An entrepreneurial model of economic and environmental co-evolution

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Abstract: A basic tenet of ecological economics is that economic growth and development are ultimately constrained by environmental carrying capacities. It is from this basis that notions of a sustainable economy and of sustainable economic development emerge to undergird the óstandard modelô of ecological economics. However, the belief in óhardô environmental constraints may be obscuring the important role of the entrepreneur in the co-evolution of economic and environmental relations, and hence limiting or distorting the analytic focus of ecological economics and the range of policy options that are considered for sustainable economic development. This paper outlines a co-evolutionary model of the dynamics of economic and ecological systems as connected by entrepreneurial behaviour. We then discuss some of the key analytic and policy implications.

Keywords: economic evolution, entrepreneurship, sustainable economic growth

1 Reconciling economic and environmental dynamics

óEstablishing the relationship between economic performance and ecological performanceô, venture Boons and Wagner (2009: 1908), óresembles something like finding the Holy Grail.ô Ecological economics is the scientific research program at the core of this endeavour to

elucidate the structure and dynamics of the complex economic-ecological relationship. It does so by mapping and modelling energy and material flows, system resilience, economic and socio-cultural behaviours, institutions and co-evolutionary processes (Norgaard 1985; Ayres 1994, Gowdy 1994; Perrings 1998; van den Bergh and van der Straaten 1997; van den Bergh and Gowdy 2000; Krausmann *et al* 2009; Ayres and Warr 2009). A basic tenet of ecological economics is that economic growth and development are ultimately constrained by environmental carrying capacities. It is from this basis that notions of a sustainable economy and of sustainable economic development emerge to undergird the ósstandard modelô of ecological economics. However, the widespread belief in óhardô environmental constraints may be obscuring the important role of entrepreneurship in co-evolutionary interactions between the economy and the environment. If this is the case, it may have distorted the analytic focus of ecological economics in a way that has limited the range of policy options available to achieve sustainable economic development.

The belief that economic growth and development are ultimately constrained by hard environmental and ecological limits is well established in the field of ecological economics. This óultimate scarcityô argument is commonly formulated in terms of the limits to loadings on ecological services (Arrow *et al.* 1995; Costanza *et al.* 1997). Ecological constraints thus define long-run limits on economic evolution and growth. This reinstates J.S Millôs concept of the tendency towards a stationary state, but conceived ecologically, rather than technologically. This argument can be traced back to the resource constraint concerns of Thomas Malthus and William Stanley Jevons, among others, through to the modern work of Nicholas Georgescu-Roegen (1971) and Kenneth Boulding (1978) and via ecological conceptions of environmental limits to economic growth (Daly 1996, 1973). This is óspaceship-earth economics,ô using Bouldingôs (1966) felicitous phrase, in which the

fundamental limits to economic development and growth are ultimately constrained by environmental carrying capacities and system resilience.

On spaceship earth, then, the human economy is locally and globally dependent upon the natural environment, *sine qua non*. Seeking a sustainable economy and sustainable economic development thus underpin the ôstandard modelô of ecological economics. This, in turn, defines an overarching research program, *viz*. Boons and Wagnerôs search for the ôHoly Grailô, in terms of a quest for the critical technical and institutional rules that yield a sustainable economy. Such rules involve consideration of behaviours, strategies, technologies, institutions and policy settings (Arrow *et al* 1995, Arrow *et al* 2004, Ayres 2008). As such, inquiry into the operational and institutional properties of such a sustainable economic model' and by ôsustainableô we refer to the capacity of the environment to sustain human life and current levels of economic activity without degrading the quality of environmental services' and the pathways by which we might achieve them is, thus, rightfully central to the research program and indeed the normative conception of ecological economics.

The necessity to consider the complex interaction of institutional, technological and industrial dynamics means that ecological economics can profitably draw upon perspectives and findings of evolutionary economics. In particular, Gowdy (1994), van den Bergh and Gowdy (2000), van den Bergh (2007) and Buenstorf (2000) have all drawn useful and insightful attention to the many distinct commonalities between evolutionary and ecological economics, including population methods, complex systems analysis, energetic flows and other such correspondences. They argue that evolutionary economics can provide greater insight into the properties and characteristics of a sustainable economy than neoclassical economics. This is due to the specific attention that evolutionary economists pay to such concepts as endogenous preferences, differential selection and industrial dynamics, self-

organization, entropy and economic evolution, and institutional and technological co-evolution. In this vein, a recent special section in the journal, *Ecological Economics*, has attempted to reignite a co-evolutionary research agenda for ecological economics (Kallis and Norgaard 2010). Thus, it would seem uncontentious that evolutionary economics and ecological economics should be viewed as contiguous fields with (evolving) ecological systems defining the ultimate constraints for (evolving) economic systems (Perrings 1998, van den Bergh and Gowdy 2000). This perspective is near axiomatic in ecological economics; as Kallis and Norgaard point out, the co-evolutionary approach ôhas not taken off within ecological economicsô (2010: 690). But is it actually true?

As a further development of arguments encountered in the nature vs. culture, or limits to growth debate (Meadows *et al.* 1972, Cole *et al.* 1973, Meadows *et al.* 1992, Ekins 1993, Nordhaus 1994, Costanza 2000, Costanza *et al.* 2000, Meadows *et al.* 2004), an alternative perspective can be assembled by recognising that the environmental or ecological constraint may not always be hard, but only apparently so. For example, ecological constraints may become apparent as a problem before they impact fully upon economic activity. Typically, such constraints take the form of looming resource scarcities or increasing stress loadings on particular environmental services. Evolutionary economics tells us that, if there is adequate information and the problem is not entirely ôlocked inô, adaptive behaviour is likely to be manifest in such circumstances. Exploratory search will occur and innovative solutions will emerge. Those who engage in this kind of activity are ôentrepreneurialô: they look to create value in states of uncertainty where market signals are weak or non-existent. What do we mean by entrepreneurial? We view it as a product of a cognitive state, as discussed by Nooteboom (2009: 174ï 84), and, thus, quite distinct from the ôrational agentô perspective of conventional economics.

