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Abstract

Entrepreneurial innovators have been agents of transformation throughout history, but they have not had the scope to perform this role in the environmental domain. We propose an explanatory model that depicts the processes that give rise to innovation by new entrant firms. We apply this model to evidence from a study of problems faced by 73 environmental ventures. We present supporting evidence from case studies that demonstrate how entrepreneurial innovation is brought about by problem solving practices under resource constraint and decision-making flexibility. We point to the value of promoting technological options and the diversity and complementarities to which new entrants give rise.

I INTRODUCTION

To meet the challenges posed by climate change and environmental degradation, innovations are needed that are no less far reaching than those that gave rise to today's digital economy (Freeman 1992; Kemp and Schot 1998). In the past, entrepreneurs have played a key role in setting off and diffusing the radical innovations that ushered in new industries (Nairn 2002). New entrants from outside the mainstream industry of their time developed and diffused steam power, the railways, telegraph, radio and telephone, petroleum, the automobile, the PC, biotechnology and the Internet. Yet the role of entrepreneurial innovation in addressing environmental problems has received relatively little attention (Hart and Milstein 1999; Walley and Taylor 2002). Thinking today is still influenced by developments in the mid 20th century when the concentration of industrial power in a few giant companies and scale economies in the petroleum, electricity generation and chemical industries had erected barriers to new entrants. Schumpeter was the first to celebrate the creative destruction wrought by the entrepreneur in the economy (Schumpeter 1928), but by the 1940s he came to believe that their role as innovators had been taken over by the R&D labs of large companies (Schumpeter 1942). The entrepreneur was marginalized in contemporary economic theory and excluded from economic textbooks (Barreto 1989).

The neglect of the role of small new entrants as agents of innovation in the environmental policy arena is symptomatic of the extent to which scale economies and centralization requirements continue to dominate thinking about energy, as it did in the 1940s (Sine and David 2003). In other sectors things have been different. Throughout the Cold War, there was massive spending by the US government on computerization (Lécuyer 2006) and the life sciences (Lewen 1997), which unexpectedly created conditions in which enterprise was to flourish from the late 1970s. The funding of new knowledge in the public domain provided a resource initially more critical than capital to those entrepreneurs who saw the opportunity to create economic value from new knowledge. Pioneers funded by government grants laid the basis for venture capital and transformed the world of computing and pharmaceuticals (Mowery and Rosenberg 1998). In telecommunications, the government-initiated privatization and deregulation that started in the 1980s has

created a wide range of opportunities for entrepreneurial innovation since the 1990s (Fransman 2002).

There are signs of change underway in the environmental area. The Asia-Pacific Partnership on Clean Development and Climate (AP6) has been promoted as a stimulus to innovative cleaner technologies.[1] In the UK, the main focus of evidence for this paper, policies in support of research on new environmental technologies have been announced.[2] There is new interest from venture capital and by investors in London's Advanced Investment Market (AiM) in environmental enterprises (Library House 2005). Some of these ventures are achieving very high market valuations in relation to their level of business development.[3] The UK government set up the Carbon Trust with £50m of seed funding to invest in ventures with renewable technologies (Carbon Trust 2005).[4]

These developments are still on a small scale. Large companies appear to have the necessary resources for ambitious innovations in the renewable area but they face pressures to maintain their current rate of return on capital and may need to partner with innovative new entrant companies, as has occurred in the biotech sector. What conditions would make it possible for entrepreneurial innovators to play their historic role as agents of change in the environmental area? Before this can be established, we need a better understanding of the way environmental entrepreneurs innovate.

In this paper we propose an explanatory model of the mechanisms that give rise to entrepreneurial innovation and we apply this on a preliminary basis to evidence on 73 (mainly award winning) environmental companies in the UK, identified from a government database (Dee, Ford and Garnsey 2006). We gain further perspectives on distinctive problem-solving practices from twelve case studies of environmental

[1] http://www.asiapacificpartnership.org/ Some criticisms by environmentalists are summarized on http://news.bbc.co.uk/1/hi/sci/tech/4602296.stm

[2] The new UK Energy Technology's Institute's remit is to accelerate the development of secure, reliable and cost-effective low-carbon energy technologies towards commercial deployment, http://www.dti.gov.uk/science/science-funding/eti/page34027.html Significant portions of this funding will be for nuclear energy.

[3] Exceptional incentives to invest in their new technologies are experienced during the boom period of a transition to a new technology, when previous returns have become sufficient to attract speculation. Market sentiment typically goes through phase of skepticism, excitement, euphoria, disillusionment and realism (Cassidy 2001). Investment in clean tech is at the early stages of any such cycle, which may also experience early false starts.

[4] In 2006-7 the Carbon Trust received total grants worth £106 million to undertake a variety of carbon reduction activities, including objectives other than supporting radical technological innovation.

ventures. This evidence confirms the potential of new entrants but also identifies the challenges they face if they are to make a difference in the environmental sector.

Entrepreneurial value creation

While issues surrounding the negative externalities of pollution have been the subject of extensive theorizing, of model building and policy experiments, the issue of entrepreneurial innovation is under-theorized and implications for environmental policy have been little explored. There is relevant evidence in entrepreneurship studies, but in recent years the emphasis there has been on marking out the study of entrepreneurship as a distinctive field (Shane 2000; Shane and Venkataraman 2000). The early Schumpeterian agenda of identifying the contribution of entrepreneurial ventures to innovation in the economy has received less attention.[5] Research on eco-enterprise is sparse and for the most part a-theoretical, or using concepts based on static equilibrium conditions (Dean and McMullen 2002; Metcalfe 2004; Dean and McMullen 2005).

The most important entrepreneurial innovations set off cascades of complementary innovations. Two influential heterodox economists, Edith Penrose and Christopher Freeman, independently highlighted the extent to which innovation has stemmed from the entrepreneurial provision of newly combined resources to meet market needs (Penrose 1959; Freeman 1982). Recent work on entrepreneurship has subsumed this entrepreneurial matching process (in so far as it gains recognition) under the heading of the pursuit of opportunity, taken to be a defining feature of entrepreneurial activity. Some authors also characterize as entrepreneurial the application of new 'means-ends frameworks' (Shane and Venkataraman 2000; Shane 2003). The focus of most entrepreneurship studies is the genesis of the business idea and its translation into a business model that can attract investment. But for the study of entrepreneurial innovation it is necessary to follow the entrepreneurial process on through various iterations and attempts to launch and diffuse innovations.

