2 Where Do New Technologies Come From?

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We live in an age where everything seems to happen at faster and faster speeds. New technologies seem to supplant old technologies on a regular basis, and at a pace which our grandparents would have found dizzying and their grandparents would have found frightening. Many of these new technologies create new markets servicing new needs, while others completely transform established markets by meeting existing needs in entirely new ways. Although not all new markets are created by new technologies, it helps to understand how markets are created and how they evolve by asking where new technologies come from. It is probably simplest to start with a concrete example.

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Television

Deciding exactly when anything starts is not an easy task, particularly when there are substantial rewards to be claimed by those who can establish that they were, somehow, first responsible for it. It is, for example, arguably the case that Joseph May, a worker at the Telegraph Construction and Maintenance Company in the United Kingdom, triggered off the chain of events that ultimately led to 'Friends', 'The Nine O'Clock News' and countless other televised delights. In 1872, during routine maintenance operations checking on the transmission of messages through the underseas telegraph cable that ran from the UK to America, he noticed that the ability of a material called selenium to conduct electricity was affected by light. It did not take much effort for his contemporaries to see that this photosensitivity makes it possible to think about using selenium to measure the intensity of light, or, indeed, to translate variations in colour in a picture into a pulsating electrical current (it turns out that selenium has some drawbacks as a conductor, and people rapidly moved on to other materials). For a generation of scientists and engineers who were busy discovering and developing radio, this discovery was very interesting (amongst other things, it was referred to as 'seeing by radio'), and it stimulated a great deal of unstructured scientific and engineering activity. Progress was rapid, and by 1880 the learned journal *Nature* announced that the '. . . complete means of seeing by telegraphy have been known for some time by scientific men . . .'.

This may or may not have been true, but there was still some distance to go before May's accidentally acquired insight was turned into regular evening viewing. To transmit a picture, one needs to use many light sensitive receptors (made from mater-ials like selenium), and, indeed, the more you use, the more

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precise the picture will be. One also needs to scan these receptors very rapidly (particularly if one aspires to broadcast moving pictures), transmit the resulting bursts of electricity to a receiver and then one has to put it all back together on a screen at the other end. The first scanning mechanisms that were developed were mechanical (based on the so-called Nipkow scanning disk), and, from the late 1870s until electronic scanning was firmly established in the middle to late 1930s, a great many such mechanisms were developed: '. . . there were vibrating mirrors, rocking mirrors, rotating mirrors, mirror polyhedra, mirror drums, mirror screws, mirror disks, and scintillating studs; lens discs, lens drums, circles of lenses, lenticular slices, reciprocating lenses, lens cascades, and eccentrically rotating lenses; there were rocking prisms, sliding prisms, reciprocating prisms, prism discs, prism rings, electric prisms, lens prisms, and rotating prism pairs; there were apertured discs, apertured bands, apertured drums, vibrating apertures, intersecting slots, multi-spiral apertures, and ancillary slotted discs; there were cell banks, lamp banks, rotary cell discs, neon discs, corona discs, convolute neon tubes, tubes with bubbles in them; there were cathode ray tubes, Lenard tubes, X-ray tubes, tubes with fluorescent screens, glass screens, photoelectric matrices secondary emitting surfaces, electroscope screens, Schlieren screens and no screens at all.'

Early television, when it finally appeared as a series of faintly flickering shadows on very small make-shift screens, was not obviously a money making proposition. Aside from the inherently uninteresting nature of what was transmitted (one experimental group was fond of transmitting pictures of smoke rings), there was no ready market of advertisers anxious to fill the airwaves with claims for their products. Indeed, Francis Jenkins, an early American pioneer, gained approval from the Federal Radio Commission (a forerunner of the FCC) to broadcast only

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for experimental purposes, which meant no advertising (amongst other things). His television system—and this was true for all of them at the time—was a proprietary system (meaning that his television receivers could not pick up the broadcasts of other groups, and visa versa), and he planned to make his money by selling TV receivers. By the middle to late 1930s, however, it became evident that 'broadcasting' was the right way forward, and this, of course, meant that a range of technical standards needed to be set. This took some time, notwithstanding the aggressive championing of television (and, of course, his own proprietary system) by David Sarnoff, legendary head of RCA (some commentators have suggested that standard setting was so slow in part because he was so aggressive). One way or the other, standards were established in time to trigger a boom of entry into the industry in the immediate post-War period (and an induced wave of entry into television tube production) which peaked in the early 1950s with eighty-five producers in the United States alone.

