wars, triggered ultimately by scarcity of environmental resources.”

Future generations may soldier on, but it may be in a radically changed world where built capital and natural resources have become rare once again. If we are presently having difficulty as a global society affording policy objectives due to a relatively minor economic downturn, we may be in for a terrible shock by the middle of the century when our available natural resource base will be smaller at the same time as the world population is 35% larger and the environmental challenges perhaps several magnitudes larger.

In this turbulent new century likely to be characterized by unpredictable breakdowns and catastrophes brought on by climate change, peak oil, and other problems we will create trying to solve those, it is imperative that much deeper consideration be given to how desirable resilience can be built into economics and economies in order to better prepare them to weather these coming storms and stave off complete collapse. Ecological economics needs to live up to the ecological part of its name and break from the clockwork Newtonian understanding of the world epitomized by neoclassical economics. It needs to move away from understanding the world as well behaved, linear, predictable, controllable, and able to be optimized to an understanding which assumes surprise, chaos and catastrophe are the new normal.

This can perhaps best be achieved by creating a fourth policy pillar in ecological economics called Resilient Design. One of the key strengths of resilience thinking is how flexible it is as a concept and theory. No matter when or where shocks and breakdowns may occur, the precautionary principle which ecological economists support (Farley 2007 interview) demands our consideration of resilience so we can prepare for them. Homer-Dixon (2006, 293) concludes:

> Conventional economics is the dominant intellectual rationalization of today's world order. As we've overextended the growth phase of our global adaptive cycle, this rationalization has become relentlessly more complex and rigid and progressively less tenable. Breakdown will, all at once, discredit this rationalization and create intellectual space for new ideas to flourish. But this space will be brutally competitive. We can boost the chances that humane alternatives will thrive by working them out in detail and disseminating them as widely as possible beforehand.

Most certainly we need to begin the immediate transition to a more safe-fail society by designing for and building desirable forms of resilience into every aspect of our economies, while also being conscious of the potential tradeoffs involved and either balancing them smartly or seeking complementary solutions that lead to mutually reinforcing gains. Making the world economy resilient can potentially go hand-in-hand with global sustainability goals (O'Hara and Stagl 2004, 550-51). But we need to build in this resilience while keeping economic growth constant – in fact, we need to reduce the scale of the economy simultaneously to stay within shrinking biophysical limits. This will be one of the greatest challenges in human history.

“I think we have little option but to prepare for the worst and assume that we have already passed the threshold. Like paramedics, [government’s] first priority is to keep the patient, civilization, alive during the journey to a world that at least is no longer undergoing rapid change” (Lovelock 2006, 153). We must start this process now, ahead of time, or our future will most certainly be marked by loss on a grand scale: “Most people (including many policy makers) would be tempted to assume that policy can always catch up with history. If too little is done now, there is always the possibility to take stronger actions in the future, and thus the problem will be solved. The trouble with this notion is that it assumes an infinitely forgiving world, ignoring irreversible processes and the possibility of structural reorganizations in the global system that lead to situations that are, in practical terms, irrevocable” (Gallopin 2002, 379). In an era when political leaders seem oblivious to the coming catastrophes and concerned citizens feel powerless to persuade them, resilience thinking at least provides a comforting fallback: we can all do things to start preparing our own local communities for what lies ahead. Ideally we should seek out initiatives that have near term benefits as well as longer term catastrophe mitigation, transformation and recovery benefits.

The seemingly insatiable drive for humans to expand, destroy and inevitably collapse may be a product of culture more than a fatal flaw of the human condition. Resilience theory gives us hope that the coming breakdowns will provide a once in a millennium opportunity to strip away the accumulated web of social structures and behaviours underlying our planet killing economic system. In its wake will be fresh ground for the creation of a truly ecologically minded society. While the future cannot be foreseen, that ground can be made more fertile by building the capacity and willingness to transform as necessary to survive and flourish no matter what comes our way, guided by shared goals such as those provided by ecological economics: “As we approach bifurcations that lead to species extinction and the degradation of the biosphere, we seek the bifurcations of our technical knowledge and our social organization that will prevent a total collapse and allow for our survival and even for our improvement. Let us hope that as past crises have sometimes induced economic mutations, so our present ecologic crisis will lead us to mutate a new and better relationship with our environment and our world” (Rosser 1991, 269).

