The Paradoxes of Disruptive Technologies

Abstract

The Six Countries Programme has been investigating innovation and its impacts on society and industry since its inception in 1975. Many insights have been gained, particularly as they relate to the application and development of technology in Small and Medium Enterprises (SME). In the case of established technologies, important management issues dealing with markets, investment, infrastructure, and product development are well understood.

But in the case of emergent, disruptive technologies, the story is different. Rapidly accelerating and complex change in uncertain markets requires the development of new competencies – not to mention nerves of steel.

The Six Countries Programme will hold a workshop on SMEs and disruptive technologies in June to identify and discuss key strategic management issues for dealing with this new world.

Is there such a thing as a predictable surprise?

One would not think so, and yet comedians, magicians and other entertainers, in seeking to perfect their craft, look for a formula that will reliably give them the results they want – every time, without fail. To some extent they succeed. Yet in the end there is always an elusive dimension that separates the art from the craft.

Paradox 1: Always expect the unexpected.

Is there such a thing as an innovation process?

Perhaps. Certainly after innovation has happened we can identify many contributing factors. But in the end we can only partially define the process and identify its parts, for if we strictly follow a pre-defined process, what comes out the end is no longer innovation. Once again, there is always an elusive spark that is essential to the creative process that separates creation from manufacture.

Many have sought the formula for innovation, for the benefits of innovation are the life force behind our technology-based economy. But the secret does not reveal itself easily or often. We are like the knights of medieval legend who sought the Holy Grail. No matter how close they might come, they could never possess it, but in the process they gained at least illumination.

Paradox 2: A good question will yield more information than a good answer.

The Six Country Programme also has its own grail, understanding the role of innovation in national progress. In each of their workshops they have explored a new dimension of innovation.

The Paradoxes of Disruptive Technologies

The November 2002 workshop in Karlsruhe, Germany took a reflexive approach by tracing the early experiences of new, more systemic modes of governance for innovation. Innovation is a systemic, holistic, horizontal phenomenon. It involves many factors, which somehow come to reside in narrowly focussed political institutions. Innovation becomes departmentalized and fragmented. This, in turn creates bottlenecks in the innovation process. The Karlsruhe workshop came across the idea of disruptive technology, albeit in the guise of creative destruction.

Paradox 3: Before you can create, you must destroy.

In February 2002, the Conference in Brussels cast doubts on the effectiveness of innovation policy. They asked, "Do we know whether today's innovation policies really make a difference? Has the innovation policy community been able to demonstrate the 'additionality' of innovation policies of the last decades? What has innovation policy really achieved so far and how could it possibly contribute to stimulating environmental sustainability? Is innovation policy up to the challenge of widening its scope?"

Paradox 4: Greater doubt can lead to greater certainty.

In the Autumn Conference 2001 in Dublin participants assessed the role of creativity and culture in the innovation process. They noted how creativity is nurtured and exploited in different ways in industry, education and the cultural sector. The conference presented delegates with the opportunity to examine these different interpretations in some detail, noting the influence of culture on creativity, and the influence of creativity on value.

Paradox 5: To be good at play, you must be able to work. To be good at work, you must be able to play.

The innovation process is multi-faceted. It can be looked at in many ways. In the upcoming workshop in Vancouver, Canada in June, 2003, the theme will be the innovation process in a world dominated by disruptive technologies. There will be a special focus on how small and medium enterprises (SME) survive, and fail, in this high risk world.

Disruptive technologies are those that upset the status quo. An historical example is the introduction of gunpowder which not only changed military tactics but also put out of business an entire armaments industry (suits of armour for example).

Disruptive technologies can show their influence in much more subtle ways. The invention of the clock, for example, transformed the social action of getting together. The previous technology consisted of hanging around the market or the court. An entire day could be spent waiting to meet the right people. In the process you also met the wrong people and everyone knew your business. Clocks enabled people to meet at pre-arranged times thereby creating opportunities for collective action that were not previously available. You could never be in more than one place at a time, but with clocks you could be in multiple places, with different people, at different times of the day.