An act of entrepreneurship can ameliorate a constraint, rather than being limited by it (Rammel 2003). There are multiple ways that this might be achieved: for example by shifting resources, by making resource substitutions, by bringing new technologies or business models to bear on the problem, or by new forms of contracts, organizations or institutions. An environmental constraint can, thus, function as an incentive within which entrepreneurial agents can see opportunities. There are many examples of the operation of this 'entrepreneurial loop' in evolutionary economics and in the related field of innovation economics. There is no reason why such a loop should not also operate at the interface of economic and ecological dynamics. In considering such a possibility, we may arrive at a very different sense of the mechanisms that dynamically connect economic and environmental systems.

The defining feature of this alternate perspective is that the 'fast' evolutionary dynamics of the growth of knowledge process, manifested in, for example, economic evolution and associated creative destruction, comes to dominate the 'slow' evolutionary dynamics of the ecosystem, weakening its resilience (Gual and Norgaard 2010). The knowledge-base of the economic order is ever changing and 'restless' (Metcalfe 1998). This creates a serviceable or 'bounded environment' that is sufficient for most purposes or 'good enough', but not more-so; it does not contain 'slack' or unexploited opportunities (*cf.* Leibenstein 1978). The properties of ecosystems are determined by revealed preferences for environmental qualities, services, etc, but not more-so. From this perspective, the observation of growing environmental damage or the onset of an impending ecological collapse presents entrepreneurial opportunities. Note that we specifically say 'the onset of', and do not refer to a final state of ecological collapse. This is because those states do not always eventuate, most notably in those societies where entrepreneurial behaviour is encouraged. The entrepreneurial mechanism, in appropriate conditions, can operate effectively on the basis of an expectation

of an impending collapse. Entrepreneurs seek out ways to provide innovative solutions that can be traded profitably in newly created market mechanisms. What is a ónegative externalityô can be removed by entrepreneurial actions that permit those who feel damaged by it to purchase goods and services that fix the problem, perhaps not entirely, but enough to avert disaster.

But entrepreneurship is not limited to the economic domain; such conditions can also present entrepreneurial opportunities in the political or the socio-cultural domains, or perhaps in both. Baumol and Strom (2010) cite historical evidence that much of entrepreneurship prior to the 18th Century was in these domains with rewards in the form of power and status. Entrepreneurial opportunities in the economic, political and cultural domains can thus lead to different forms of technological, behavioural and institutional change. These integrate to produce complex adaptations in anticipation of environmental change. Entrepreneurial action thus has a dual impact. Entrepreneurial success in introducing innovations and generating economic growth causes environmental stresses in an unintended manner but entrepreneurs also respond to the value creating opportunities that such stresses offer. Thus, we can have a process of cumulative causation where entrepreneurial activity, in states of uncertainty, leads to unintended negative environmental affects which, when revealed, stimulate entrepreneurial activity that mitigates such effects. And on it goes, with each new solution inducing new and different environmental problems that in turn create new economic opportunities. Thus the notion of convergence upon a global óstationary stateô at an environmental limit is not always helpful. Equally, it becomes difficult to know how to define what a long-period ósustainable economyô (Krausmann *et al* 2009; *cf*. Gowdy 1994) is at any point in economy-environment co-evolution and what its stability properties might be. In complex systems, saying anything definite about long periods is difficult. For example, Malthus clearly under-estimated the

power of innovating entrepreneurs but Diamond (2005) gives us several examples of societies that collapsed in the face of hard environmental constraints.

The historical evidence points to the fact that humans are both ecologically destructive (Penn 2003) as well as entrepreneurial in response to opportunities. But these tendencies are connected: a widespread expectation of ecological destruction alerts entrepreneurs to opportunities (Boons and Wagner 2009). This can happen in many ways. It is common, for example, in ecological economics to recognise the primacy of the incentive effect of environmental regulations on induced technical innovations and entrepreneurship (Rennings 2000; Beise and Rennings 2005). But there are other pathways via direct market signals, as well as indirectly via socio-cultural pathways, yielding multiple opportunities for entrepreneurial responses to ongoing challenges posed by environmental degradation. Regulatory adaptation is often slow, so these other pathways can be critical. Indeed, regulatory change can be an endogenous response to movements along these other pathways. If entrepreneurship is, indeed, responsive to environmental degradation, it can be argued that a co-evolutionary connection exists between economic and ecological systems. This co-evolution centres upon the growth of knowledge about environmental degradation and the capacities of entrepreneurs to take the opportunities that are presented.

Environmental and ecological problems are omnipresent, but entrepreneurial actions can solve them if prevailing socioeconomic and cultural rules permit them to do so. Entrepreneurs do not usually respond directly to information concerning degradation but, instead, react to information about its impacts upon human welfare and wellbeing. Price signals often translate a problem into economic terms. For example, when overfishing seriously reduces fish stocks, fish prices usually rise to unprecedented levels. Entrepreneurs who anticipate that fish will be in short supply, either because of stock exhaustion or severe governmental restrictions on fishing, will see opportunities to invest in sustainable fish

farming. This maintains fish supply while removing environmental pressure. However, this will not be possible without adequate flows of information, appropriate regulatory frameworks and the existence of viable market institutions. Because we live in an uncertain world, there tends to be continuous lurching from one environmental crisis to the next. Each current ecological crisis is the unintended consequence of previous economic innovations which, in turn, can be resolved by new economic innovations. So while Gowdy, van den Bergh and Buenstorf *et al* do correctly elucidate the benefits of integrating evolutionary economics and ecological economics, they nevertheless underplay the self-organizational feedback implications of entrepreneurial activity. Although governments can devise regulatory frameworks that facilitate the process of environmental protection and regeneration they cannot act as rapidly as entrepreneurs in introducing the necessary innovations and inducing the associated creative destruction. Governments are constrained and slowed by vested interests; entrepreneurs destroy such interests.

2 Elements of a model

What then are the elements of a co-evolutionary model of the complex interactions and evolutionary dynamics of economic and ecological systems?

