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Opportunities and Resources for Disruptive Technological Innovation

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OPPORTUNITIES AND RESOURCES FOR DISRUPTIVE TECHNOLOGICAL INNOVATION

CC HANG AND EW GARNSEY

Abstract

Whether entrepreneurial firms discover or create opportunities is a classic debate, here explored in the context of disruptive innovations. In this paper we reframe the question to focus not on the nature of entrepreneurial opportunity but on how and for whom entrepreneurs undertake disruptive innovations. As to whether entrepreneurs detect or create opportunities, we show with examples that they do both. To reveal how they do so, we examine how entrepreneurial innovators obtain and organise resources for their ventures as part of the opportunity creation process. This theme is grounded in conceptual work on disruptive innovations by Christensen (1997) and work by Penrose on how resources are matched to opportunities by entrepreneurial firms (1995). In the context of three areas of demand growth, we examine how entrepreneurial firms provide innovations to meet demand through opportunity discovery, opportunity creation and by combining the two. This reveals the creative thought and endeavour required to turn possibility into reality. This often involves devising disruptive technological innovations, as shown by examples of opportunity detection and creation among entrepreneurial firms. We begin by looking at varieties of technology that can be used to exploit opportunities in growth markets by multi-national firms. Case profiles show how small resource-constrained firms also address growth opportunities - by developing frugal engineering and business models to launch disruptive innovations. Entrepreneurial firms configure resources in new ways to meet neglected customer needs as part of the act of opportunity creation. We conclude with some questions for future research.

Introduction

The issue of opportunities for enterprise and innovation has continued to attract interest in recent years, updating the classic controversy on whether entrepreneurial opportunity results from the discovery of an existing opportunity or from deliberate effort (Alvarez and Barney 2007). Schumpeter maintained that entrepreneurs disrupt markets through creative innovations which open up new opportunities (1934). In contrast, Kirzner held that entrepreneurs restore market equilibrium because they are alert to overlooked opportunities to provide for unmet demand (1997). New interest in market failure as a source of entrepreneurial opportunity represented a return to Kirzner's concern with market equilibrium (Garnsey et al., 2011). But more prominent work has been concerned with the nature of entrepreneurial opportunities and forms of opportunity search (Shane and Venkataraman, 2000; Zahra, 2008; Murphy, 2010). In this literature, the issue of how entrepreneurs secure resources is subsumed under the heading of entrepreneurial opportunity, which is held to include resource availability. In this paper we reframe the classic question to ask how and for whom entrepreneurs undertake disruptive innovations. As to whether entrepreneurs detect or create opportunities, we show with examples that they do both. To reveal how they do so, we need to examine how entrepreneurial innovators obtain and organise resources for their ventures as part of the opportunity creation process. This in turn raises the issue of business models for innovation. We explore these issues with reference to disruptive innovations and emerging economies, areas which until recently did not figure in the debate on opportunities for innovation. They highlight the disruptive potential of many entrepreneurial innovations, providing a new perspective on Schumpeter's theme of disruption. Our evidence is drawn from diverse case examples, which are used to categorise opportunities for disruptive technological innovation and to explore ways in which entrepreneurs configure resources in frugal business models to realise such opportunities.

Disruptive innovations change the terms of competition, reaching new customers, disrupting incumbent firms or opening up new markets. They can do this because they offer a new value proposition, a more affordable, more convenient offering than that previously available. Sometimes they meet current demand in new ways, on other occasions they tap into latent demand for a product or service that did not previously exist. They tend to be the fruit of greater understanding of new customers, of customer needs and how these can be met. We start by examining opportunities for disruptive technological innovation and go on to review how this can be resourced by small companies no less than by MNCs.

The term disruptive technology was coined by Clayton Christensen and the phenomenon has attracted much attention by both scholars and practitioners (Christensen, 1977; Christensen and Raynor, 2003). Recently, R&D strategies aiming to create technology candidates for disruptive innovation at the fuzzy front end have come to some scholars' attention (Linton, 2004; Yu and Hang, 2011). Though Christensen at first used the term disruptive technology (1997) he later preferred the term disruptive innovation to encompass the need for new business models (Christensen and Raynor, 2003). Thus the theory of disruptive innovation has been extended from its original formulation to other areas. We limit the scope of this paper to innovators who depend on technology to improve their competitive position, often through new business models. Our study extends beyond developed countries to consider disruptive technological innovations in emerging markets and their potential to become candidates for "reverse innovation" in mature economies (Immelt, Govindarajan and Trimble, 2009).

While Christensen's work is widely known, complementary ideas from resource-based theory of the firm (Penrose, 1995) relevant to the theme of opportunities to innovate have been largely overlooked. This work can be seen to reconnect recent study of disruptive innovation to Schumpeter's early interest in entrepreneurs as disrupters of current markets. Penrose showed that entrepreneurial firms realise opportunities by configuring their resources to match emerging market needs (Penrose 1960). Recent work on entrepreneurship diverted attention from this entrepreneurial matching process onto the entrepreneurial pursuit of opportunities, which has been proposed as the defining feature of entrepreneurial activity (Venkataraman, 1997; Shane and

Venkataraman, 2000; Shane, 2003).[1] In contrast, to ask what is distinctive about the way entrepreneurs innovate makes it necessary to examine specifically how they mobilise and configure the resources needed for their innovation. We show that the work of Penrose provides theoretical grounding for analysis of the way innovative start ups and smaller firms can resource disruptive innovations. At a time when it is difficult for entrepreneurial firms to attract external investment, Penrose's work is of interest because she was concerned with how firms can release resources from within to realise opportunities for growth. Penrose wrote that growth in a firm 'is governed by a creative and dynamic interaction between a firm's productive resources and its market opportunities' (Penrose, 1960, p. 1). Entrepreneurial managers are continually alert to opportunities that result from their 'increased experience and knowledge of the external world and the effect of changes in the external world' (Penrose, 1959, p. 79).