The concept of disruptive technology, particularly in the context of small to medium enterprises, has recently been popularized by Professor Clayton M. Christensen of the Harvard Business School in his book "The Innovator's Dilemma - When New Technologies Cause Great Firms to Fail"

Christensen defines two types of technology - "sustaining technology" and "disruptive technology." The distinctions between the two are as follows:

<u>Sustaining technology</u> has a well developed market. It is maintained by mainstream companies that supply the technology, which in turn undergoes incremental improvements based on technical as well as market changes. These companies are well managed, have a focus on process improvement and believe they understand and respond to their customers.

<u>Disruptive technologies</u>, initially at least, are often simpler and cheaper than the established sustaining technology, but usually have less functional capability. They do not fit into the traditional market and subsequently have lower volumes and lower profit margins. Sustaining companies, which focus on efficiency and volume, therefore avoid them.

Christensen offers a number of examples in his book: computer disk drives (5.25 inch to 3.5 inch) and automobiles (from internal combustion to electric cars).He also demonstrates how disruptive technologies gain a foot hold and eventually challenge and displace sustaining technology. In the case of disk drives, for example:

1. Initially, the 5.25 disk had sufficient capacity to satisfy the main market, while the 3.5 disk did not hold enough data.
2. The 3.5 disk market developed as a special device for compact computers and other specialized niche markets.
3. Over time, areal data density increased. The 5.25 exceeded market requirements, while the 3.5 disk now met them and had a preferable form factor.
4. The 3.5 disk began to dominate the market. Manufacturers that did not make the switch went out of business.

Eventually, the small innovative companies became mid-sized market leaders, and the established companies became smaller. (With some exceptions, IBM for example.)

Paradox 6: Big companies have to think like small companies. Small companies have to think like big ones.

The Paradoxes of Disruptive Technologies

The switch from niche market to dominant market can be subtle, even though the initial introduction can spark considerable interest. Consider the following list of technological and engineering achievements of the 20th century.

Electrification	Spacecraft
Automobiles	Internet
Airplanes	Household appliances
Electronics	Health technologies
Radio and TV	Chemical and petroleum technologies
Mechanization of agriculture	Laser and fiber optics
Computers	Nuclear technologies
Telephones and telegraphs	High performance materials
Air conditioning and refrigeration	

Many of the early innovators in these technologies were very small. Pioneers in flight, the Wright brothers, owned a bicycle repair shop. It is a tribute to human ingenuity that all this innovation could occur over a span of 3-4 generations. What is more remarkable, and a tribute to human adaptability, is that it all happened without anyone particularly noticing its transformative power. Early adoption of telephones in the home was viewed at the same level as fashion statements, such as a raised hemline or a new hat. Society took it all in stride and accepted it as the normal course of progress. We absorb innovations into our lives and seem to forget that there was a time when they were not there. (The exception being war. Here the tactics of the previous decade crumble under the force of new weapons with devastating results.)

Certainly scientific discoveries and technological innovations are central to social progress. It is expected that their role will continue and increase over time. If we look into the future we can even see the outlines of the new disruptive technologies. It is becoming increasingly clear that there are six inter-related technology trends that are converging, merging, and supporting each other. These converging technologies are:

1. biotechnology, which combines a range of new disciplines – genomics, proteomics, metabolomics and bio-informatics;
2. nanotechnology, which will revolutionize materials, robotics, pharmaceuticals and medicine;
3. information technology and computing, which have shown a three decade run of disruption yet with smaller chips and artificial intelligence shows no sign of slowing down;
4. medical sciences which will combine with the three previous technologies to permit unprecedented understanding of the human body and permit a host of remedial capabilities;
5. cognitive sciences and neurosciences which may permit the enhancement of intellectual abilities; and
6. systems sciences which will make possible a holistic understanding of how complex systems, such as organisms and organizations operate.

The Paradoxes of Disruptive Technologies

Any one of these technologies, taken individually, would be a source of considerable disruption to an existing society. Indeed one of them, information technology, has been the driver of many deep and penetrating changes to our world. But we are no longer dealing with just one force. All six of these trends are happening together, synergistically. They do so because, down in the nanometer range, at a material level, their components – genes, neurons, bits and atoms all become the same thing.