First, it is necessary to acknowledge that the environmental degradation that we observe is, ultimately, due to the use of free energy flow to drive economic activities that yield goods and services to growing populations. Such degradation is a manifestation of the entropy process that must accompany increasing order and complexity in economic systems (Ayres and Warr, 2009; Foster, 2010). This perspective was first presented in Georgescu-Roegen (1971) and generalised to an open system (or dissipative system) context in Foster (1996) and Raine *et al* (2006). Spaceship earth travels according to the laws of physics,

whereby large energetic transformations must satisfy the second law of thermodynamics. Economic evolution thus runs *up* an energetic gradient (Schneider and Sagan, 2005) Increased energetic throughput is associated not only with an increased quantity of energy conversion but also with changes in the quality of the energetic form, as in the highly controlled use of energy for moving electrons or photons in precise ways to perform computation (Huber and Mills 2004). Because entrepreneurs must, necessarily, make decisions in uncertainty, they are the key actors in the process whereby increased energy use has resulted in economic growth. But they have also been key players in the introduction of innovations that have resulted in more efficient energy use. Environmental degradation depends critically upon the energy-entropy nexus and entrepreneurs, for better or worse, have always been at its core.

Second, our model must recognise that environmental resource depletion and degradation in ecological systems and services present new opportunities for human action. Economists commonly conceptualise this negatively in terms of increased scarcity, i.e. action in response to a rise in the price of a factor, inducing reduced use of that factor relative to others. But, as we have discussed, this may also lead to longer term thinking about how to achieve the underlying goal in a different way. Invention and innovation can result in new connections and combinations that can generate value or new ways of creating value. There are no hard environmental constraints on economic evolution and there are no hard economic constraints on natural evolution. Economic evolution is a fast process that modifies the natural environment while natural evolution is a slow process that can inflict catastrophic impacts on human society in the longer term. Knowledge of the possibility of the latter provides entrepreneurial opportunities, for example, in developing alternative energy sources and carbon trading.

Third, our model must recognise that the increasing complexity in the institutional rules that are operative in an evolving economic system is an outcome of the co-evolving economic-ecological process. As ecological systems become stressed by the growth of economic systems, the latter can respond by becoming more (not less) complex. The presumption that environmental stresses lead inexorably to economic stress, as in the Malthusian hypothesis, is a false analogy from the ecosystem context whereby a species in a diminished environment cannot respond ‘entrepreneuriallyô by creating and implementing new technologies, organisational structures and institutional rules. Instead, population dynamics over extant variety is the prime ecological mechanism of resolution. This is not true of economic mechanisms. Although we can find historic examples where economic exploitation has wholly depleted a natural environmental niche, we can also find cases where depletion did not occur because of adaptive, forward looking behaviour by entrepreneurial risk-takers.

Subject to cultural and legal/political constraints, economic entrepreneurship can create new organisational, institutional and technological rules that can resolve environmental problems. This may seem counter-intuitive if it is increased economic activity that causes environmental problems in the first place. So to suppose that further increases in economic activity might resolve these problems may seem perverse. But ‘economic activityô is not homogenous over time; it is adaptive and can change qualitatively. This does not deny that new activities will not create new environmental and ecological problems' for they almost certainly will' but the point is that these are mostly unknown or latent and cannot be anticipated in the cost-benefit calculations of contemporary economic activity. Economic and ecological systems are at different ‘orders of complexityô and the former has a creative and adaptive capacity that the latter lacks (Foster 2005).

Fourth, our model must recognise that the political arena in such a co-evolving world is one of several possible spaces where endogenous action can occur in response to changes in current or anticipated environmental circumstance. Environmental constraints and ecological problems present emergent opportunities for political entrepreneurs. This is also a legitimate mode of response (Lachmann 1986). There may also be behavioural or socio-cultural change (i.e. changed preferences induced by changed models of behaviour that are then adopted) as well. Furthermore, these political, socio-cultural and economic entrepreneurial responses may interact in complex ways.

A model of economic-environmental co-evolutionary dynamics of this kind must emphasise the core role of experimental new ideas. This ónew knowledgeô dimension is commonly neglected in models of economic-ecological dynamics. Entrepreneurship provides the experimentation that both causes and maintains these dynamics. Economies are only sustainable, in other words, through their capacity to facilitate, rather than constrain, the ability of entrepreneurship to generate new solutions to extant environmental problems.

3 The dynamic structure of ecological and economic co-evolution

Economic activity is always embedded in an ecological context. Economic activity is ósqueezedô at the margin as increased environmental scarcities will cause price rises that induce substitution toward economic activities with lowered environmental impact. But there is nothing automatic about such substitutions in complex situations since they always involve uncertainty and it is here that neoclassical economics can be highly misleading because too strong assumptions are made about knowledge and risk. The substitution of one technology for another is a difficult matter and history is littered with failures. We can think of a

degrading environment as opening up an entrepreneurial opportunity space as a map of the actual and perceived constraints. Within this space, four complex systems co-evolve:

1. the economic system
2. the ecological system
3. the political system
4. the socio-cultural system

These are connected through multiple interactions and feedbacks. As such, any model of this co-evolution must have the following three mechanisms:

1. how economic systems evolve (e.g.. Dopfer and Potts 2008)
2. how ecological systems respond (i.e. the ecological part of ecological economics)
3. how political/socio-cultural systems respond to ecological change caused by economic evolution

We sketch the structure of our co-evolutionary model in Figure 1. In the beginning, there is an economic innovation derived from a new ógenericô idea that changes the structure and level of resource use (we call this a ómeso trajectoryô). Eventually, this creates a set of environmental and ecological impacts. When the environmental conditions that originally prevailed have been seriously damaged, or are perceived to be so in the foreseeable future, new entrepreneurial opportunities emerge (Shackle 1972). However, inasmuch as new actions emerge to resolve that problem, new problems are, in turn, created (Arthur 2009). So the co-evolutionary process can continue as one of emergent cumulative causation with many possible end states.