Penrose highlighted ways in which firms can gain leverage from their existing resources. They can also create new resources in reconfiguring their activities to meet 'the productive possibilities that its 'entrepreneurs' see and can take advantage of' (Penrose, 1995, p. 31). In her case study of a former division of Dupont, she showed how the de-merged company exploited expertise they had developed in explosives to move into new markets in the then-emerging plastics industry (Penrose, 1960). They did so by building the complementary resources that their knowledge of the market identified as necessary.[2]

In drawing on the work of Penrose we adapt her ideas in two ways. Firstly, we apply a resource based approach to new and small firms, in contrast with her focus on growth in the larger entrepreneurial firm. Secondly, we take up her notion that resources are valuable not in and of themselves, but rather for the services they render. However, we apply this notion to customers where she applied it to producer firms. Disruptive innovations render useful services to customers by meeting previously unmet needs;

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[1] Venkataraman specified that entrepreneurship as a scholarly field "seeks to understand how opportunities to bring into existence 'future' goods and services are discovered, created and exploited, by whom and with what consequences" (Venkataraman 1997, p.120).

[2] Penrose recognised that firms grow through mergers, but she was more interested in organic growth, in particular in the ways in which firms could make better use of existing resources and obtain complementary resources needed to exploit emerging opportunities. In her later work, she recognised the role of networks in providing complementary resources and opening up opportunities for entrepreneurial firms.

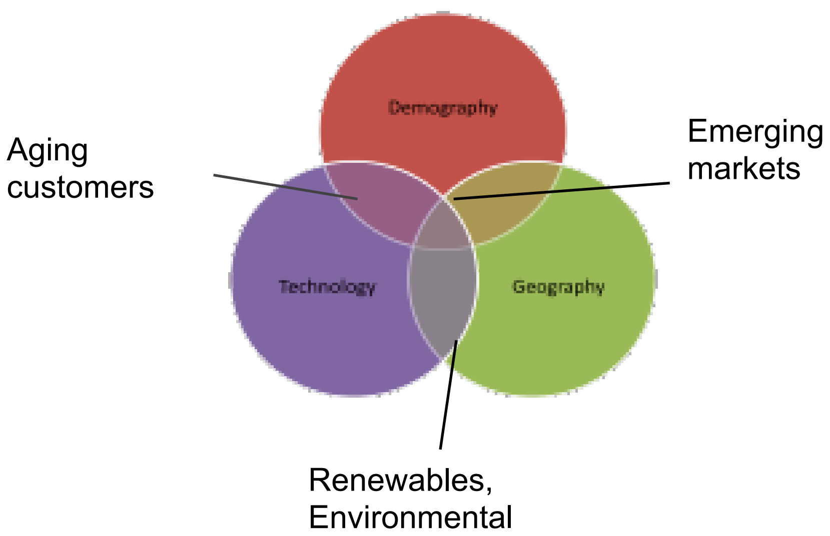
they are innovative offerings that perform in new ways what Christensen and Johnson call the customer's 'jobs to be done' (Christensen and Raynor, 2003; Johnson, 2010).

Evidence is presented in the form of case examples that are selected to illustrate the very wide variety of disruptive technological innovations and associated business models that offer business opportunities; settings range from base-of-pyramid markets to leading edge research activity. In what follows, we discuss how entrepreneurial firms, large or small, may purposefully search for opportunities to pursue disruptive technological innovation and show from examples in what respects this involves opportunity detection and creation. We begin by looking at varieties of technology that can be used to exploit opportunities in emerging markets by multi-national firms but also by entrepreneurial firms. Case profiles show how small resource-constrained firms can also address growth opportunities by developing frugal engineering and frugal business models. We conclude with some questions for future research.

Where are the Opportunities?

We select cases in particular from three areas of opportunity, created by changes in technology, changes in demographics, and changes in the geographic distribution of markets for innovations (Figure 1). These areas provide examples of opportunities that are objectively "out there" to be discovered, but the case evidence demonstrates that it takes creative endeavour for companies to detect possibilities and convert them into viable opportunities for generating value.

Figure 1 Areas of Growing Demand



In developed countries, changes in demand are stimulated by demographics as the post-war baby-boom generation ages while longevity increases and the birth rate declines. This enlarges markets made up of older customers (the silver market) which has already emerged in Japan and in Germany and will be followed in other countries. The aging population is on limited retirement incomes and need simple, easy to use products and services. This provides potential markets for another wave of disruptive innovations (Kohlbacher and Hang, 2011). These are areas where frugal engineering and frugal business models can support disruptive technologies that provide more affordable and convenient offerings for new groups of customers, both in emerging economies and in mature economies.

Growth of demand, the mainspring of opportunity, is much more rapid in emerging economies than in mature ones. The emerging economies of Brazil, Russia, India and China (BRIC) are forecast to contribute over 45% of global growth to 2020, while the G3 advanced economies will contribute only 25% of global growth. The middle class in BRIC countries is set to double in size over the next decade (Goldman Sachs, 2010). Here too there are opportunities for innovation.