Bits – the zeros and ones of the computer and data communications world are now used for visualization of complex molecules and their interactions. It will be increasingly possible to create models of chemical reactions and investigate the properties of new substances by digital means. Bits become atoms.

Genes – ultimately they are just sequences of four nucleotides (Cytosine, Thymine, Adenine, and Guanine). The code for computers is written in base2, the code for life in base4, not a big difference. As more is known about genomics and proteomics it is not beyond the realm of imagination to suppose that the process of life, from atoms up, can be modeled and simulated.

Atoms – in the world of nanotechnology, objects, molecules, and machines can be built one atom at a time. Single electron transistors (SET) are the ultimate in miniaturization. Atoms have become bits.

Neurons – neural networks simulate the actions of the brain so that computers mimic human thought processes. But there is more. Nano-electro-mechanical systems NEMS will be small enough to directly interface circuit-based logic systems with individual dendrites of neurons. Silicon life meets carbon life.

It is not a coincidence that major areas of science and engineering are converging now, at this point in technological history. Each of the major scientific disciplines – biology, physics, and chemistry – has been examining the fundamental principles of their science. In doing so they have all pursued smaller and smaller elements of their subject matter. Eventually they have all been drawn to the nanoscale.

Common tools have been brought to bear on all of these sciences. The scanning tunneling microscope, developed for the semiconductor industry permits atomic level investigation of chemical and physical processes. Advances in computing and visualization have permitted the modeling of phenomena in all fields.

Clearly these technologies will be both transformative and disruptive. Among a few of the visionary capabilities that are anticipated are:

- Software agents and robots that are more useful in their tasks than humans. They will operate far beyond repetitive mechanical tasks by being programmed to understand general goals and have problem solving capability.
- Direct linkages between machines and the nervous system.
- Medical technology specifically designed for individuals.

- Strong, light materials with a wide range of properties, including memory, colour change, or electrical conductivity.
- Major advances in the ability to control genetics in humans, plants and animals.
- Increase in agricultural yields as well as the reduction of spoilage

This list, which could easily be extended, is remarkable in that it only deals with the synergies involved in the convergence of information technology, biotechnology and nanotechnology. Over and above these are the opportunities presented by what we would call normal technology, the process and product improvements to be found in the business-as-usual sustaining technology.

The situation we now face is reminiscent of the mid to late 1980s when national governments faced the implications of the early semiconductor revolution. Policy makers in all industrial nations recognized the importance of micro-electronics and scrambled to make sure that their own economies were prepared to participate at all levels: infrastructure, investment, skills, and application expertise. As a result, a receptive environment was created that permitted many start-up SMEs to jump in and create local expertise throughout the industrialised world.

Today the situation is slightly different in that we appear to have multiple strategic technologies moving forward at the same time.

- Information technology continues to fuel the overall growth with its ability to manipulate very complex data structures, to create visual models of nanoscale objects that cannot be seen, to rapidly communicate information, and through artificial intelligence to find meaning in the vast amount of data that is produced. Moreover, IT is making possible holistic and systemic views of things as large as entire ecosystems.
- Biotechnology not only holds great promise in areas that are of critical human importance, such as food and health, but is also raising our understanding of the interrelationships within and between organisms. This technology has moved out of the labs and is now established in commercial areas. The rapid growth of capability has run policy makers straight into an ethical and legal territory that we are simply not prepared for.
- Nanotechnology, as we have seen will result in the creation of materials with a host of properties including the ability to interface with biological objects.

Taken together, we must face the fact that strategies for innovation within SMEs will go beyond looking for venture capital and creating decent marketing plans. These technologies are not only disruptive to sustaining companies and industries; they are disruptive on a broad social and economic level. The design of supportive policies will require a much broader look at the overall innovation environment.