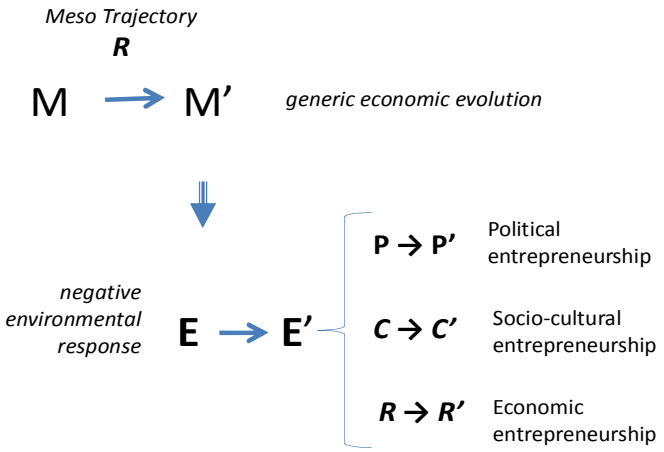

Figure 1. Economic and environmental co-evolution

In constructing a co-evolutionary model, we employ the ómicro meso macroô analytical framework (Dopfer *et al* 2004; Dopfer 2005; Dopfer and Potts 2008). In this framework, the economic system is viewed as having at its core an inter-connected system of rules. The application of these rules in a diverse range of microeconomic contexts results in the generation of value which can be aggregated at the macroeconomic level of inquiry. Economic evolution occurs when new rules to generate value are applied at the microeconomic level by entrepreneurial action. These rules spread as they are taken up by a population of adopters. At the same time, some rules fall out of favour and decline in importance. What the micro-meso-macro framework does is depict the economy as a network structure where ócreative destructionô is concerned with the coming and going of rules.

We can start with an initial state where there is an economic order (**M**) that is composed of a coordinated macro system made up of generic (meso) rules. Each rule is carried by a population of micro agents. So **M** = {M_1, M_2, é M_i, é M_n}, where the elements M_i are the populations that have adopted each rule. Thus **M** is the knowledge-base of the

economic order. This óknowledge economyô is capable of transforming human energy, physical energy and natural resources into flows and stocks of goods and services.

Economic evolution is defined as a change in the set **M** Ÿ **M′** by the origination, adoption and retention of a new generic rule M_{i+1}. This so-called ómeso trajectoryô (Dopfer *et al* 2004; Dopfer and Potts 2008: chapter 4) defines economic evolution as the process by which a new ógeneric ruleô in the form of an idea, technology, or business model results in the transformation of the generic structure of the economic order to **M′**. As such, **M′** is associated with higher system complexity, higher total economic value and more ówork ô achieved either through higher energetic throughput and/or the more efficient use of energy. **M** contains rules that relate to the exploitation of the natural environment. Generally, it has been accepted in human civilizations, at least since the hunter-gather era, that the natural environment is an exploitable resource to be degraded at will to meet agricultural, industrial and urbanisation needs. So we have ecological degradation (**E** Ÿ **E′**)**.** This is the response since natural evolution is too slow to adapt to fast moving economic evolution.

However, now that we have represented the economy as a system of meso rules which changes in response to the application of new knowledge, we know that the rules that relate to the economy-environment interface will also change if opportunities to generate value arise. Clearly, the best way to generate value into the future is not just to exploit to the point of total degradation. This is a point of maximum entropy and precisely what dissipative systems are always seeking to avoid. So the tendency towards serious degradation provides economic opportunities to devise and apply new rules to generate value through reduced exploitation and environmental protection. Whether this succeeds depends critically upon the extent to which vested interests allow new rules to be applied. Here we observe wide variations throughout history but also an increased tolerance of entrepreneurial activity as we have moved towards more open, democratic societies.

Economic value is generated by the transactions and transformations of resources made possible by the existence of meso rules. Energy flow is unavoidable in all such economic operations. For much of human history the energy used was largely food fuelled human activity and the burning of biomass. This did result in environmental degradation but not on the grand scale that we have witnessed in the era of fossil fuels. In the modern economy, economic operations can involve direct energetic processes (e.g. transformations such as smelting metals) which use large amounts of fossil fuel energy with clear environmental effects. However, there are also economic operations that are mainly concerned with the storing and manipulation of information. These tend to be electronic and use relatively low levels of energy but they can result in very significant increases in the efficiency of energy use in delivering both existing and new goods and services. Correspondingly, innovations in such operations increase significantly our access and use of information about the environmental impacts of human activity.

This emergent capacity to use electronic energy to access a vast amount of information and computational power has opened up new kinds of entrepreneurial opportunities. Viable alternative energy generation systems have been made possible, affordable technologies to monitor environmental conditions have emerged and electronic communication systems have provided platforms for millions of people to understand and discuss the environmental impacts of economic activities. Two kinds of meso rules have been emerging: first there are technological and organisational ones that entrepreneurs adopt to create value from the sale of environmental protecting systems; second, there are those that are socio-cultural in nature that are adopted by people in a way that influences political processes and related institutions. In our co-evolutionary process, adopters of the latter meso rules are, in effect, representing the óinterestsô of both the natural environment and the welfare of future generations.

Economic evolution (**M** Ÿ **M′**) thus moves the economic order up an energy gradient (**E** Ÿ **E′**). This is associated with a higher throughput of energy that as a vector of both quantitative and qualitative change is consistent with the first phase of an environmental Kuznets curve. Environmental degradation may take many possible forms, including pollutants or environmental loading, loss of bio-diversity, loss of resilience, depletion of a resource stock, or increases in population driving increased use. All of these constitute signals, either directly or indirectly, to possible entrepreneurial agents that opportunities are coming into existence.

There are at least five ways this may arise. The first is via *direct observation*, as for example with observation of atmospheric pollution or deforestation. A second way is *theory-based observation*. This relies on scientific concepts and measuring technologies, as for example, pesticides or the ozone hole. A third way goes via *media and social networks* (Potts *et al.* 2008), as for example, global warming. A fourth way is via *market operations* due to: (1) supply changes, in which price changes signal changes in scarcity conditions; or (2) demand changes where preferences have endogenously changed (Earl and Potts 2004). A fifth mechanism is via *expectations*. These can be embodied in prices in markets with a future dimension, which is only possible where there is an interaction of mental models at the ófourth orderô of complexity (Foster 2005). Each of these mechanisms offers an opportunity for entrepreneurship to occur, whether it is the political entrepreneurship involved in the introduction of new *laws*, the social entrepreneurship of promoting new *fashions*, the economic entrepreneurship of devising *business models*, or as a complex entrepreneurial opportunity involving some or all of these. There is a considerable literature on entrepreneurial opportunity which presumes that opportunities are exogenous. Here we regard them as endogenous in a similar way to Acs *et al* (2009), but from a different analytical perspective, as discussed below.