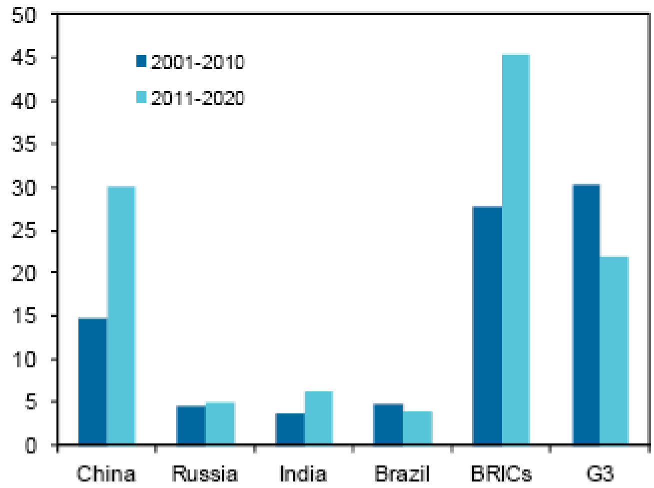


Figure 2 Economies of BRIC Countries are Growing faster than Mature Economies

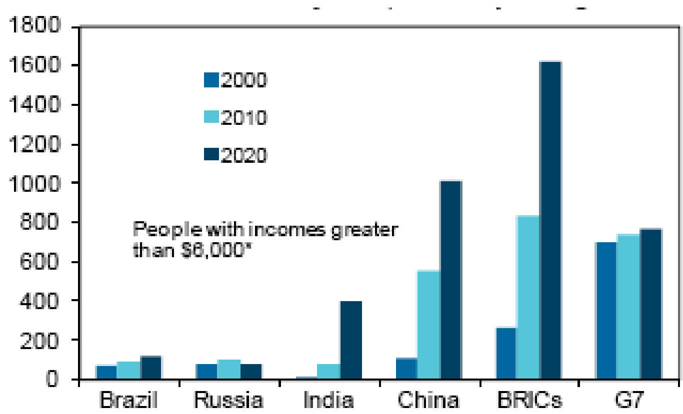


Figure 3 Middle classes are growing rapidly in BRIC countries

Figure 1 also identified opportunities for environmental innovation as areas of growth, in view of the pressures to address the adverse impact of climate change. While there are many other areas of opportunity (e.g. medical innovations, media etc.) our examples of disruptive technological opportunities are drawn from the areas of rapid growth outlined in figure 1.

Opportunity Discovery

Opportunities for disruptive innovation arise through a combination of technology push and market pull. In what follows we show how entrepreneurial firms are detecting opportunities in technological advance, harnessing converging technologies and reviving abandoned R&D efforts. However they do not simply move in on ready-made opportunities but have to make significant inputs to convert possibilities into reality.

Technological Advance

In some areas multiple technologies are available that are both powerful and affordable, as in the case of information and communication technologies (ICT). It is well known that the progress of microprocessors enabled personal computers, smart phones and many consumer products to become smaller, cheaper and easier to use. But many such technologies were developed for use in specific sustaining innovations or new-market radical innovations; the potential for many further low-end disruptive products requires input from entrepreneurial firms. A recent example is the widespread application of a microprocessor and associated IC chips from a young enterprise, ARM, which offered adequate performance at very low cost and found mass applications in mobile phones.[3] This case is further discussed in the context of frugal business models, below. Another start-up company that introduced a disruptive technology was MXR Corporation of Singapore which combined a low-cost digital camera and PC to introduce a new user-interface (Zhou et al., 2004). Advances in ICT further inspired attempts to produce a lap-top computer to be sold at US$100. Users were to be school children in third world countries, and the technology was to offer a generic platform for affordable intelligent instrumentation and other automation applications (Vance, 2010).

A second area of technological advance is in Micro-Electro-Mechanical-System (MEMS) in which a mechanical system such as an acceleration sensor has been miniaturised drastically and mass produced using the semiconductor wafer fabrication process. The MEMS accelerometer successfully used in the sensing of car crash for activating air-bags was available as a low-cost mass produced component; it was adapted and used by Nintendo to develop the successful *wii* games controller now used by female and older players from demographic groups new to video games (Subramanian, Chai and Mu, 2011). A third example is the successful use by new entrants such as Creative Technology and Apple to disrupt the analogue Walkman type of portable music players by introducing MP3 players with a digital sound compression technology licensed from the German Fraunhofer Gesellshaft. This MP3 technology had been developed for about 10 years, but had not previously been applied (Li, Subramanian and Hang, 2011). It was Apple's new business model for on-line music distribution that ensured its success – pointing to the need for technologies to be supported by novel business models, further discussed below.

A further area of opportunity is made up of renewable energy sources (solar cell, wind, thermo-electric etc.). In advanced economies, large companies invest heavily in R&D and manufacturing in renewables and electric power generators as an alternative to conventional fossil fuel power generators. Their efforts are not yet commercially viable and require public subsidies. At the same time, entrepreneurial firms are finding less

[3] http://www.economist.com/blogs/baggage/2011/03/tablet_computers

costly ways to innovate. Suntech Power in China, for example, has built a commercially viable renewable energy venture by exploiting photovoltaic solar cells for small-scale applications to serve consumers who lack conventional power sources or affordable power supplies - e.g. in lighthouses, remote military posts.[5] Likewise, Suzlon energy of India has developed commercially viable wind power plants for Indian industrial clients by capitalizing on India's low manufacturing costs, importing German technologies and further improving them using indigenous R&D.[7]

Advancing technologies in many other areas, including biomedical engineering, environmental engineering, transportation engineering, construction engineering and offshore engineering have opened extensive innovation potential for entrepreneurial firms to identify and exploit. Some of them are suitable for innovations that sustain prevailing competitive positions. Others may be inferior relative to the needs of incumbent firms that seek innovations to sustain their competitive position, but be good enough for disruptive applications identified by entrepreneurial firms, as in the examples above. How affordable the innovation must be to constitute a disruptive innovation depends on the costs of the incumbent technology.[8]

Convergence of Technologies

Some of the above examples pointed to independently developed technologies that reached the stage where combining them could create a new capability. The innovation potential to be exploited by entrepreneurial firms may then prove disruptive. An obvious example lies in ICT innovations combining advances in communication technologies (transceivers, antennas, voice and digitization etc.) and computer technologies (microprocessors, displays, disk drives, semiconductor memories, computer networks, etc.). This has led to disruptive technology creation and applications that include multimedia PCs, smart phones and other consumer products.