We characterize the entrepreneurial endeavor as involving *the activation of opportunities to combine limited resources in order to create value and secure*

[5] E.g. Schumpeter is not mentioned by Aldrich 1999 in his study of new entrant organizations.

returns in new ways. This set of concepts leads us to investigate the nature of the entrepreneurial process and how it differs from standard project management within an allocated resource budget. By this definition enterprise is not a process that precedes or is confined to business start up.[6] But the business enterprise is the preferred vehicle of the entrepreneur in a market economy, where it offers a legally protected base from which to pursue cumulative cycles of value creation and value capture.

Economists who have addressed the role of entrepreneurs in the economy have focused on the improved resource allocation which results from their putting resources to better use. Their alertness to opportunity leads to a new means-ends calculus in recognition of the deficiency of current price signals (Casson 1982; Bhidé 2000).

In practice, however, entrepreneurs not only reallocate and recombine existing resources (Brush, Greene et al. 2001), but also create new resources. Among the ways in which they do so is by enlisting unrecognized talent, by seeing value in knowledge and by generating new technologies. Lacking extensive capital, entrepreneurs are particularly responsive to the potential in unvalued waste. They thereby confer on waste outputs a real value as opposed to the nominal or opportunity cost value attributed to them in carbon trading schemes.

The most obvious scope for the eco-entrepreneur lies in the solution of waste problems in a process that resembles symbiosis in the natural world. They gain returns from reconstituting the waste into a value creating product and provide incentives to imitators. This process is stimulated by regulations imposing penalties on waste emitters who face new incentives to pay for reduction and removal. The waste may become valuable. Petroleum was originally a waste product from kerosene.

[6] We use terms as follows: entrepreneurial practices constitute entrepreneurship; enterprise is entrepreneurial activity; an enterprise is the business founded by entrepreneurs; a venture is an immature business of this kind. Firm is the term for an enterprise used in economics, company is used in legal language, business in ordinary usage. Terms are interchanged for stylistic variety. An environmental enterprise refers to one that pursues business opportunities in addressing environmental problems. Incremental innovation makes step changes in within existing technological approaches, which may cumulatively be very significant. Radical innovations involve discontinuities in technology and depth of impact while generic technologies have breadth of applications. See Maine and Garnsey 2006 for further definitions of types of innovation.

Some examples follow. The first illustrates a low technology solution open to entrepreneurs who are alert to existing opportunities. Combining known methods with new technical know-how can enhance and protect the innovation.

1. Edward Miller began looking at ways of turning a commonly used throwaway item into a product with a longer lifespan. He discovered that in the U.K., over 3.5 million plastic cups are collected for recycling each year. Over two years he developed a process for recycling plastic cups into pens and pencils, and launched Remarkable Pencils Ltd in 1996. By 2001, Remarkable Pencils was diversifying its product range, to mouse mats and notebooks, along with pencil cases made from recycled tyres. The same year Remarkable became the first U.K. recycling brand to be sold by major retailers such as Tesco and Sainsbury, establishing two UK factories and sales in Europe.

Our next two examples illustrate the application of scientific knowledge to create opportunities to reconstitute waste in new ways.

2. Most of the 650,000 tonnes of drinks cartons produced each year in Western Europe end up in landfill sites. These Tetra Pak style cartons are composed of thin layers of a variety of plastics, paper and aluminium – a design aimed at preserving freshness that creates difficulties for recycling. This results in a loss of 40,000 tonnes of valuable aluminium per year, significant as landfill costs and aluminium prices are rising. Dr Carlos Ludlow-Palafox and Professor Howard Chase from the Department of Chemical Engineering at the University of Cambridge have patented and developed a continuous prototype based on microwave induced pyrolysis to recover this aluminium, and set up a new company, EnVal, to commercialize the technology. Reaching the finals of a university business plan competition in 2005 enabled them to present to private investors. The EnVal team negotiated £150,000 of investment, and have continued progress towards commercializing their recycling process to generate industrial grade aluminium.

3. ApaClara is a newly founded company that holds out the prospect of extracting fresh water from seawater. Over 1.1 billion people lack access to sufficient drinking water, but desalination technologies are currently very costly. ApaClara's technology will decrease the costs of water purification using a process known as 'forward osmosis' (FO), which holds the promise of lowering the energy requirements and costs for membrane seawater desalination, along with increasing source water recovery. Initial economic models comparing traditional seawater reverse osmosis and forward osmosis found the cost of water would be around 30% less for FO. Apaclara's innovative use of macromolecules generates osmotic pressure to drive a membrane purification process, but the macromolecules can be separated using a field gradient to provide pure water. The company is currently supported by development grant revenue and is working in partnership with Cascade Designs of Seattle, Washington to develop a prototype unit. ApaClara will start generating product revenue by licensing the use of its materials, but there is a longer term opportunity to develop and manufacture high-performance systems based materials technology

developed at Bath and Bristol Universities.[7]

These cases illustrate some of the ways in which environmental entrepreneurs can turn resources of little or negative utility into a source of value. Emerging technologies that could contribute to a major shift in the current techno-regime are of particular interest. But the contributions that low tech solutions can make should not be underrated. Operating close to final users, low tech entrepreneurs can change consumer behaviour and because they harness readily available resources rather than specialist knowledge, they may offer a more extensive repertoire of solutions.

Beyond harnessing waste using both high and low tech methods, eco-entrepreneurs go about realizing new opportunities in ways that resemble practices found among ventures in other sectors. Given that entrepreneurs are so diverse, and that the same person is entrepreneurial in some circumstances and not in others, is it possible to characterize these innovation-generating practices?

To answer this question requires an explanatory model, developed and refined through iterative learning from theory to evidence and back. Its conceptual elements should have measurable indicators but be grounded in contextual evidence, which calls for a base in qualitative research.[8] With these criteria in mind, we propose the following analysis of the processes of entrepreneurial innovation.

II THE ENTREPRENEURIAL PROCESS OF VALUE CREATION AND CAPTURE

"What hole can we fill in the market?" was the question that the founders of a solar thermal business asked themselves. This is a classic question which led Say (1803) and Von Mises (1949) to define the entrepreneur as an agent who connects up supply and demand. Technical and economic change on the scale required to address environmental issues would give rise to significant, fast evolving disparities between demand and current supply and so provide multiple opportunities for enterprise.

[7] Information supplied by the CEO, Dr Eric Mayes.
[8] The concepts used in model building are better understood if they are in current use in related inquiries, another of our objectives. For principles of theory building on which we draw, see Dubin (1978) and Carlile and Christensen (2005).

The source of returns to entrepreneurs differs from that of speculators who gain by selling at a price above what they paid, or of proprietors whose returns are based on ownership but who may create nothing new. It is by creating goods and services that provide new sources of value to others that entrepreneurs secure returns. They do this by combining resources in new ways on the supply side to solve problems experienced on the demand side. If they provide utility to users who are other than customers, they must engage customers to provide them with returns. They may involve insurers, government grants or advertisers to pay for the goods and services they provide to users.