4 Entrepreneurial response

Environmental loss, as caused by prior economic evolution, thus offers *four classes* of entrepreneurial opportunity: political; socio-cultural; technical; and economic, as in Table 1 below.

Class	Mode	Mechanism	Example	Incentive
Socio-cultural	Changed beliefs, preferences, or values	Cultural imitation, signalling	New ógreenô lifestyles	Intrinsic, social signalling
Political	New laws, or resource transfers	Law, force	Carbon taxes	Reputation, votes
Technical	New production techniques, new machines	Science, education, training	Solar PV cells and systems	Profit, provision of public goods
Economic	New business models, commodities or services	Market, consumer choice	óGreeningô of the economy	Profit, market share

Table 1: Four modes of entrepreneurial response to environmental problems/opportunities

First, we may conceive of the lead response emerging in the form of *social* or *cultural entrepreneurship* in the form of corporate leadership, celebrity leadership, or fashion leadership, or in general the process by which a local initiative has wider effect. The socio-cultural mechanism works via seeking to change beliefs, preferences and behaviours via an imitation or social learning mechanism. This creation and adoption of meso-rules may be spontaneous, in the form of the emergence of cultural leadership and fashion, or it may be more systematic and programmed via education and media mechanisms. This socio-cultural mechanism does not require a single general solution (i.e. a new law), but will issue from a

diversity of behaviours that are then subject to differential copying or replication over social networks (Bentley *et al* 2007). In this way, new models of thought and behaviour, as well as social organizations and institutions, may emerge in response to environmental problems. The entrepreneurial response here refers to the agents that provide the institutional or cultural seeds, in the form of new models of thought, action or organization that might subsequently be replicated by others.

Second, environmental problems present *political opportunities* to the entrepreneurial politician or law-maker if a socio-cultural meso-rule concerning action to solve an environmental problem has been widely adopted. Such political solutions (i.e. fiscal or regulatory response) are retailed by most political franchises. Such political entrepreneurship creates new conditions for ongoing economic evolution by changing the underlying constraints and opportunity sets for value creation, thus providing entrepreneurial feedback (via constitutional rules) from the environmental problem to new economic rules of the game. In the Hayek/Schotter model, laws (as governing institutions) are the product of self-organization, the codifying of emergent patterns of actions. Yet even from this perspective, we may view laws as the product of *political entrepreneurship* both in proposing new órules of the gameô or in leading the drive to their codification. Environmental problems are thus entrepreneurially resolved politically in the form of new laws, treaties, agreements, etc.

The third entrepreneurial mechanism concerns scientists, technologists and engineers. All are part of processes that yield physical, chemical (and now micro-biological) discoveries that can be used to devise new techniques and new combinations of components in machines and mechanisms that can do work using energy. Because there is a significant ópublic goodô dimension to technologies, there is governmental support for education, training and research. Entrepreneurs in this space seek to secure patents or simply be first to develop and profit from a new technology or machine. For example, the increased concern over global warming

has stimulated a great deal of entrepreneurship in the development and commercialisation of new, low carbon emitting power generation. Because of the public good dimension, support for this kind of entrepreneurship and the associated innovation process is both private and public. This is because the uncertainty involved renders these technologies too high risk to be financed adequately only by the private sector yet it is a high social priority to ensure that they are developed once the meso-rule that originated in the socio-cultural domain becomes embedded in the political process and related policies. Because of the ócreative destructionô that the development of such technologies can bring, often political entrepreneurs are essential to overcome entrenched vested interests.

The fourth entrepreneurial mechanism concerns the *economic agent* engaged in seeking to create value by the discovery, origination and realization of new market opportunities created by new environmental problems (Dean and McMullin 2007). Such entrepreneurial ventures will seek to provide new solutions, in the form of new goods or services, either as new choices or product niches within existing market categories or as new business models and technologies. For example, there is seemingly high and growing demand for ógreen consumptionô (which in part of course derives from the effects of socio-cultural and political entrepreneurial actions; e.g. Keogh and Polonsky 1998). Thus, there are profit incentives to develop new ógreenô goods and services, a process presently working its way through much of the economy.

It should be apparent that these four entrepreneurial mechanisms have to interact in order for there to be effective action. There are examples in history where this has occurred (Schaper 2005) but there are others where there was failure. The volume by Landes *et al* (2010) contains a number of examples where there was a disconnect between these four mechanisms of entrepreneurial action by political interest groups or defenders of cultural

norms led to the negation of entrepreneurial attempts to enact, and profit from, changes that could have averted crises and catastrophes.

5 Implications

This entrepreneur-centred co-evolutionary model has several implications for the analytic focus of ecological economics.

First, it implies that the value of a resource, and indeed the very notion of what even ócountsô as a resource, along with how it is distributed and owned are less fixed from the entrepreneurial-evolutionary economic perspective. This is due to the entrepreneurial possibility of changing the órules of the gameô, or effecting change in the knowledge-base of the economy. As such, the co-evolutionary perspective is sceptical of standard notions of exogenously imposed resource constraints (i.e. a known non-renewable stock of *x*, or of a maximum flow of environmental services of *y*), or of concepts of sustainability that leave no role for new knowledge that is the result of entrepreneurial experiment and innovation.

Secondly, expectations play a larger role in this model than in conventional models of economic-environmental dynamics because of the central role of entrepreneurial action in formulating responses by creating new rules, solutions, business models, etc, in the face of uncertainty (Lachmann 1986). Here the perspective is starkly different to standard, neoclassical economics since all four of the entrepreneurial responses discussed occur in states of uncertainty where meso-rule óunderstandingsô have to emerge to enable innovative experiments to occur and best practices to spread through imitation, collaboration and selection (Earl and Wakeley, 2010). The neoclassical perspective lays most stress upon economic responses to price incentives where, for example, the increasing scarcity of

resources or costs imposed as negative externalities due to depletion of environmental services raise prices.