The most central question of the 21st century is how we should act in an age defined by uncertainty. For the survival of our civilization, it is imperative that we make the difficult and radical shift from an economics obsessed with trying to maximize our maximum gains to one concerned most with minimizing our maximum losses. From an economics infatuated with growth to one focused on preserving, refining and better distributing what we already have.

"We can only hope that our race may be spared a decline as precipitous as is the upward slope along which we have been carried, heedless, for the most part, both of our privileges and of the threatened privation ahead."

Alfred J. Lotka, 1925

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Glossary / Definitions

Adaptability (Adaptive Capacity) – The ability of human actors to adapt successfully to breakdowns by planning ahead, learning, adjusting and improvising. A principle needed for economic resilience.

Autarky – The ability for a system component to survive and/or continue functioning even when cut off from other systems. A principle needed for economic resilience.

Basin of Attraction – "a region in state space in which the system tends to remain. For systems that tend toward an equilibrium, the equilibrium state is defined as an 'attractor'" (Holling et al. 2004, 8).

Bifurcation – The "splitting of equilibria at critical points" (Rosser 1991, 2).

Breakdown – Occurs when a shock overwhelms the traditional stability mechanisms of a system causing normal predictable system operations and organization to be disrupted. A system experiencing breakdown initially remains within the same basin of attraction, however breakdowns can potentially cascade into a Catastrophe that crosses thresholds. See also Synchronous Failure.

Catagenesis – Renewal through breakdown (Homer-Dixon 2006, 22). See Transformability.

Catastrophe – A partial or system-wide breakdown that has cascaded to the point where it causes the system to cross a threshold that significantly alters the behaviour and/or characteristics of that system, potentially leading to a new equilibrium basin of attraction.

Catastrophe Theory – Theorizes "that systems will undergo dramatic, sudden changes in a discontinuous way" (Kay and Schneider 1994, 34). Relies on concepts of system thresholds and flips.

Chaos Theory – Establishes mathematically that tiny random undetectable variances in initial conditions can become magnified over time, leading to rapidly growing errors in any efforts to predict future outcomes. In other words, even with perfect computer models, complex dynamic nonlinear systems remain completely unpredictable (Kay and Schneider 1994, 34).

Collapse – A terminal, long-lasting reduction in the size and/or complexity of a system following a catastrophic event.

Collapse (human civilizations) – a "drastic decrease in human population size and/or political/economic/social complexity, over a considerable area, for an extended time" (Diamond 2005, 3). Significant welfare loss among the population must also occur.

Complexity – A measure of the combined growth and efficiency in a system.

Dispersity – The degree to which a system's components and functions are distributed and decentralized across scale, space and time. A principle needed for economic resilience.

Diversity – The degree of variance in the type and characteristics of components that make up a system; similar to biodiversity in natural ecosystems. A principle needed for economic resilience.

Ecological Economics – "The study and modeling of the linkages between economic and ecological systems" with the economy viewed as a subsystem of the earth ecosystem (Field and Olewiler 2002, 429; Daly and Farley 2004, 431). Also called "The science of sustainability" (Schiller et al. 2002, 323).

Ecological Resilience – "the capacity of a system to absorb disturbance and reorganize while undergoing change" (Holling et al. 2004, 6). Recognizes the potential for multiple stable states, but the need to preserve enough of the system to prevent its terminal collapse.

Economic Development – The improvement in the quality of the economy and expansion of the psychological welfare/wellbeing/potential derived from the economy, it can be theoretically decoupled from material and energy use (Daly and Farley 2004, 6).

Economic Growth – The physical (material and energy) expansion of the economy, in particular throughput – the flow of natural resources from the environment, through the economy and back to the environment as waste (Daly and Farley 2004, 6). Distinct in ecological economics from economic development.