In a business enterprise, the cycle of value creation and capture leads to new firm growth by attracting further resources which allow the scaling up of activity. As resources accumulate, the firm itself becomes an asset of value in the capital market. Even the prospect of this occurring can stimulate capital investment, as occurs during a technology boom. But uncertainties as to entrepreneurs' ability to capture returns on capital are more commonly a deterrent to investment in their ventures. There are systematic reasons why such doubts should arise, and yet they have an element of self-fulfillment. Without the reserves that funds provide, inevitable delays between productive activity and the generation of returns create cash shortages that can halt further activity.

The entrepreneurial venture experiences endemic resource constraints. If resources were abundant, new entrants would instead be engaged in budgeted project management (Stevenson 1999). Indeed they are encouraged to approach business development in a structured and predetermined manner by investors and business support agencies. But evidence on the entrepreneurial process from idea to value capture shows that in practice, entrepreneurial breakthroughs that bring in investor returns are often the result of trial and error as unpredictable developments continually alter entrepreneurs' assessment of dynamic opportunities.

The founder of one new venture closed his first company and set up a new one because the venture capitalists would not countenance what appeared to be a bizarre shift in strategic direction into a completely different market and application. This had become appropriate following the discovery of a promising collaborator company

when reliable partners had been lacking for the previous application. This opening altered the founder's perspective on the application and entry market that provided a real opportunity for his generic technology.

Even when acute early shortages have passed, resource limitations call for flexible solutions that enable the continued pursuit of new opportunities in the entrepreneurial firm. This leads to on-going reappraisal of aims and resources well beyond the startup period in the entrepreneurial firm (Best 2001). It is not until the pressure to protect the firm's assets and current performance preempts the pursuit of new and uncertain opportunities that the firm and its managers cease to be entrepreneurial. A company founder explained how the same people can become less entrepreneurial as their firm expands:

"We'd given all we had … to build the company from nothing. For years we'd paid ourselves peanuts. Now the company was valuable – and it was our only asset. If we made the wrong decisions we could lose everything. We realized we had become risk averse." Although they had not initially planned an early exit, a purchase offer for their company was too hard to resist.

The problems entrepreneurs face are often described as barriers to firm growth, but the concept of obstacles does not adequately convey key features of the entrepreneurial endeavour. Entrepreneurs who succeed typically do so by transforming the constraints they face into enabling factors (Hugo and Garnsey 2004). Not all obstacles can be turned into opportunities; many are insuperable in the face of entrenched competitors and short term investment. New ventures are challenged to the limit to innovate in such environments.

What they attempt systematically to do, nevertheless, is to turn 'positive externalities' to advantage. In economics, externalities are a form of market failure: they represent costs incurred by, or benefits conferred on, parties other than their originators.[9] Positive externalities that deter investors are, from this perspective, an external obstacle to the new firm's capture of value. But entrepreneurs use the value that others can gain from their efforts to enlist external support. Technical entrepreneurs

[9] Under perfect competition market failures would not arise. Market failures have been identified as the source of opportunities for eco-enterprise (Dean and McMullen 2002, 2005; Cohen and Winn 2005). In contrast Metcalfe argues that to class as market failure the very asynchronies that give rise to market dynamics is to wed analysis to static equilibrium assumptions (Metcalfe 2004). The present analysis shows that beyond the market failures identified by Dean and McMullen as sources of opportunity to eco-enterprise, there are many other market failures, such as market entry barriers, that limit such opportunities.

create new knowledge about ways of innovating which benefits not only customers but spills over to the benefit of investors, co-producers and suppliers, complementary producers and distributors. Studies show that entrepreneurs create social value much greater than the economic value they capture (Teece 1986). As explored below, their distinctive way innovating has the further effect of creating diversity and complementarities in the economy.

Entrepreneurial value creation and capture are summarized in Figure 1, which depicts a simplified version of the entrepreneurial process from the genesis of a new business idea to the capture of value from the ensuing new activity.

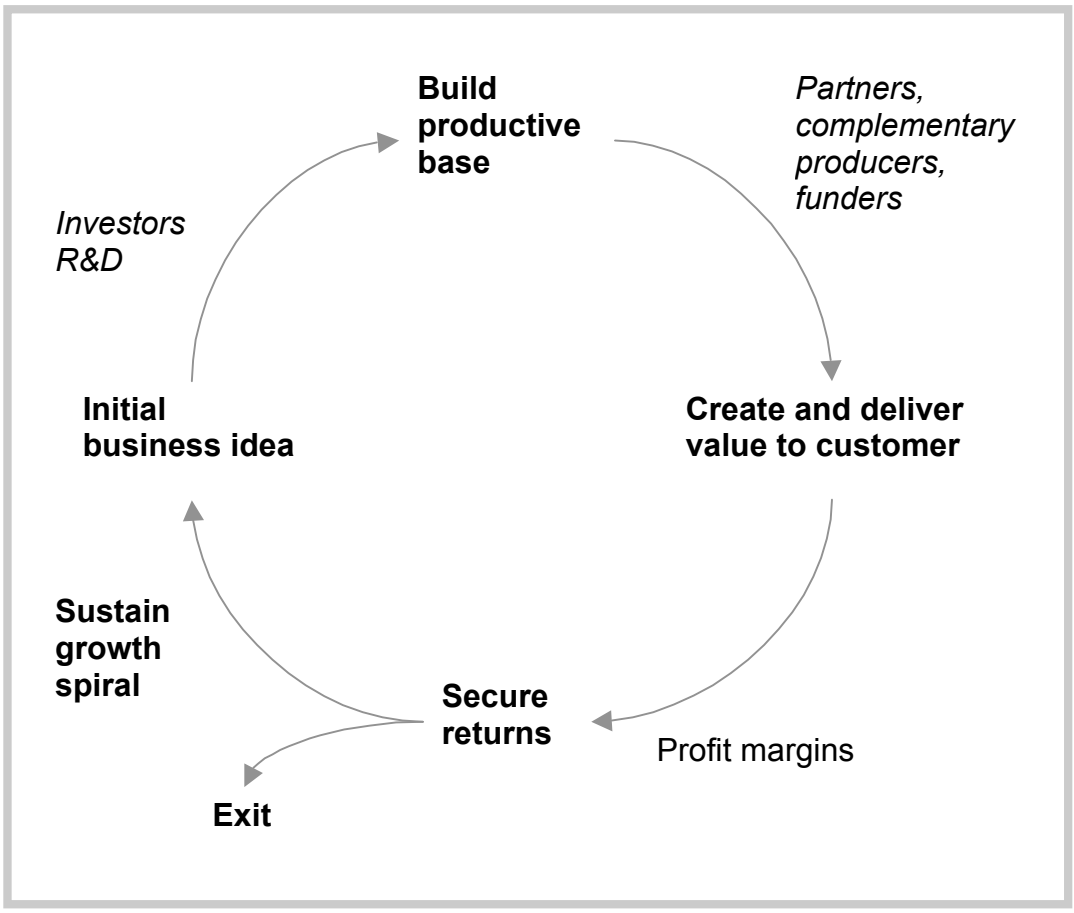

Figure 1. The entrepreneurial process of value creation and capture

The cycle extends into a growth spiral in an expanding enterprise.[10] By tracing the