Now, there is little doubt that prices are important in signalling entrepreneurial opportunity (Kirzner 1973), but, because of the uncertainty involved in innovative experimentation, considerable entrepreneurial failure always occurs. So there is much more involved than simply the neoclassical response, which presumes either certainty or quantifiable risk. Only through the adoption of meso-rules in the formation of beliefs, aspirations and common understandings, will entrepreneurs respond to price incentives. The entrepreneur does not just react to prices set by a market, s/he seeks to bring a new market into existence and to lead in such a market by forecasting how particular patterns of change play out with conjectures of future relative prices or what expected patterns of relative demands and scarcities might be. This kind of future-oriented, connection-establishing behaviour is an example of what Foster (2005) calls fourth-order complexity. Note also that, just as we can speak of different domains of expectations, we may also speak of different domains of uncertainty as corresponding to, for example, technological, market, political, regulatory, cultural and even ecological circumstances. There is scope for entrepreneurial response over each dimension of uncertainty and their interconnections.

A third observation is that entrepreneurial action is properly understood as making conjectures about the value a new idea might create, and then putting that into action in pursuit of profit. As we have noted, this is not necessarily a pecuniary profit, but may include identity, social attention, power or favours, many of which can be converted to material forms through subsequent exchanges. Profit-seeking is not the only class of strategic action in the face of opportunities; the other of course is rent-seeking. Rent-seeking in economic-environmental co-evolutionary contexts is likely to be as prevalent as in any domain of economic life. Its main effect operates via the formation of coalitions, both within and across

economic, cultural and political domains that act to lock-in particular institutional rights or advantages or to exclude or make difficult the adoption of new solutions to emergent problems. In other words, they operate by seeking to shut-down ópositiveô entrepreneurial responses (whether political, cultural or economic). Thus, the meso-rules embodied in existing institutions that determine the nature and extent of connections between economic and environmental systems need to be evaluated not only in terms of static properties such as allocative efficiency, fairness and so on, but also in terms of their adaptive flexibility and openness to change.

Fourth, because economic activity is often mobile and responsive to both relative prices and institutional regimes this model opens new perspectives on globalization. The main implication that follows from the entrepreneur-driven evolutionary model is that environmental degradation must spread over the entire planet, a process we might think of as óglobalized ecological degradationô. This also implies that our four entrepreneurial feedbacks in the face of such degradation also have to be global in reach. In this regard it should be apparent that both economic systems and socio-cultural systems by far lead the way in the global context, and thus have a powerful competitive advantage over political entrepreneurship at the global level, which is the opposite of the situation at more local levels where political forces tend to have a greater impact. This points to the likelihood that global environmental treaties may be necessarily parasitic on, or symbiotic with, economic treaties, or global cultural movements (religious or secular). For example, these interconnections are very evident in the global debate concerning global warming and what to do about it. What we observe is not a logical discussion but a struggle between existing adopters of both socio-cultural, e.g., religious, and economic (e.g., a belief in maximal economic growth) meso-rules versus adopters of an emergent meso-rule that we must act to mitigate climate change. This is

not a scientific discussion but one involving the struggle between existing and emerging meso rules, driven by entrepreneurial behaviours.

Fifth, the co-evolutionary model points toward conceptualising policy responses in terms of entrepreneur-led adaptation rather than expert-led optimization. In a co-evolutionary context there is no ideal or optimal policy setting for the simple reason that the set of ‘old’ meso-rules, embodied in existing institutions, will be subject to ongoing change and the nature of this is uncertain in a radical sense. This change comes from continuous experimentation and learning, consolidated by entrepreneurial value creation as circumstances change. Just as there is no ultimately final most-winning competitive business strategy but rather a race without end, so too is there no ultimate optimal environmental policy but rather a continual process of ongoing experimentation, learning and policy adaptation (Potts 2009). The key role of government is not ‘picking winners’ intervention but the careful nurturing and formalization of facilitating meso-rules and the provision of an incentive structure in markets that signals to entrepreneurs the direction that their ventures should take. Generally, entrepreneurs will do a better job more quickly than government planners. For example, in countries such as Spain and Germany, the provision of feed-in tariffs has led to entrepreneurially driven innovations and reductions in unit costs in solar power generation that government could not have achieved through direct action. Market-based emissions trading schemes, coupled with appropriately reinforcing political and socio-cultural meso-rules, promotes a diversity of entrepreneurial experiments and beneficial outcomes that would not be otherwise possible. This meso rule reinforcement is also important because such policies are expensive and taxpayers will only tolerate a rising cost burden if there is a well-established meso-rule that mitigation of climate change is a very high priority.

Sixth, it is entirely reasonable to question the efficacy of entrepreneurial responses in the market domain in relation to their specialization and experience. Entrepreneurs in a market economy may be well-honed to take advantage of opportunities presented in solving problems in the domains of consumer and producer goods and services, but they may be less well-versed in dealing with environmental opportunities. Raising awareness of environmental problems and proposals for their solution begin with socio-cultural entrepreneurship and, if an associated meso-rule set is adopted widely, political entrepreneurs will begin to devise appropriate policy proposals. An immediate effect is likely to be increased public support for appropriate technological entrepreneurship but lack of experience is likely to mean that economic entrepreneurs will experience high failure rates. It is for this reason that venture capitalists are often reluctant to finance entrepreneurial, high risk projects and it is, therefore, essential that government is heavily involved in providing appropriate support and facilitation to solve what is principally a public good problem. In instances where environmental problems have a high degree of visibility (e.g. urban smog), emotional salience (e.g. genetic modification), or low discount rates (e.g. climate change) political entrepreneurship may well be highly effective in this regard. But when problems are less visible or charismatic, such as with krill stocks, or involving environmental problems that do not respect political boundaries, then global socio-cultural entrepreneurship, Greenpeace style, may have a comparative advantage.