[5] http://en.wikipedia.org/wiki/Suntech_Power

[7] http://suzlon.com

[8] The term 'disruptive' is to some extent relative, depending on whether the technology is simpler, cheaper, easier to use etc. *in comparison to* the technology used by the incumbent firms that sustains their competitive position (sustaining technology).

The convergence of mechanical and electronics engineering has given rise to mechatronic technologies, used by entrepreneurial firms to introduce low-cost automation in consumer goods, manufacturing plants, and research/testing laboratories. Researchers have recently explored the feasibility of affordable social robots with different functions from those of sophisticated industrial robots. Paro, the first generation robotic companion (Wada and Shibata, 2007) has found applications for old people in Japan and elsewhere, indicating further scope for more frugal and affordable versions.

The convergence of media technologies (digitization of voice, pictures, movies, TV etc.) and the infocomm technologies has created yet another innovation opportunity for entrepreneurs in e-learning, training and education, and other interactive digital media domains. As in the case of Technological Advances, entrepreneurial firms have to establish whether the technologies identified are candidates for sustaining high end innovations, or, being simpler and cheaper, represent 'good enough' ways of meeting user needs, and so are candidates for disruptive technology.

Abandoned R&D Projects

Most public and private R&D laboratories and innovation centres focus on challenging projects to advance the state-of-the-art in an existing domain for specific purposes. Given the unknowns and uncertainties of R&D, these efforts often fail or are repeatedly modified. When the R&D goal is to achieve superior performance, failed prototypes tend to be discarded and serious consideration is not given to alternative applications. Peter Drucker pointed out in 1985 that unexpected failures of high level projects may be a source of innovative ideas but this has not been much discussed in the literature. It is not generally recognised that the two well known examples below represented previously failed or abandoned R&D projects.

In the early 1980s, Sony engineers aimed to develop a pocket sized tape recorder. But despite their best efforts, Sony engineers failed to fit the recording head into the limited space specified. The co-founder, Ibuka, recalled a lightweight headphone developed elsewhere in the laboratory. This had not yet found a useful application and he suggested combining the two. The idea was supported by the CEO, Morita (CEO and co-founder), resulting in the disruptive 'walkman' product which had extensive and long lasting market impact (Nayak and Ketteringham, 1986).

Reverse innovation can come from unexpected sources. In the 2000s Professor Negroponte, Director of MIT's Media Lab, conceived and launched the OLPC (One Laptop Per Child) initiative to develop a good enough and affordable (US$100) Laptop PC for the children of third world countries. Many hardware and software advances were made, but the target price of $100 proved to be too difficult to attain and the mission of the OLPC initiative was not achieved. ASUS, one of the Taiwanese manufacturing contractors familiar with the MIT Media Lab OLPC initiative, was inspired to take a different route by offering a new product to the developed market. The resulting $299 ultraportable mini-notebook computer (Eee PC) was surprisingly well received by new consumers who found the light weight and affordable product good enough for their portable use, as a mobile device to play computer games, watch TV and surf the internet.[10] The new wave of Netbook Computers was set off.

Opportunity Creation

Technological disruptive innovation in developed countries has largely been based on opportunity discovery, as so far discussed. Many opportunities have been identified from technology push - technological advances and potential - rather than arising from market pull. Technologies can also be developed specifically with a view to disruptive innovation. There is then a recognised need to develop intellectual property protection to fend off imitators (Lindsay and Hopkins, 2010). Scientists and engineers in leading companies, top universities and public research institutes have long been engaging in sophisticated R&D that has resulted in breakthrough technologies and eventually radical innovations. There has not been an R&D agenda to create disruptive technologies as such. However, greater understanding of the nature of disruptive innovation makes it possible to deliberately design disruptive technological innovations with customer needs in mind.

[10] http://wiki.eeeuser.com

An example of deliberate design of a disruptive technological innovation was the development of the inkjet printer by Hewlett Packard. HP went ahead with this project despite potential cannibalization of its mainstream laser printer business. The first mass-produced, personal inkjet printer from HP in 1984 was a slow, messy machine which could not match the high performance of the much more expensive laser printer. But it eventually overcame the technology hurdle through extensive R&D, to produce a good-enough yet low-cost inkjet printer protected by over 300 patents (Hang, Yu and Chai, 2007). Another example is the probabilistic CMOS chip of Prof Krishna Palem.[11] Unlike precision digital logic and fuzzy logic, this chip uses probabilistic bits which take on a logic value of 0 or 1 but only with probability 'p'. Current computing hardware, using conventional bits, expends large amounts of energy calculating with absolute certainty. With probabilistic logic, the computing hardware uses much less energy with decreasing probability as the voltage level is reduced correspondingly. It makes use of the noise inherent in semiconductor hardware as a 'free' source of the randomization needed in the probabilistic algorithm. Using such probabilistic computing hardware, Palem has created a disruptive technology just good enough for many commercial applications, but with order-of-magnitude saving in energy consumed. He envisages its applications in robotics, natural language processing, data mining, signal processing and bio-engineering. Much reduced power consumption could provide this technology with many applications in mobile devices.

Innovative companies are recognising opportunities to apply simpler, affordable technologies in emerging markets and finding that this creates opportunities for 'reverse innovation'. This approach involves alertness to the pull of market potential rather than being driven primarily by the push to exploit a firm's technologies, actual or potential. An example is General Electric (GE). In 2002, GE served the Chinese medical ultrasound market with machines developed in the US and Japan. But the expensive ($100K) bulky devices sold poorly. An enterprising local team in China went on to leverage GE's global resources to develop a cheaper, portable machine using a laptop computer enhanced with a probe and sophisticated software which replaced some costly hardware components. Its $30K-$40K price was more acceptable to the rural

[11] Special reports on 10 emerging technologies, MIT Technology Review, March/April 2008.

clinics that purchased the machine. In 2007, GE introduced a model that sold for as little as $15K, which became a hit in rural clinics, where doctors used it for simple applications such as spotting enlarged livers and gallbladders and stomach irregularities (Immelt, Govindarajan and Trimble, 2009). Not satisfied with the opportunity thus created in the emerging market, GE went one step further to explore the commercial potential of this portable ultrasound device back in the US. It soon found new applications where portability was critical or space was constrained, such as at accident sites where the portable machines could be used to diagnose problems like pericardial effusions, in emergency rooms where they could be used to identify conditions such as ectopic pregnancies, and in operating rooms, where they could aid anaesthesiologists in placing needles and catheters. Convinced of the future trend that new innovative products may be first created in emerging markets based on their needs, and subsequently find new applications back in developed countries, GE has announced an ambitious plan to create such 'reverse innovations; proactively (Immelt, Govindarajan and Trimble, 2009).