[10] In practice the entrepreneurial process is a non-linear spiral of iterative activity which may involve regress or staggered developments. If the process were shown as steps, entrepreneurs could be climbing two sets of steps at a time as they use returns from one type of output to pay for development in another, or could take off from higher

entrepreneurial process associated with a new company depicted in Figure 1 (shorn of the iterations and parallel developments of real life) we can review the developmental problems encountered by entrepreneurial attempts to create, deliver and capture value.

Business Idea to productive activity; development and funding

Entrepreneurs do more than discover opportunities overlooked by others (Kirzner 1997).[11] By accessing and mobilizing appropriate resources they also create or activate opportunities. Resource constrained entrepreneurs continually review their business idea in the light of experience and alter it as they learn more about market needs and the resources at their disposal.[12] If the aim is to create value from a new technology it is necessary to finance research and development work, depending on how market-ready the technology was at start-up. All but exceptionally endowed new firms have to build a productive base for commercialization, whether for in-house production, or to manage outsourcing to bring the technology to market. Licensing requires its own form of resource base to ensure the capture of returns. Though the investment required often comes from entrepreneurs' own savings, the scale of the undertaking may require that outside investors be brought on board before and after the productive base is operating (Gill, Minshall et al. 2006). Investor relations have a major impact on the new company, providing greater scope than the founders' resources allow, but also restraining their decision-making flexibility.

Partners are needed but often difficult to enlist before the firm has a track record. When infrastructure or complementary technologies must be created, complex collaborations with co-producers are required. It may be necessary for the new firm to create as yet unavailable supplies of inputs for a radical innovation, e.g. a new type of glass for solar thermal units. This stimulates a search for complementary producers with which the new firm has common interests. When such developments are occurring collectively among a number of innovators, co-evolution of new complementary new technologies comes about. Creating effective relationships is

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level if they inherit resources, or gain height from partnerships. Many new firms aim at generating revenues through market-ready value creation to pay new product development

[11] In contrast, see Ardichvili et al. (2003) who also argue, though on a theoretical basis, that opportunities are developed not discovered.

[12] Start up date does not always map activity. 'New firms' that are immediately revenue generating may have inherited resource endowments through de-merger or spin out. Others undertake an activity that is immediately revenue generating like consultancy, sometimes to fund new product development.

among the greatest challenge faced by innovators, large and small (Fraser, Minshall et al. 2005).

Creating and delivering value to customers

The creation of value depends on providing a solution that meets user needs. This does not guarantee the ability to deliver value to customers who are ready and able to pay. If entrepreneurs can find out what value is sought by customers, the creation of such value becomes less speculative. Technical design consultancies, for example ensure that customers specify and pay for development work. But many entrepreneurs start out with a resource that they believe will create value without having established this for a fact. With a very new and different product, the innovator may have to prove to the sceptical customer that this will be a source of value to them. Until a trial product has been produced, it is seldom possible to elicit a customer response. Often funds are needed for proof of product. This may require endorsement from partners or customers who can lend credibility and legitimacy to the venture (Aldrich and Fiol 1994; Florin, Lubatkin et al. 2003; Fraser, Minshall et al. 2005).

It is often necessary to gain the recognition of regulatory authorities or standards bodies. Certification may in itself be costly and time consuming process. Evidence below shows that this is a particular problem for environmental entrepreneurs operating in sectors that are highly regulated. Certification represents both a challenge and a factor enabling access to customers if appropriate endorsement is achieved.

Delivering value to customers is made difficult by another market failure: information asymmetry when innovators and customers are in mutual ignorance of customer needs and technology potential. The dangers of doing business with an unknown agent is a 'moral hazard' problem in economic theory, making sources of supply unacceptable. Moreover the customer for a technology may not have the incentive to invest if someone else pays the running costs, e.g. of a building. Principal-agent problems of this kind are a justification for standards being imposed by regulators.

The innovating new firm that proves its ability to create value depends on early-innovator customers (Rogers 1995). The adoption cycle does not reach larger numbers of customers until problems of scale up and of distribution have been

overcome. The technical and managerial problems of innovation inherent in production scale up are commonly underrated even for large companies.

4. National Power, a large electricity provider, sought to develop a battery storage technology. It took a decade of committed R&D in the 1990s to make this technology operational. It was advanced through contributions from over 50 research partnerships with external groups. The Regenysis project faced extensive systems integration issues and unexpected scale-up requirements which posed scientific and advanced engineering problems. The Regenysis technology was sold off after acquisition of nPower instead of being implemented by the company. This is an instance among others of large companies failing to adopt their own radical innovations (The Engineer 2004).

This case provides some indication of the massive investment that may be required to bring a radically new technology to operational readiness.[13] Expansion problems may also be created by supply shortages, for example of the quality of silicon needed for solar panels. Many business plans of new ventures fail to allow for the challenges of expansion with the result that investors expect unrealistic lead times. Only 0.05% of UK venture capital investment in clean technology enterprises is currently devoted to expansion (Library House 2004, p. 6)

The ability to access customers to demonstrate the value the new company can offer them may be blocked by large retailers who control the channels to customers. This is a well known problem for organic food producers but suppliers faced by oligopsonistic distribution channels elsewhere must reach volume output to compensate for the low margins such retailers are able to impose in return for the customers access they offer (Moore and McKenna 1999).

Demand by users is not necessarily forthcoming even for technologies that can be shown to provide utility. Innovations have historically encountered delays in the course of adoption cycles (Rogers 1995; Nairn 2002). This is illustrated by evidence on consumer adoption problems facing environmental innovators, discussed below.

The capture of value; the appropriation challenge

Having proved capable of satisfying customer demand, the new firm that aspires to

[13] Other examples of the costs of scale up are provided in Maine and Garnsey (2006) and in Lim, Garnsey and Gregory (2005).

growth must generate revenues by enlarging its market or providing a stream of new products to sustain expansion. We discuss in relation to performance measures the challenges of achieving profitability while increasing the scale of operations, which may require inputs more costly than revenues. The profitable young firm attracts attention from imitators who may grind down the innovator's margins before start up and development costs have been amortized, as Schumpeter anticipated (1928). To preserve market incentives, new technologies are protected by legally endorsed intellectual property arrangements, but this offers the prospect of incomplete protection. Investors may not believe that the new entrant could afford to challenge incumbent infringers of their IP, thus adding IP risks (the probability of infringement) to the firm's technology risk.