6 Conclusion

We have sought to outline a co-evolutionary model of economic and environmental systems connected, both negatively and positively, by entrepreneurial endeavour. In this model ǿeconomic-onlyô entrepreneurship and innovation tend to have negative environmental and ecological effects that, in turn, create new entrepreneurial opportunities over several domains:

political, cultural, technological and economic. These different entrepreneurial pathways can lead to new meso-rule sets, embodied in new institutions. However, in an interconnected economy-environment system we can expect new environmental problems to arise that then present new entrepreneurial opportunities, so beginning the cycle again. Thus, we believe that it is necessary to adopt a co-evolutionary, non-equilibrium modelling approach in which the core processes are the application of both free energy and new knowledge (Foster, 2010)

The schematic model that we have sketched here is preliminary. However, it provides a sound basis for further analytical and empirical development. In dealing with the behavioural mechanisms that connect two open complex adaptive systems that evolve through a mix of self-organization and competitive selection, a new methodology is required. Foster and Potts (2009) have proposed a mix of historical, statistical and agent-based simulation and calibration that would seem to be a good starting point in studying the interaction between economic system and environmental system co-evolution. We have argued here that this is not only a resource interaction (*á la* Nicholas Georgescu-Roegen and Kenneth Boulding *et al*, and subsequently by John Gowdy and Jeroen van den Bergh *et al*), but it also involves complex entrepreneurial feedbacks, and it is this latter mechanism of co-evolution that, in our view, properly defines the dynamic relation between evolutionary and ecological economics.

Yet if we are correct about this mechanism, then this implies that the conceptions of sustainable economic growth and also of environmentally-friendly economic policy are both widely misconstrued. In both cases, entrepreneurship is the proximate cause of many ecological problems but can also be their solution. However, such solutions can never be final, or in equilibrium, because solving one set of problems inevitably introduces a new set ï this is a fundamental feature of a co-evolutionary interaction. We have also emphasised that entrepreneurial responses play out over different and sometimes competing domains:

variously economic, political, technological and socio-cultural. That these can be either competing or synergetic domains is insufficiently appreciated in models of economic and ecological dynamics, which commonly presume just ómarket failureô with uniquely political solutions such as environmental regulations, taxes or transfers. Yet when environmental crises are recognised as unintended consequences of past entrepreneurship, we may then appreciate how further entrepreneurship may resolve these problems. So there may well be no such thing as a definitive economic solution to an environmental problem. Rather, environmental problems are better conceptualised as due to the continuous presence in human systems of entrepreneurial action to solve emergent problems in innovative ways. For the entrepreneur, an environmental problem is just another problem that presents an opportunity for gain. However, entrepreneurship can only occur if there are a set of facilitating rules that allow the possibility of gain. In this sense, the environmental context is no different and environmental policy should be oriented much more towards entrepreneurial facilitation than it is at the present time.

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References

Acs, Z.J., Braunerhjelm, P., Audretsch, D.B. and Carlsson, B. (2009) óThe knowledge spillover theory of entrepreneurshipô *Small Business Economics,* 32, 15-30.

Arrow K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S., Maler, K., Schneider, S., Starrett, D. and Walker, B. (2004) óAre we consuming too much?ô *Journal of Economic Perspectives,* 18(3): 147ï 72.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C., Jansson, B.O., Levin, S., Mäler, K.G., Perrings, C. and Pimentel, D. (1995) óEconomic growth, carrying capacity, and the environmentô *Ecological Economics*, 15(2): 91ï 5.

Arthur, W.B. (2009) *The Nature of Technology*. Free Press: New York.

Ayres, R. (1994) *Information, Entropy and Progress*. AEP Press: Washington.

Ayres, R. (2008) óSustainability economics: Where do we stand?ô *Ecological Economics*, 67: 281ï 310.

Ayres, R. and Warr, B. (2009) *The Economic Growth Engine: How Energy and Work Drive Material Prosperity*. Edward Elgar: Cheltenham.

Baumol, W. and Strom, R.J. (2010). óUseful knowledge of entrepreneurship: some implications of the history.ô In Landes, D.S., Mokyr, J. and Baumol, W. (eds.) *The Invention of Enterprise: Entrepreneurship from Ancient Mesopotamia to Modern Times* Princeton University Press, Princeton.

Beise, M. and Rennings, K. (2005) óLead markets and regulation: a framework for analysing the international diffusion of environmental innovationsô Ecological Economics, 52: 5ï 17.

Bentley, A., Lipo, C.P., Herzog, H. and Hahn, M.W. (2007). óRegular rates of popular culture change reflect random copying.ô *Evolution and Human Behavior*. 28: 151ï 58.

Boons, F. and Wagner, M. (2009) ôAssessing the relationship between economic and ecological performance: distinguishing systems levels and the role of innovationô*Ecological Economics*, 68: 1908-1914.

Boulding, K. (1966) ôThe economics of the coming spaceship-earthôin Lippit, V. (ed) *Political Economy: Explorations in Alternative Economic Analysis* M.E. Sharpe: Armonk, NY, pp.357-67. Available at: http://www.panarchy.org/boulding/spaceship.1966.html

Boulding, K. (1978) *Ecodynamics: a New Theory of Societal Evolution*. Sage Publications: Beverly Hills.

Buenstorf, G. (2000) ôSelf-organization and sustainability: energetic of evolution and implications for ecological economicsô*Journal of Ecological Economics*, 33: 119ï 34.

Cole, H.S.D., Freeman, C., Jahoda, M. and Pavitt, K.L.R. (Eds), (1973) *Thinking about the Future: a Critique of the Limits to Growth*. Chatto and Windus for Sussex University Press: London.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R.G., Sutton, P. & van den Belt, M. (1997) ôThe value of the world's ecosystem services and natural capitalô*Nature* 387: 253ï 60.

Costanza, R. (2000) ôVisions of alternative (unpredictable) futures and their use in policy analysisô *Conservation Ecology* 4 (1): 5 (online) URL: http://www.consecol.org/vol4/iss1/art5.

Costanza, R., Daly, H., Folke, C., Hawken, P., Holling, C.S., McMichael, A.J., Pimentel, D., Rapport, D. (2000) ôManaging our environmental portfolioô*BioScience* 50: 149ï 155.

Daly, H. (1973) *Towards a Steady State Economy*. San Francisco: Freeman.

Daly, H. (1996) *Beyond Growth: The economics of sustainable development*. Beacon Press: Boston.

Dean, T. and McMullin, J. (2007) ôToward a theory of sustainable entrepreneurship: Reducing environmental degradation through entrepreneurial actionô*Journal of Business Venturing* 22(1): 50ï 76.

Diamond, J. (2005). *Collapse: How Societies Choose to Fail or Succeed.* New York: Viking Books.

Dopfer, K. (2005) ôEvolutionary economics: a theoretical frameworkôin Dopfer, K. (ed) *The Evolutionary Foundations of Economics*. Cambridge University Press: Cambridge.