Progressive multinational companies have also started to invest in a new type of R&D which targets potential applications initially in the high-growth emerging markets. For instance, HP Labs in India has a focus on 'reducing complexity of interaction, affordability, etc.' in order to create products suitable for the next billion of emerging consumers. Likewise, Siemens R&D Labs in India and China have launched their SMART initiatives, which will help create products which are Small, Maintenance friendly, Affordable, Reliable and Timely to market.[12]

The companies in mature economies discussed above had the resources to perform both the disruptive type and the radical/breakthrough type of R&D. For them the challenge was to recognise opportunities and commit to allocating resources to disruptive innovation. Smaller entrepreneurial firms lack such resources. Nevertheless there are examples of resource-constrained firms pioneering disruptive innovations by first building a foothold in a new or low-end market, and then continuing to grow. Galanz in China is one example. When Galanz decided to enter the microwave market

[12] www.siemens.com/about/en/index/vision_strategy/strategy.htm

in 1992, it did not follow in the footsteps of other Chinese companies, which served as manufacturing contractors for foreign companies exporting Chinese-made products back to developed countries (Christensen, 1997). Instead, it decided to design and manufacture its own products for the newly emerging middle class market in China. At that time, most Chinese households could not afford microwave ovens and few had kitchens large enough to accommodate units built with Western users in mind. Licensing the basic microwave technology from Toshiba, the company built core competence in manufacturing, followed by heavy, sustained investment in R&D and design, to develop a simple, energy-efficient microwave oven that was small and affordable (Hang et al., 2010). To stimulate demand, it was proactive in educating consumers about the benefits of microwave ovens; the marketing materials included cooking techniques and recipes. The product was well received and sales grew steadily, allowing the company to take advantage of economies of scale and expand its manufacturing automation. This further reduced the product's price, making it accessible to even more consumers. By 2000, Galanz dominated the Chinese market with a 70% market share.

E-bikes provide another example from China. In the mid 90s, some visionary Chinese firms like Jinhua Luyuan EV were formed with the vision to build a "green" product to replace the heavily polluting gasoline motorbikes as a new solution of affordable transportation in China (Yu, Hang and Ma, 2011). As the high-end and high-cost e-bike technologies were not available or not even suitable for a developing market like China, local Chinese firms had to develop prototype first-generation e-bikes themselves. While they attracted some early customers, there were many technical problems in batteries, motors, controllers and battery chargers. Much R&D was expended by these pioneering firms to improve this disruptive technology ignored by all the gasoline motorbike firms. The momentum accelerated during the 2000s when commuters avoided public transport during the SARS crisis in 2003, and when some local Chinese authorities banned gasoline motorbikes in major cities to reduce air pollution. With continuous performance upgrading, e-bikes became an alternative choice to motorbikes and manual bicycles. It also created a huge demand among female consumers, children and older folks who were not consumers of gasoline motorbikes. This combined new-market and low-end disruption has allowed pioneering firms such as Luyuan to build up new ventures that will be well positioned to export the affordable and much improved product in due course to other emerging markets and eventually to developed markets, following a reverse innovation path now being adopted elsewhere.

Opportunity Discovery/Creation

In addition to being alert to changes in order to discover innovation opportunities, or being proactive to create disruptive technologies for new lines of innovation, entrepreneurial firms increase their chances of success by combining the two approaches, i.e. they discover *and* create opportunities and repeat the cycle if necessary. This is suitable when the firms do not yet have a clear idea of the nature of a new business opportunity. They can adopt a discovery-learning approach to create new technologies which have disruptive characteristics (being smaller, simpler, easier to use, mobile etc.) and are affordable in the mass market. Two examples are outlined below

Before 1997, Seagate, which succeeded in disrupting and then dominating in the 5.25 inch and subsequently the 3.5 inch disk drive markets, was a technology follower with excellent marketing and manufacturing capabilities. After acquiring Conner Peripherals in 1995, Seagate boosted its capability to develop 2.5 inch disk drives for the emerging markets of laptop and notebook computers. However, these new markets did not take off as fast as originally expected and there was not much incentive and pressure from the market to invest heavily to develop the technology further. Nevertheless, in 1997 Seagate surprised its competitors by changing its strategy from that of a technology follower to that of a technology leader (Yu, 2008). Its Chief Technology Officer, Tom Porter, believed that the only way to succeed greatly in the 2.5 inch business was to have leading technology. The change resulted in the establishment of the new Advanced Concepts Laboratory, which had the mission of looking 2-5 years ahead, and the new Seagate Research Lab with about 100 PhD level researchers to pioneer research with a 4-10 years horizon. With its rapidly increased patents and advanced technologies, Seagate was well positioned to win large market share when the untapped market of consumer electronics began to prosper after 2000. This success was soon followed by the high-growth market of mobile computing which in turn spurred demand in laptop and notebook computers.