The new firm with good prospects may launch on the stock market in an Initial Public Offering (IPO) to obtain the funding required to scale up its products and reach more extensive markets. This realization of the value of the company represents the capture of value by founders and other early investors. The continual search by fund managers for high growth firms offering the prospect of returns maintains the churn of deals in the financial world. Sustained, uninterrupted growth is very rare in young companies. But a young company that goes public must maintain a steady performance to avoid alienating shareholders and to keep open the possibility of further share rounds. The public scrutiny to which the company is now exposed may curb the ability to experiment.

If the venture raises enough share capital, it may be possible to accelerate its expansion through the purchase of another company and its value creating capacity. Much more common, however, is a sale of the company to an acquirer – another route to exit (i.e. value appropriation). Large companies have increasingly been turning to small innovative firms, either for purchase or partnership. Acquisition enables founders who have retained ownership to realize some of value of their company. The sale of the company may promote the adoption and diffusion of the emerging technology by the acquirer. However it seldom preserves the innovative culture of the acquired venture, often triggering departures among the founders and further startups. Some established companies prefer to build alliance relationships with a new firm, on the grounds that the team is more likely to continue to create value through a stream

of innovative products if its autonomy is preserved. The independent young company operating on low reserves remains vulnerable.

Thus the transition from start up to profitability is liable to short circuit at many points, so preventing ideas of potential value from yielding utility to customers and denying entrepreneurs returns on their effort. Nevertheless, even when ventures close, the knowledge generated there is frequently recycled into further productive activities, as entrepreneurs turn their attention to other possibilities. In high tech centres of entrepreneurial activity there is continual renewal of firms and capabilities through spin out, acquisition and knowledge recycling (Garnsey and Heffernan 2005). The locality secures value that has been created by clusters of entrepreneurial activity.

Measuring value creation and returns

The complexities of the entrepreneurial cycle can be outlined by a variety of measures taken at intervals to provide longitudinal evidence. Measuring the performance of young companies makes it possible to compare cases over time on a standard accounting framework and by headcount. The various measures of growth diverge from each other, but taken together they are revealing of the pressures experienced by young firms.Thus science based firms incur salary costs for R&D, shown by a rise in employee numbers, which accompany early loss making. An input of resources is needed to set off the entrepreneurial process but short circuiting will occur if endowment resources are burnt up before further funding or revenues are achieved.

Value creation can be measured by consumer surplus, which represents the utility of the innovation to the customer. An indicator is the price of the innovation to the consumer less the price of a substitute product that offers similar utility. If there is no useful substitute available on the market, the value of a functioning innovation may be very high for the customer. But before scale up, the costs of production to the new company may be even higher, so preventing producer surplus from keeping pace with consumer surplus. This syndrome caused the closure of the firm from which ApaClara (case 3) was spun out.

To secure returns from their expenditure, the new firm must achieve producer surplus,

which can be measured by the margin of profit over costs. Software ventures have had the advantage of relatively low scale up costs once they have a working prototype. But scaling up innovations from prototype to functioning plant is very costly in the utilities sector, as the Regenysis electricity case (5) illustrates. When costs increase with scale, they may do so more rapidly than returns. Whether from malfunctioning or major delays, technological risk may prevent producer surplus from being achieved. In addition to technical problems, there is the market risk of customers failing to adopt the product designed to create value for them.[14] Market risk increases for the new entrant when established companies are able to lower their costs by improvements to the incumbent technology faster than the new company can scale up its discontinuous innovation. Competition of this kind, sometimes subsidised by government support, can delay or pre-empt more radical innovations.

Growth is measured periodically by performance figures that can be taken to reflect value creation and capture. Sales (turnover) result from delivering value to customers, while the capture of returns is measured by profit margin over costs.

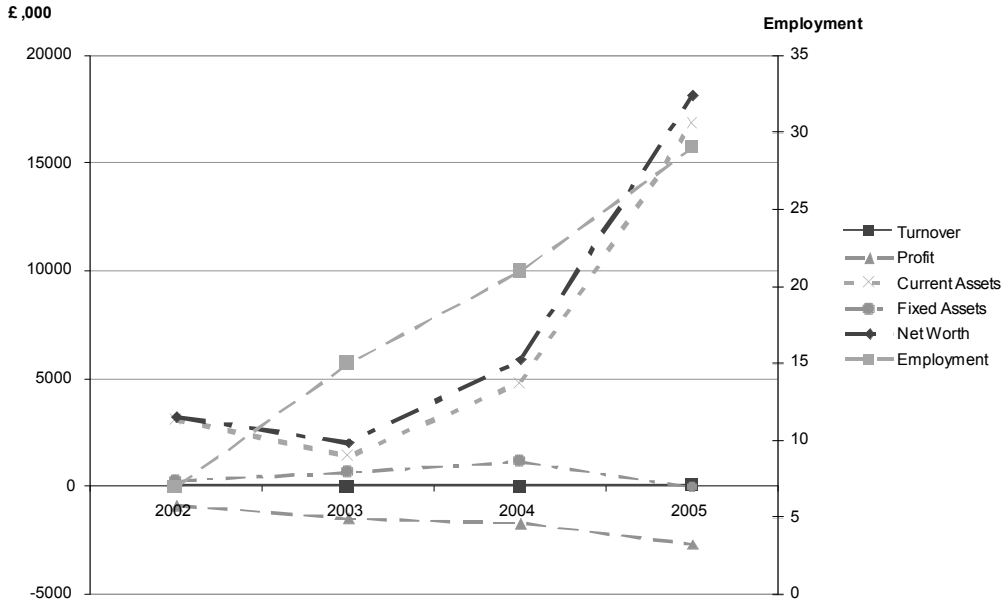

Figure 2. Growth Measures for Ceres Power

(Source: Companies House, graphic by James Andrews)

[14] Technical risk is measurable as the probability of not achieving R&D objectives for a specific product, multiplied by the likelihood of failure for the firm if the project's R&D objectives are not achieved. Market risk can be measured by the probability that the market will not adopt their product if the R&D project objectives are achieved, multiplied by the likelihood of failure for the firm if the market does not adopt that product (Maine and Garnsey 2006).

The firm in Figure 2 is unusual as a science based spin-out in generating revenues early. This was achieved by targeting an immediate market application. High start up and scale up costs mean that value capture in the form of profits cannot be achieved before further development and expansion occur. Investors' assessment of a firm's capacity to capture or appropriate value is shown by the capital market value of the firm. The London AiM market on which Ceres Power floated exists to allow new firms without a trading record to sell its shares in a public market. The value of a company's share and hence capital value depends on market sentiment over the business cycle as much as on firm performance. The firm's technology and market risk status as assessed by investors affects share price and hence the firm's ability to make further share issues.