Dopfer, K. and Potts, J. (2008) *The General Theory of Economic Evolution*. London: Routledge.

Dopfer, K. Foster, J. and Potts, J. (2004) ôMicroï mesoï macroô*Journal of Evolutionary Economics*, 14: 263ï 79.

Earl, P. and Potts, J. (2004) ôThe market for preferencesô*Cambridge Journal of Economics,* 28: 619ï 33.

Earl, P.E. and Wakeley, T. (2010) ôAlternative perspectives on connections in economic systems.ô*Journal of Evolutionary Economics.* 20, 163-184.

Ekins, P. (1993) ó'Limits to growth' and 'sustainable development': grappling with ecological realities' *Ecological Economics*, 8: 269-288.

Foster, J. (1996) 'Economic evolution and the science of synergetics' *Journal of Evolutionary Economics*, 6: 239-260.

Foster, J. (2005) 'From simplistic to complex systems in economics' *Cambridge Journal of Economics*, 29(6):873–92.

Foster, J. (2010) 'Energy, aesthetics and knowledge in complex economic systems' School of Economics Discussion Paper No. 404 Available at: http://www.uq.edu.au/economics/index.html?page=130924.

Foster, J. and Potts, J. (2009). 'A micro-meso-macro perspective on the methodology of evolutionary economics: integrating history, simulation and econometrics.' In Gaffard, J-L, Nesta, L. and Cantner U. (eds.), Schumpeterian Perspectives on Innovation, Competition and Growth, Berlin: Springer/Physica, 2009, pp. 53-70

Georgescu-Roegen, N. (1971) *The Entropy Law and the Economic Process*. Harvard University Press: Cambridge (MA).

Gowdy, J. (1994) *Coevolutionary Economics: the Economy, Society and the Environment*. Kluwer Academic Publishing: Boston.

Gual, M.A. and Norgaard, R.B. (2010) 'Bridging ecological and social systems coevolution: a review and proposal' *Ecological Economics,* 69: 707-717.

Hayek, F. (1945) 'The use of knowledge in society' *American Economic Review*, 35(4), 519–30.

Huber, P. and Mills, M. (2004) *The Bottomless Well*. Basic Books: New York.

Kallis, G. and Norgaard, R.B. (2010) 'Coevolutionary ecological economics' *Ecological Economics*, 69: 690-699.

Keogh, P. and Polonsky, M. (1998) 'Environmental commitment: A basis for environmental entrepreneurship?' *Journal of Organizational Change Management*, 11(1): 38–49.

Kirzner, I. (1973) *Competition and Entrepreneurship*. Chicago University Press: Chicago.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.H., Harbel, H. and Fisher-Kowalski, M. (2009) 'Growth in global materials use, GDP and population during the 20th century' *Ecological Economics*, 68: 2696–705.

Lachmann, L. (1986) *The Market as an Economic Process*. Basil Blackwell: New York.

Landes, D.S., Mokyr, J. and Baumol, W. (2010) *The Invention of Enterprise: Entrepreneurship from Ancient Mesopotamia to Modern Times* Princeton University Press, Princeton.

Leibenstein, H. (1978) *General X-efficiency: Theory and economic development*. Oxford University Press: New York.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W. (1972) *The Limits to Growth*. Universe: New York.

Meadows, D.H., Meadows, D.L., Randers, J. (1992) *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future*. Chelsea Green: Post Mills, Vermont.

Meadows, D.H., Randers, J., Meadows, D.L. (2004) *Limits to Growth: The 30-Year Update*. Chelsea Green: Post Mills, Vermont.

Metcalfe, J.S. (1998) *Evolutionary Economics and Creative Destruction*. Routledge: London.

Nooteboom, B. (2009) *A Cognitive Theory of the Firm: Learning, Governance and Dynamic Capabilities.* Edward Elgar: Cheltenham.

Nordhaus, W.D. (1994) *Managing the Global Commons: The Economics of Climate Change*. The MIT Press: Cambridge, MA.

Norgaard, R. (1985) ôEnvironmental economics: An evolutionary critique and a plea for pluralismô*Journal of Environmental Economics and Management*, 12: 382ï 94.

Penn, D. (2003) ôThe evolutionary roots of our environmental problems: towards a Darwinian ecologyô *Quarterly Review of Biology*, 78(3): 275ï 301.

Perrings, C. (1998) ôResilience in the dynamics of Economy-Environment systemsô*Environmental and Resource Economics*, 11(3-4): 503ï 20.

Potts J, Cunningham S, Hartley J, Ormerod P (2008) ôSocial network markets: A new definition of creative industriesô*Journal of Cultural Economics*, 32(3): 166-185.Potts, J. (2009) ôThe innovation deficit in public services: A curious problem of too much efficiency and not enough waste.ô*Innovation: Management, Policy and Practice*, 11(1): 34ï 43.

Raine, A., Foster, J. and Potts, J. (2006) ôThe new entropy law and the economic processô*Ecological Complexity*, 3(4): 354ï 60.

Rammel, C. (2003) ôSustainable development and innovations: Lessons from the Red Queenô*International Journal of Sustainable Development*, 6(4): 395ï 416.

Rennings, K. (2000) ôRedefining innovation: eco-innovation research and the contribution from ecological economicsô*Ecological Economics*, 32: 319ï 32.

Schaper, M. (2005) *Making ecopreneurs: Developing sustainable entrepreneurship*. Ashgate Publishing. London

Schneider E. and Sagan, D. (2005), *Into The Cool: Energy Flow, Thermodynamics and Life,* Chicago: Chicago University Press.

Shackle, G. (1972) *Epistemics and Economics*. Oxford University Press: Oxford.

van den Bergh, J. and van der Straaten, J. (eds) (1997) *Economy and Ecosystems in Change: Analytic and Historical Approaches*. Edward Elgar: Cheltenham.

van den Bergh, J. and Gowdy J. (2000) Evolutionary Theories in Environmental and Resource Economics: Approaches and Applicationsô*Environmental and Resource Economics* 17**:** 37ï57.

van den Bergh, J. (2007) Evolutionary Thinking in Environmental Economics, *Journal of Evolutionary Economics* 17: 521-549.