When digital cameras were first introduced by Japanese and US companies in the early 90's, price was high while the image quality (picture resolution) was not very good; consumers were limited to hobbyists and internet enthusiasts. Then in 1995, a Japanese company, Casio, which was known primarily for its calculators and digital watches, entered the market by introducing the QV-10 digital camera at an affordable price of 65,000 Yen. The image resolution of 250,000 pixels was acceptable as it was positioned as a fun product, good enough for taking snapshots at parties or at similar occasions. What was particularly special about the QV-10, however, was a small liquid-crystal display (LCD) screen where the most recent image could be instantly viewed. Users could preview the pictures, delete if necessary and reshoot immediately. Its simplicity also outdid the Polaroid instant cameras. QV-10 became an overnight success. The LCD screen soon became an essential part of the dominant design for digital cameras. One important reason why Casio took the surprising step of adding the LCD screen was that it was not a conventional camera or film company. Hence it was not encumbered by the traditional concept of what a digital camera ought to be (Benner and Tripsas, forthcoming). In fact, the original concept for QV-10 was not a digital camera with an LCD screen, but the reverse: an LCD TV with a built-in digital camera. The TV tuner feature was eventually taken out as the concept evolved.

The opportunity discovery/creation approach is well suited to entrepreneurial firms which aim to create products/services for the emerging countries. These firms can create or acquire an appropriate technology and identify a specific business opportunity where the disruptive technology candidate could be used. Methods such as Design Thinking (Brown, 2008; Utterback et Al., 2008) may be used to discover latent customer demand. If it is not successful, the discovery/creation cycle may be repeated until a viable market is identified and developed (Christensen, 1997). In view of the extensive research findings available in universities, research institutes and large companies, it should be possible for translational R&D to convert more of these basic research results into disruptive technology candidates which could then be used by entrepreneurial firms including the small and medium size companies, to initiate the discovery-creation process. Dynamic public research agencies could take the lead obtaining resources and promoting partnerships, to commission and fund such translational R&D.

Summary of opportunity discovery/creation issues

We have outlined and discussed three categories of opportunity search for disruptive technological innovations, namely discovery, creation and discovery-creation. Discovery and creation can be used in combination to facilitate discovery-creation opportunities. We have illustrated differences between these categories using examples from developed markets and new examples from emerging markets.

Emerging markets will continue to offer many technological innovation opportunities to entrepreneurial firms because there is high aggregate demand for good-enough products and services which are also affordable. Many MNCs have started to take note of these developments because the growth potential of emerging markets would not only compensate for the slowdown in growth in advanced economy markets, but are also likely to create reverse innovation candidates to stimulate new markets. Figure 4 illustrates the contrast between conventional innovation where products for mature markets are modified for middle classes in emerging markets, and the reverse innovation trajectory discussed above in the case of GE.

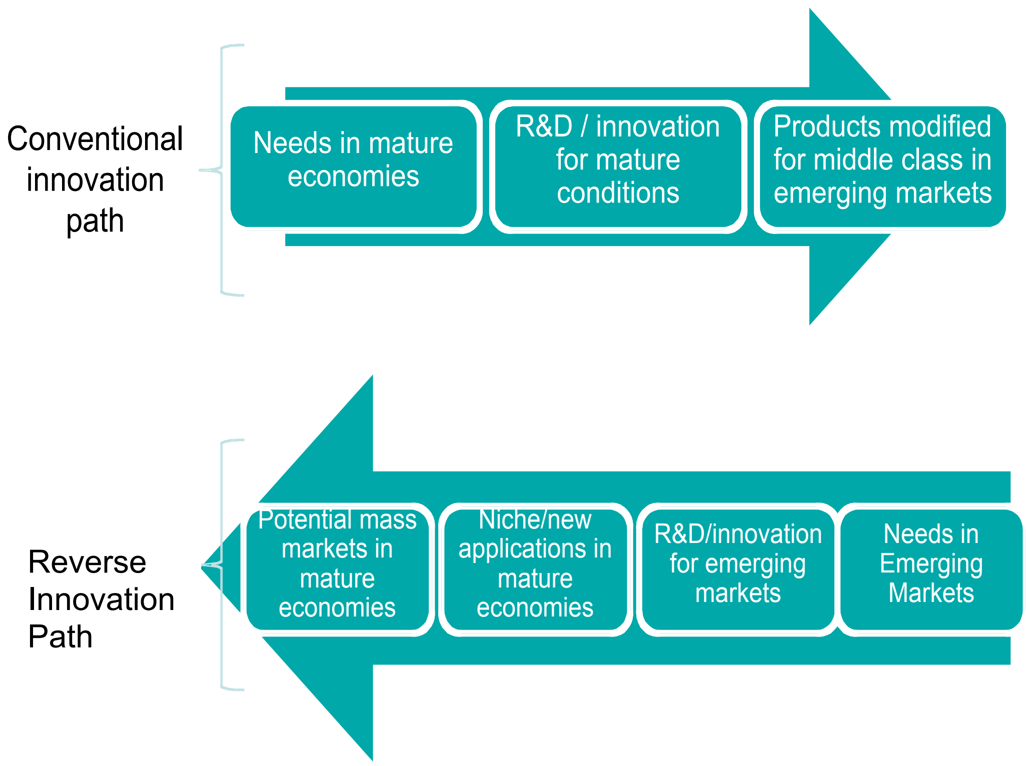


Figure 4 Conventional and Reverse Innovation Paths

Resources for Disruptive Technological Innovation

R&D requirements for disruptive innovations are very much less costly than long term R&D for radical innovations, such as are required in biopharmaceuticals and many advanced materials. However the pursuit of opportunities for disruptive innovation still entails costs. In the final part of this paper we ask how SMEs can obtain the resources to cover such costs, especially in conditions where bank credit is tight and/or interest rates high. In the introduction we pointed out that Christensen's work on disruptive innovations is complemented by the resource-based view of the firm and in particular by the stream of research initiated by Penrose (1995).