Economic Resilience – The capacity of an economy to endure, adapt to and successfully recover from shocks in order to maintain a base level of welfare for all people at least equal to that enjoyed before the shock occurred. It encompasses both preventing breakdowns from cascading into catastrophes, and avoiding collapse following a catastrophe.

Ecosystem Resilience – The capacity of an ecological system to endure, adapt to and successfully recover from shocks in order to both prevent breakdowns from cascading into catastrophes (stay in the same basin of attraction), and avoid collapses following a catastrophe if the system crosses a threshold.

Efficient Allocation – The allocation of society's limited resources to their most productive (highly valued) ends in order to maximize the total combined utility of all economic actors. One of the three primary goals of ecological economics.

Endure (catastrophe) – To survive a catastrophe with a minimum amount of human suffering, economic disruption and ecological degradation so that society is left in a strong position to recover.

Engineering resilience – The ability to return to the steady state following a disturbance.

Environmental Resource Shock – A sudden and unexpected scarcity of natural resources and/or a failure of ecosystem services resulting primarily from unsustainable levels of economic throughput and/or human population.

Fail-safe – A system designed to predict and evade all foreseeable failures.

Functional Redundancy – The degree to which a system's functions are duplicated or there is functional substitutability of one element for another. A principle of economic resilience.

Human-caused Catastrophes – Catastrophes that result from human action or inaction independent of the natural environment (e.g. ethnic wars).

Just Distribution – the equitable apportionment of wealth and resources within and between generations (Daly and Farley 2004, 12). One of the three primary goals of ecological economics.

Natural Catastrophes – Catastrophes that result entirely from natural phenomenon (e.g. asteroid impacts).

Perturbation – Any disturbance or stress placed on a system, be it gradual or sudden, small or large, predicted or unforeseen.

Recover (from catastrophe) – To return to a level of economic welfare for all approximating that enjoyed pre-catastrophe, though not necessarily with the same type or structure of economy, and preferably with more sustainable and equitable characteristics.

Redundancy – see functional redundancy.

Reliability –The ability of a system to withstand calculable, predictable kinds of failure (Lovins and Lovins 2001, 189).

Resilience – "the ability of a system to remain functionally stable in the face of stress and to recover following a disturbance", possibly in a new steady state (Redman and Kinzig 2003, 5). See also Ecological Resilience, Engineering Resilience, Ecosystem Resilience and Economic Resilience.

Revolt – See Synchronous Failure.

Robustness– The ability to shrug off disturbances with no disruptions or changes in any part of the system. A fail-safe approach that focuses on maintaining all parts and their functions.

Safe-fail – Approach to design and planning that advises being precautionary in case of unforeseen disasters or developments by taking the lowest risk path in order to minimize maximum losses and ensure recovery (i.e. you're safe if it fails).

Shock – A sharp, sudden, unexpected disturbance or stress placed on a system. See also Environmental Resource Shock.

Social-ecological System (SES) – "an ecological system intricately linked with and affected by one or more social systems" (Anderies et al., 2004, 2).

Sustainable Scale (Maximum) – The carrying capacity of the earth for humans, given current technology and managerial capacity. Continuing to exceed this invariably leads to environmental catastrophes and eventual system-wide collapse.

Sustainable Scale (Optimum) – "Occurs when the increasing marginal social and environmental cost of further expansion are equal to the declining marginal benefits of the extra production. Beyond the optimal scale growth becomes uneconomic" (Daly 2004, 437). Known as the "When to stop" growing rule. One of the three primary goals of ecological economics. Not identifiable with any precision and also subject to unanticipated phenomena inevitable in complex systems, and therefore its pursuit must be combined with a substantial precautionary cushion.

Synchronous Failure – The cascade and magnification of initial system breakdowns within and across different systems and scales of an economy (the domino/snowball effect).

Throughput – The flow of low entropy raw material resources and energy through the global economy and back to the earth's ecosystem sinks as high entropy waste (Daly and Farley 2004, 440).

Transformability – "the capacity to create untried beginnings from which to evolve a new way of living when existing ecological, economic, or social structures become untenable" (Holling et al. 2004, 8). A principle needed for economic resilience.