Biopharmaceutical firms face technological risk, but they stand a good chance of having their drug adopted in the market if it gets through the sequence of clinical trials. Environmental innovations involving radically new technology face not only technological and market risks but the uncertainties of climate change and the regulations that these will elicit.

Performance measures are closely watched by financial analysts, but it is only by examining the dynamics of opportunities opening and closing to the entrepreneurs and their venture that the rationale for their decision making can be understood. Measures of the kind illustrated for a firm with a new fuel cell technology in Figure 2 are crude indices of the possibilities and achievements of the new company. They provide a common accounting basis but need to be enriched by more detailed evidence, e.g. based on questionnaire surveys (Part III) and case histories, as profiled briefly in Part IV.

III EVIDENCE ON DIFFICULTIES FACED BY SMALL AWARD WINNING ECO-TECH COMPANIES

Secondary evidence is scarce because of the paucity of research in the area, but in what follows we report on findings from a pilot analysis of clean tech venture. This evidence provides preliminary proof of concept for the model of analysis, which

enables us to provide a more comprehensive account of the evidence than 'barriers to growth' frameworks (Dee, Ford et al. 2006).

A study was carried out for the UK Department of Trade and Industry of a database of 150 clean technology companies, with an emphasis on small and medium sized enterprises[15]. The aim was to examine constraints on their growth and activities, using a database refined by the authors. We looked more closely at 73 of these companies and carried out nine more detailed case studies. Further analysis is available in Dee, Ford et al. (2006).

The problems identified were based on self-reported difficulties, as in many studies of 'obstacles to growth'. The findings appear discrepant when they differ between companies facing similar external conditions. This occurs because self-reported problems reflect the perceptions and aspirations of respondents. Firms that do not seek to expand on a scale that requires external finance do not cite its absence as an obstacle. A major US study showed that firms lacking growth aspirations reported fewer problems that more ambitious firms (Reynolds and White 1997). Nevertheless, the study reported here reveals the relative magnitude of difficulties involved in the creation and delivery of value by young firms in environmental sectors and points to some important contrasts between the sectors. These were disaggregated as Cleaner technologies and processes (largely pollution prevention products), Recovery and Recycling, Waste and Wastewater Treatment; and Renewable Energy, the latter divided into renewables for transport and for non transport (Figure 3).

The evidence from this study illustrates many of the problems identified in the model of the entrepreneurial process described above, as can be seen if we examine these problems and the evidence in Figure 3 in terms of the issues raised by that model.

[15] The Environmental Innovations Unit of the DTI collected the data between 2004-5.

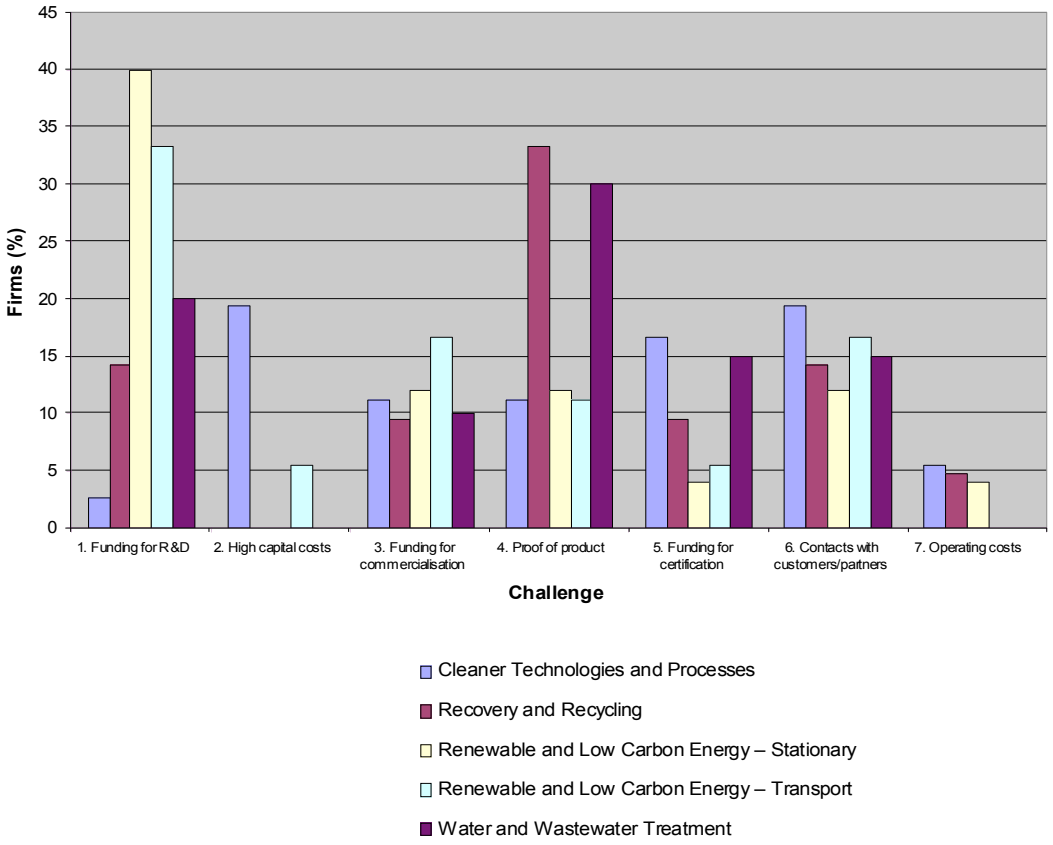

Figure 3. Developmental challenges facing 73 environmental SMEs (Dee et al. 2006)

To develop knowledge to the point where it can be applied to address and meet business needs, firms need R&D funds. Many firms with new technologies in low carbon energy are developing products such as fuel cells or urban wind machines which are not yet market-ready and require further R&D. In this study 40% of such firms reported difficulties funding R&D, with 30% of renewables firms with applications in transport reporting problems funding R&D. Funding for commercialization of their technology was experienced over and above the need for R&D funding, since commercialization involves scaling up, which can be very costly for a new company and requires a different skill set from design.

The difficulty of creating a production base varied according to the firm's technology and market. One in five of the companies with cleaner technologies and processes

(mainly pollution prevention technologies) reported that high capital costs were an obstacle, a problem also reported by 5% of the companies with renewable and low carbon technologies for transport. In these sectors, new companies are likely to be competing with established industrial companies and need scale economies to make their activities viable, hence the problem of capital costs.