While a common focus today is on attracting external investment for firm growth, Penrose was concerned with how firms can release internal or potential resources to realise opportunities for growth. To achieve a good match between their resources and external opportunities, entrepreneurial managers must continually update their ability to spot opportunities. 'Expectations and not objective facts' are the immediate determinants of a firm's behaviour' (Penrose, 1995, p. 41). This makes it possible for entrepreneurial firms to detect and act on opportunities overlooked by established companies. Penrose anticipated later work in recognising the importance of the services rendered by resources: 'No resources, not even entrepreneurial resources, are of much use by themselves'. (ibid.,, p. 86). 'Resources consist of a bundle of potential services and can for the most part be defined independently of their use, while services cannot be so defined, the very word service implying a function, an activity.' (ibid., p. 25) or, in today's terminology, a 'job to be done' (Johnson, 2010). When this insight is applied to customers as well as to producers, it becomes clear that products are useful resources to the purchaser insofar as they render useful services.[13]

[13] A firm's products 'are also resources, once they are produced;.(Penrose, 1995, p. 24)

Independently of the work of Penrose, theorists of marketing and innovation recognise that customers buy products for the useful services they provide (Christensen et al., 2005). If firms focus on these needs and the way in which they can be met instead of focusing on optimizing current products, a company is more likely to innovate successfully. Following the work of Levitt (1960), Christensen described the useful services rendered by products as meeting the 'jobs to be done' for customers. Thus customers do not need an electric drill, what they actually need is a hole in a material. New combinations of product and service can meet such customer needs, but today it is recognised that this requires new business models. Disruptive innovations render useful services (to use Penrose's phrase) to customers, via new business models which involve new combinations of resources in new product and service offerings.

New business models make it possible to provide these more affordable, more convenient, products through new combinations of services and resources (both internal and external to the firm). These offerings are disruptive in the sense that they change the terms of competition, shifting it onto different product attributes and integrated service offerings. Emerging markets provide users who value product attributes different from those preferred by users in mature markets, and who may be attracted to disruptive innovations. As we have seen, business models for disruptive innovations address the needs of users directly by providing offerings that actually meet unfilled needs, rather than optimizing current products (Johnson, 2008).

Small companies cannot necessarily obtain resources from investors in order to activate such business models. If not, they have to find other ways to release resources so as to exploit new opportunities. We turn now to case examples of resource configuration in new business models for disruptive innovation. Cases of leading edge technical enterprises with advanced R&D functions are at first sight quite different from entrepreneurial consumer product firms producing innovations in and for emerging countries, as discussed above. However, both are distinct from large MNCs in that both types of innovators are resource-constrained and so have to devise frugal technologies and frugal business models in a climate of risk-averse investment and tight credit. We draw examples from a cluster of high tech enterprises in Cambridge UK to illustrate leading-edge technologies delivered through frugal business models that meet user needs in new ways and so disrupt established terms of competition. Such firms may turn out to be attractive to venture capitalists. Venture capital is well known for enlarging the scope of enterprise. However in many conditions VC is unavailable, or available on terms unattractive to entrepreneurs. Even without recourse to external investment there are various ways in which entrepreneurial firms can secure the resources they need.

To realise opportunities, entrepreneurial firms often seek to gain leverage from their existing resources. They can also release unused knowledge resources, create new resources, (e.g. through reconfiguring their activities and divesting) and access complementary resources through partnerships, alliances and acquisitions (Garnsey and Leung, 2008). They reconfigure their resources and create new productive bases for exploiting opportunities by developing new business models.

It was the new business model that ARM developed that was the key to their success in exploiting RISC (reduced instruction chip) technology; they were able to create partnerships with a wide variety of manufacturers in various sectors (especially in mobile telephony) to whom they licensed their technology and provided support services in chip design (Garnsey et al., 2008). ARM was a spin out from Acorn Computers where their RISC chip technology was developed. ARM was able to launch the RISC chip used by Acorn in its computers in the market for embedded products. Thus key resources were made available to ARM by Acorn Computers. The offering reconfigured by ARM involved licensing IP and design services to customers, reducing the cost of chip design and implementation. This was an unmet need that they discovered by talking to customers and transformed into an opportunity by finding new ways to meet needs by providing customers with design support. Many enterprises originate in other companies when employees leave to start a new business (Klepper, 2001). The parent company can often be induced to release resources, especially if the new product is complementary rather than competitive.

Another disruptive technology that originated through spin-out was inkjet printing for industrial applications which made product identification and labelling much less costly than previous methods. Domino Printing Sciences developed a technology that was made available to them by Cambridge Consultants, the parent firm that had not exploited this technology (Garnsey et al., 2010). This was a unique offering at the time printed product identification information on regulated products became mandatory, and so met a compliance requirement. As competitors entered the new sector Domino's offering remained attractive by being better integrated with the production process. This case and the previous one exemplify ways to exploit growth opportunities in new sectors through release of resources from a parent organisation.

Small spin-out companies applying technologies from universities are another example of firms that gain resources from a parent organisation; these resources may include IP or may be useful technical expertise. A classic example is Oxford Instruments where Martin Wood applied the expertise he had acquired at Oxford University to develop very powerful superconducting magnets. Superconductivity occurs because certain metals can change their state and carry an electric current indefinitely when cooled to close to absolute zero. Initially, there were no applications of this discovery because the superconducting properties of the materials first identified disappeared when exposed to magnetic fields and could carry only low current densities. With the discovery of new materials, superconducting magnets could be energised with the equivalent of a car battery and needed only a cooling flask (cryostat) of liquid helium to keep them superconducting. Laboratories would be able to buy a light weight superconducting magnet for a fraction of the cost of the major installation required for high field copper magnets (Wood, 2000). The Oxford Instruments model could be operated by research workers and did not need the massive power, cooling plant, extensive laboratory space and specialist staff required by the standard equipment. The new company had enlarged their potential market, from a small number of well endowed laboratories to large numbers of laboratories world wide. This case illustrates the relative cost issue in disruptive technologies. The cost of their first product was around £10,000 where existing large scale magnets cost around £100,000. While

£10k is expensive by most standards, this product was cheap and simple in comparison with those used in semi-conductor research at the time, and opened such research to small labs, including those in Japan and Korea.