Society needs a visionary and strategic approach. The U.S. is already well on its way. Recent high-level planning initiatives have highlighted not only the potential for converging technologies, but emphasized the need for much greater investment so that the USA can maintain technological superiority. (See for example the report of the National Science Foundation on Converging

Technologies). This planning activity is backed up by substantial government funding for basic R&D, as well as the programs of the traditional US technology boosters, space and the military. It appears that a new technology race is about to begin.

Other countries will have to match the pace. The substantial transformations that these new technologies present will likely create a need for coordinated strategies on many levels. But how do we proceed? A good start is to ask the right questions. Here are a few that will surely be presented at the Six Countries Programme in June.

Strategic Decisions for Government

- How can governments set a tone or vision that will channel all participants to creatively envision the future?
- Should governments become first, or demonstration, users?
- How can governments provide definitive answers, or at least reasonable responses to many of the issues raised by new technologies? When the time comes, will they be able to make accurate assessments about the reliability and safety of completely new technologies?
- The mandates of all levels of government will use new technologies. To what extent should government R&D focus on using technology strategically for its own purposes, in for example, environmental protection or health care? Should it wait for the private sector to invent products, should it develop them on its own, or should it engage in partnerships?
- To what extent will legislation and regulation be technology-informed? Will progress in new technology be hampered by regulations written for a different time?
- How can government create a supportive environment for technology-based SMEs? Is there a role for increased partnerships between the government-sponsored research providers in industry?
- Should government focus on fundamental research and encourage revolutionary discoveries?
- Should it maintain a policy of inclusion and partnerships attempting to build bridges across multiple disciplines, areas, research providers and users? How can it link technology and societal aspects? How can it foster international integration?
- Should government attempt to define a blueprint as a large scale management measure which would include a broad vision, establish the R&D priorities, create interdepartmental implementation plans, and integrate short-term technological developments into a long-term framework of opportunities and socio-economic implications?

The Paradoxes of Disruptive Technologies

Strategic Decisions for Education

- How can educational institutions organize themselves to study hybrid disciplines?
- In what way can science and engineering priorities be evaluated to create conditions for convergence and synergy.
- How can the social disciplines, such as philosophy or ethics, be used to assess and enhance transformative technologies? What role do they play in leading us to better understand nature, and at the same time improve wealth, health, sustainability, and peace.
- Can educational institutions be re-oriented as a vehicle for knowledge management on a broader scale than exists now?
- How can long-term projects (beyond the term of a PhD thesis) be incorporated into an academic research setting?
- Can academic institutions establish a balance of research among three different sets of goals: pure science agendas, national priorities, and commercial enterprises?
- How does education best meet the need to create a cross-disciplinary workforce?

Strategic Decisions for Industry

- How can SMEs collaborate and compete in an uncertain environment? When should research be kept secret and when should it be shared?
- At what point in a new technology should standards for measurement, interoperability and performance be set?
- How can commercial enterprises avoid adverse social and environmental impacts if these are not known?
- How can SMEs create fluid adaptable organizations that can move from being a start-up with an idea, into a company with products and customers?
- How can SMEs chase after multiple niches simultaneously to see which one catches on?
- In a market with defined needs and standards, how do you elicit latent and emerging needs that will be the basis of the new market?
- How does a company manage the transition from the early-release product targeted to early adopters, to a more stable product targeted to a mainstream market?

This may seem like a daunting task, but it is not the first time in history that great challenges of technology and purpose have occurred. In the 18th century, at the early stages of the industrial revolution, at a time when science, industry, philosophy and art all met in an energetic way, a group of “modern men” met in what was called the Lunar Society. The club got its name because they met at the time of the full moon in whose calm and even light they could hope to discover the secrets of the universe.

These were not madmen, but the leaders of English industry including Josiah Wedgwood, the great manufacturing potter, Matthew Boulton the industrialist and James Watt the inventor. They represented the spirit of the times, an era of experiment and innovation, of manufacturing and industry, and of course an era of empire building. In their daily lives they created products and machines. Under the pale light of the moon they created the future.

Unfortunately there will not be a full moon in Vancouver on June 5. But hopefully, this will not prevent participants from following the spirit of the Lunar Society. Just as they looked ahead to the Industrial Revolution, so too we are building a future based on new technologies.