Small companies need to establish proof that their product works before they can attract customers through trials and endorsement. Taken together, the need to prove their product and pay to have it certified were the most frequently cited causes of problems to the companies in this study. Low carbon energy companies cited this problem to a lesser extent. This could be because their products were not yet market ready and so they had limited awareness of this requirement and had not factored it into their technical assessment costs. There was greater awareness of the need for funding among pollution prevention and waste and water treatment companies, where products were nearer to market readiness. Reasons given as to why it proved difficult to carry out endorsed testing and certification included cost and lack of testing equipment and trial sites.

A significant obstacle to innovators was the inability to meet existing standards because their product was radically different. One company with a novel cellular valve brick devised for secure ventilation was told that to conform to building standards they would have to provide a shutter for the brick, thus vitiating the value the brick afforded as a self-regulating mechanism for flood protection.

For environmental ventures, attracting private finance and partners was difficult without endorsed test data to demonstrate that their product was approaching certification. One company had received a £45K government grant for R&D, but potential collaborators would not consider its product until it was tested to market standards, yet the company needed their collaboration to reach this point. In the absence of intermediate test stages to show that its product was making good progress on the way to certification, the company had to close.

Setting up partnerships and making contact with customers created difficulties for companies in all the environmental sectors. This is one reason why public sector

procurement can be so valuable, providing endorsement for new products. But lack of innovative public sector purchasing was only cited as an issue by six firms; the remainders do not seem to have considered the public sector as a realistic source of custom. Government sector organizations do not commonly source innovative products from new companies in the UK, with the exception of some Local Authorities who have procured such products as urban windmills for local housing.

The low number of environmental companies in this study citing operational costs as a problem suggests that many of these companies were immature operationally or intended to license their technology; alternatively they had not factored in the operational costs of scaling up that lay ahead of them. Software companies that have a tested product face low replication costs, but scaling up is more complex in the heavy industry that generates major waste emissions. New processes are emerging, such as the FCC process offered by a university spin out company Metalysis, which reveals both the potential for lowering costs and the difficulty of achieving this without expansion.

5. Metalysis has developed a completely new process (FCC) for metal purification based on scientific research that makes it possible to avoid damaging waste output. The energy cost required to create a molten salt in the FCC process is significantly lower than that required in conventional processes. This technology could completely alter the marginal costs and benefits faced by customers, especially so in view of penalties imposed on emissions. Its technology is now in use in a pilot plant in South Yorkshire.[16]

The industry's ability to estimate scale-up costs for emerging technologies depends on pilot projects providing learning-by-doing in the industry and evidence on the gains from innovation.

Institutional Innovation

Though their voice is seldom heard in time consuming government consultation processes,[17] innovators often engage in institutional enterprise to alter regulations that affect them directly, or to set up appropriate regulatory or standards bodies.

[16] Company press release, March 2005

[17] See for example the dominance of large organization and absence of SME perspectives in the consultation process undertaken by the DTI over the European Emissions Trading Scheme, http://www.defra.gov.uk/news/2006/060515a.htm

6. Solar Century was founded in 2000. Its founder was determined from its inception to lobby the UK government in favour of renewable energies. These had been gaining more favourable treatment from governments in other European countries, especially in Germany and the Nordic countries where potentially valuable know-how in renewables was being built up that was lacking in the UK. Solar Century attempted to enlist BP, which was initially unresponsive to their initiative. The government introduced subsidies for solar roof installations following Solar Century's efforts, whether or not as a result of them.

7. A new firm with a solar thermal technology, Viridian Concepts, did not anticipate lobbying government as company strategy. On the contrary they ruled out selection of a product subject to the kind of uncertainties the Californian renewables policy had created in the 1970s and 1980s. But they were prompted by what they saw as an unfair regulatory system to take action.[18] The standard assessment procedure used to evaluate energy efficiency underestimated the amount of energy from a solar thermal panel. Viridian prepared a summary of independent research findings and proposed corresponding revisions to the standard assessment procedure, sending this out for comment and on to government. Again there was no official recognition of the entrepreneurs' contribution, but the standard assessment procedure was later changed on the basis of the figures and process suggested by Viridian.

Thus new firms have not been passive in their approach to what they have viewed as inappropriate regulations affecting their ability to create value. Divergencies have given rise to calls for technology neutral stance from the government, with adjustments to prevent a near-to-market bias (Mitchell and Connor 2004).

The observations from this study fit those expected from the model presented earlier. However the survey provided new evidence that endorsement through testing and certification the new product of a new company may be pivotal in enabling that company to deliver and capture value. Environmental policy has not extended into certification, but the perspective of the eco-entrepreneurial process shows this to be the kind of area in which policy innovation is needed. Certification processes have not been designed for innovative environmental product, for which existing standards are inappropriate. The difficulties of gaining authoritative endorsement for a product can subvert the commercialization of a new technology.

Though inventive and problem solving in approach, the respondent companies are not

[18] Energy ratings are required under Regulation 14A of the Building Regulations 1991 (as amended) and under Regulation 10A of the Building Regulations, 1985. Office of the Deputy Prime Minister http://www.odpm.gov.uk/stellent/groups/odpm_buildreg/documents/page/odpm_breg_600128.hcsp

operating under conditions favourable to their making a major impact on the economy. But they provide evidence that a period of active start up and experimentation by new entrants is underway, as occurred earlier in other sectors prior to major new innovations. These findings are complemented by case study evidence summarized below on the proactive way in which entrepreneurs innovate by reconfiguring their companies and their opportunity space.

IV DIVERSITY CREATION

Entrepreneurs do not pursue innovation for its own sake but in order to secure returns. Because resource-constrained entrepreneurs are so often thwarted, the entrepreneurial process moves beyond any simple circuit into iterative attempts at problem solving.[19] When founder-entrepreneurs cannot obtain the resources they need to implement their idea and develop the business, they revise their business idea, coming up with further new ideas. This reconfiguration of ends and means is a more multi-faceted process than Kirzner assumed (1997). It is much less likely to in large firms where planning and budgeting follows a predetermined path and where adjustment to new circumstances take longer to effect. Some international case examples illustrate this process.

8. In one Swiss solar cell company, the high cost of licensing a solar cell technology led the founders to use their research network to find ways to negotiate a license on better terms. But difficulties with development work on the solar cell shifted their business idea to providing materials and services to other licensees rather than developing the technology themselves. As barriers to commercializing the licensed technology in its present form became more widely recognized, their services became less attractive. However the entrepreneurs had recognized that they had developed generic expertise which could be applied to other technologies and markets. They began developing solar cells for the aerospace industry. Thus a series of barriers led the entrepreneurs to build generic skills which made possible for them to develop a new and different solar cell product for the high margin aerospace market.