In addition to exploiting resources unused by parent organisations, SMEs launching disruptive technologies can use the limited resources at their disposal to gain leverage. An example is Abcam, founded by life scientists at Cambridge University in 1998. They detected a business opportunity in the shortage of high-quality antibodies - small molecules critical to the testing of cells and genes in laboratories. They had the idea of applying the online retailing concept to the antibody market, building on their antibody expertise. They were joined by a telecoms entrepreneur who had extensive on-line experience. Abcam's strategy was to provide high quality antibodies directly to labs. An on-line database was built up through their relationships with other labs, enabling customers to select antibodies and they organised low cost distribution of antibodies. The company's business model was at first as an online retailer, disrupting the conventional high-priced sale of antibodies. But over time Abcam was able to raise a revenue-stream sufficient to allow them to move into antibody production, an activity that would initially have been closed to the founders for lack of resources.

An example of a less knowledge-intensive disruptive technology launched by an SME is Viridian Solar. The seed funds for opportunity detection were obtained through the sale of the founders' previous business. Here the business model involved finding a way to get potential customers to fund their product development costs and help to develop an environmentally friendly product specification of interest to customers. It was clear that new forms of energy were being held back by cost. The founders of Viridian narrowed their options to three or four opportunities for disruptive technological innovations. They chose solar hot water, the Cinderella technology to photovoltaics. It was closer to feasibility than the other possibilities for which they had the right skills. The technology was simple but current designs had flaws. These had moved too far along the curve of diminishing returns on performance. It was costing too much to make minor improvements in the reduction of heat dissipation, which were of minor benefit given the current limitation of heat storage capacity. To improve the cost performance ratio, the founders of Viridian were prepared to sacrifice marginal performance. Moreover many solar panels were unsightly and costly add-ons to the roof. If panels were built into the roof as part of the structure, they could be more aesthetic and avoid the costs of retrofitting. This pointed to new build developers as their market place. Using existing technologies, they worked on ways to reduce costs and to draw potential customers into helping their development work since they had no prior experience in this market. Viridian built up a Partnership Programme consisting of commercial house developers and social housing providers. By hosting workshops on solar thermal energy, they succeeded in attracting the attention of developers who were building 6000 houses a year including two of the top ten home-builders and major housing associations.

The entrepreneurs learned from their partners that a major part of the cost of current solar systems resulted from their lack of integration with house building schedules. What were needed were robust panels with ease of installation features (that did not, for instance, require the coordination of specialised plumbers and fitters into the production schedule). They aimed to get the cost down to a quarter of the cost for alternative designs by producing a module that could be slotted into the roof structure by builders and did not require skilled craftsmen to install them. They aimed to avoid dependence on volatile government subsidies, but did gain help from a government development grant. They worked at cutting cost in every element of design without sacrificing performance. The result is a product that made this type of renewable energy affordable and attractive in Europe. Launched in 2007, their range of solar water heating panels has helped Viridian Solar become a leading supplier to the UK construction industry, with growing exports. The case illustrates resource release from the sale of a previous company and the potential to use a partnership-based development process in other countries. This is a case of both discovery and creation, since the opportunity, once identified, was activated (enacted) by the entrepreneurs. They did this through their partnership-based business model and the need for resources was minimised by their design for manufacture.

Concluding Remarks

In revisiting the classic question of whether entrepreneurs engage in opportunity detection or creation, we have seen that exploiting opportunities through innovation requires creative endeavour whether the innovation provides a novel substitute or a completely new offering. We have reported on preliminary research that aimed to identify key issues for further inquiry. Evidence from case profiles was used to inform our thinking and exemplify ways in which entrepreneurial firms identify opportunities and proactively develop disruptive innovations. We have examined areas of opportunity for disruptive innovations including innovations for emerging markets, markets made up of older customers and markets for environmental innovations. It is clear that a creative approach to funding these innovations is needed if resource-constrained SMEs are to realise such opportunities. To achieve a revenue and profit stream, SMEs need to find creative ways of securing resources. We found businesses doing this in a number of ways. Parent organisations released unused resources for them to exploit, an option for other spin-offs whose entrepreneurs are former employees or students. Examples were found of small firms finding ways to gain leverage from their existing resources, especially from their skills, knowledge and contacts. Like our case examples, small firms can develop new business models involving use of the Internet and partnerships that provide access to resources complementary to their own. Resource economy appears to be a universal feature of disruptive innovations, and is found in firms that base their technologies on the principles of frugal engineering. This is a key reason why disruptive technologies are well suited to environmental innovation, as seen in the case of Chinese, Indian and UK innovators. It is by combining opportunity detection with creative mobilisation and conversion of resources that cash-strapped innovators can provide disruptive technological innovations for new markets, including for environmental, aging customers and those in emerging economies.

Examples revealed serendipitous opportunities in technological advance and combination, but showed that technologies can also be purposefully harnessed to meet growing demand. There is no doubt that alertness to opportunity is what makes innovation possible but this involves creative problem solving to overcome resource constraints and meet customer needs. Together these are the basis for creating and realizing opportunities for disruptive innovation. Entrepreneurial firms configure resources in new ways to meet neglected customer needs as part of the act of opportunity creation. This supports the view of business models as ways of organising a firm to create and capture value (Teece, 2009; Garnsey, 2003).

Further research will involve moving from case exemplars to comparative case study analysis, as a basis for developing datasets of firms engaged in various types of disruptive innovation in different markets. This will make it possible to identify how promising technologies for disruptive innovation are selected and to compare business models that help innovators to create opportunities. At national level, further advances are needed in the realms of education and mentoring in translational R&D, in frugal engineering and in Design Thinking. These can provide support for the kind of innovations that create value for users, including for as yet neglected customers in base-of-pyramid markets, while also generating value for the innovating firm.

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