9. Entrepreneurial engineers in Sri Lanka developed an experimental solar powered water pump for the irrigation of agriculture land. When the prototypes were demonstrated to farmers, it emerged that the pump's capacity was too small for the farmers' water requirements. But the farmers helped the company's founders identify their more pressing need: electricity for lighting and entertainment. The founders

[19] The analytic distinction between pre-venture (nascent enterprise) and post-venture activity in some of the entrepreneurship literature (e.g. Reynolds and White 1997) does not accommodate the extent to which opportunities arise through efforts to resource their exploitation.

reoriented the business and technology to develop solar home systems for rural Sri Lanka. When rural civil unrest prevented the work of their sales and servicing staff, the company trained local village youth who were paid on a commission basis. The diffused rural network created by Power and Sun's agents was to prove critical for the sales and maintenance of solar home systems in remote rural areas. The company was acquired by Shell International in 1999.

10. In 1983, a small Canadian company, Ballard Power, was nearing the end of a development contract on rechargeable batteries when they came upon an opportunity for Defense funding to develop a fuel cell that required similar competences to those they had developed for lithium batteries. Geoffrey Ballard's vision of an alternative to the current hydrocarbon based energy system called for advances in fuel cell technology, but this was a long term effort and they needed immediate returns. Over the next few years the founders filtered funds from the revenue-earning lithium battery division of Ballard to fuel cell development. When the lithium battery division required an infusion of capital to build manufacturing capabilities they were able to attract a venture capitalist whose real interest was in fuel cells. This venture capitalist wanted to invest in a company that would be scaling up and helped the team recruit an experienced CEO and to transform their company from a contract research business into a world leader in the fuel cell industry.

11. An entrepreneur in Singapore turned to international markets to overcome local barriers to entry.[20] Olivia Lum, a science graduate working at a multi-national company, decided to address the growing global problem of a shortage of clean drinking water and at the same time remove waste water from the environment. She set up Hydrochem in Singapore in 1989 with seed capital of USD $12k, based on a new membrane technology to tackle and recover value from waste. But potential customers in Singapore were not to be induced to adopt an innovation supplied by an unknown producer with no track record. Olivia Lum turned to small firms in Malaysia and persuaded them that her company could deliver the value they needed, based on the precision engineering of their technology and stringent project management. Having built a reputation for reliability, the company was ready to penetrate a larger market by 1993. Olivia Lum approached friends and raised USD $580k as development capital for Hydrochem, setting up an office in Shanghai. Their first customers in China were Singapore companies setting up manufacturing facilities there, but they rapidly built up business with Chinese companies. Within a decade, the company, renamed Hyflux, had been transformed from an unknown start-up to an established name in Malaysia and China. Now an international company of repute, Hyflux was awarded the tender to meet some 10% of Singapore's water needs in 2003, a project valued at around US$200million. The company was ready for entry into the Middle East market with a strategic alliance to build a seawater desalination plant in Dubai.

For every firm like Hyflux that solves problem after problem, there are many more that encounter insuperable difficulties. But collectively, these endeavours give rise to

[20] Agence France-Presse (2004), *Singapore techno-preneur turns waste water into gold,* Jake Lloyd-Smith (2004), *The moisture Merchant-Dealing in Liquid Assets*, *Time*, April 12,

novelty and diversity. Entrepreneurial innovation is an outcome of problem solving that takes place under resource constraints where there is autonomy to make decisions flexibly, even where these infringe convention. Though often overlooked in entrepreneurship studies, the trial and error manner in which many entrepreneurs proceed has been identified in other research (Nicholls-Nixon, Cooper et al. 2000). Features of this mode of operation have been termed improvisation (Bhidé 2000), bricolage (Garud and Karnoe 2003) entrepreneurial contingency (Sarasvethy 2001) or conjectural, in evolutionary economics (Metcalfe 2004). This *modus operandi* can be viewed as erratic by investors, far from the optimization of means to achieve predetermined goals advocated for rational decision-making.[21]

What has not been recognized is the extent to which it constitutes the source of both diversity creation and co-evolutionary impetus by entrepreneurs. It involves them in continual interaction with others who provide resources at the time when they are needed in return for a share in the appropriation of value to come. Through this mode of activity, the new technology firm connects itself in to complementary technological developments from which it might be closed off by self sufficiency. It involves them in continual alertness to serendipities and in experiments with new solutions to match resources to emerging market needs (Hugo and Garnsey 2004).

Policies that have promoted radical enterprise and diversity in other sectors

This paper opened by contrasting the environmental sector with others in which greater influence has been exerted by new entrants. There are structural differences between the sectors but also over-arching policy issues.

We have argued that the multiple challenges faced by new entrants, which operate under resource constraints but retain decision making flexibility, is a source of their innovative and diversity-creating behaviour. But if the vulnerability of new entrants is one of the drivers of their diversity-creating behaviour, this does not justify complacency about current conditions facing eco-entrepreneurs. New entrants are more likely to create diversity in a rich habitat where they can obtain resources to

[21] It could be said to involve accelerated decision making that is continually reassessing means as new ends are considered, but it also involves a high degree of intuition in the face of uncertainty.

combine in new ways and where there are opportunities for symbiosis.[22]

New ventures are far more numerous in information technology and biopharm than in the environmental sectors, even though many of these innovations have environmental applications. IT and biopharm ventures have been nurtured by regulatory frameworks different from those currently operating in the environmental sectors such as building, energy and transport. Among other differences, established companies in IT and biopharm were not offered government incentives to lower the costs of their incumbent technologies and make these more efficient.

Little attention has been paid to conditions needed to encourage and stimulate a diversity of possible ways of addressing environmental problems by nurturing a pool of technological possibilities among new entrants and providing the means for them to be brought to market. This economic equivalent of bio-diversity is what allows for adaptability and new solutions to new problems. New ventures are particularly well suited to creating economic diversity and complementarity. When the conditions to which climate change will give rise are so uncertain, it is desirable that policy stimulate technological options.

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[22] Under such conditions, new entrants in IT pursued innovation and introduced radical innovations that were overlooked by established firms (Bhidé 2000). Such a habitat was created for information technology ventures in the US as a side effect of other policy objectives, but we can identify which policies had this effect (Mowery and Rosenberg 1998) The most important among them were the public provision and governance of early infrastructural facilities, extensive grant funding for R&D, a liberal IP policy leading large firms to license new technologies on favourable terms, government procurement from small new companies that provided them with innovative users, support to university computer science departments and to small firms (Connell 2006). In these conditions new IT ventures seized upon new knowledge in the public domain as a source of business opportunity, creating complementarities through partnerships with large firms and with each other and stimulated further innovation by the next wave of new entrants (Garnsey, Heffernan and Ford 2006.)

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