The Drivers of Innovation: Demand Pull and Supply Push

It is clear that the story of how television came to be developed is consistent with a number of possible drivers of innovative activity. By far the simplest theory about innovation which emerges from the story is that it was all a matter of luck, that the technology was discovered—and, perhaps, developed—mainly 'by accident'. This certainly seems to be a story that one could tell about the development of many technologies. For example, Post-its, Viagra and Aspartame are all well known examples of amazingly successful products which emerged from research

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programmes designed to produce something entirely different. Post-its was an offshoot of a project designed to discover a very strong (not a very weak) adhesive, while Viagra emerged from research on heart conditions. In fact, the inventor of Post-its had a fair bit of difficulty even building support for it within 3 M, not least because the inventor himself saw its market as being very small and specialized. Aspartame, a sweetener 200 times sweeter than sucrose and known for its clean taste, was discovered in 1965 when a scientist doing research on amino acids to develop a treatment for ulcers licked his fingers to pick up a piece of paper. What neither he—nor anyone else at the time—realized was that aspartame would be highly valued among diabetes sufferers unable to ingest sugar.

Accidents, however, happen for a reason, even if one cannot always fathom exactly what that reason is. To understand what is really going on when an accident occurs, one needs to understand who was at the scene, and what they thought they were doing at the time (and why). Since somehow, someone did something that 'caused' the accident, it seems reasonable to look for an underlying explanation of what happened in the actions and decisions of 'interested parties'. The fact that it takes at least two agents to make a market—a buyer and a seller—suggests (at least to economists) that there are, in principle, at least two important forces involved in the innovation process that are worth keeping track of. One is demand, which, if effective, can 'pull' the new innovation out of the laboratory and on to the market. Since a new technology is developed to meet important needs (and it certainly is not going to be very successful if it does not), one might reasonably think that those who were responsible for its development were being guided by the desire to meet those needs. The other potential driver is supply, which may 'push' a new innovation out into the market. Supply, in this

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context, refers both to the individuals (scientists and engineers) who do the serious tinkering, as well as to the underlying base of scientific knowledge which they draw from in their tinkering. It also applies to those non-scientists who spot a commercial opportunity and organize others to develop new products and services from a new technology, and bring them to market. Supply push arises whenever a scientist follows a whim and develops something simply because s/he is curious about 'what might happen if . . .?', or when an entrepreneur follows a 'hunch' that flies in the face of conventional wisdom about what consumers really want. It also arises when one scientific discovery sparks off another, and then another, as scientists follow their curiosity or the logic of their thinking into new but unknown pastures.

Although it is more than likely that a full and proper account of the emergence of new technologies involves both demand and supply side influences, it is useful to start by considering each of these two 'theories' in isolation, as if they were competing hypotheses. Having understood each on its own merits, it then ought to be easy to put them together in a sensible way to get a comprehensive explanation.

Demand Pull

Demand pull is a very simple story about the drivers of innovation, one which everyone understands (or thinks they do). It is clear that successful innovations are successful because there is a demand for the goods and services which embody them, and this must mean that, at the very least, demand is an important driver of innovation. Although superficially very appealing, this argument is, however, too simple. For a start, many of innovations

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that are produced and brought to market are not successful (most new products are failures), and it is hard to argue that these were demand driven. Further, as we have just seen, some innovations were developed to meet one particular demand but ended up having an entirely different use. One might say that these innovations were demand driven, but one would also have to say that they emerged as a response to the wrong demand or perhaps that they were the wrong response to the right demand!

We might make more progress by thinking about the expectations that scientists and business people take into the decision to explore a particular technology. Clearly, no one consciously sets about to develop something that consumers do not want, but then again no one knows for sure what consumers do want. Hence, it is reasonable to suppose that putative inventors or innovators will form expectations about the likely demand for what they are doing. These expectations might be formed around one or both of two propositions: that at least a few people really want the innovation and will be willing to pay a high price for it, or that many people want it and so the market for it will be large. All of this is easy to accept: the really interesting question is what drives these expectations; that is, how do potential innovators learn about such demand signals? One very common answer is the following: if the market that the new innovation will be sold into is large and growing rapidly, one can confidently assert that demand is there. Indeed, the risk that the goods and services associated with a new innovation sold into that kind of market will fail for lack of demand is very small. This argument means that one expects that large, rapidly growing markets will stimulate innovative activity; that is, these demand signals will pull forth innovative activity to meet the needs underlying that demand.

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Plausible and sensible as this argument sounds, it can, at best, only account for incremental innovations that develop and extend existing markets. New radical innovations create new markets: they serve needs that have not yet been served by any good or service, or they meet existing needs in radically new ways. Either way, before they are developed there is no well defined market for them to be sold into and, hence, no demand signals of this sort exist to stimulate their development. Conversely, many of the innovations which are developed to serve existing markets are in the nature of product extensions or process innovations: they are designed to deepen and broaden an existing market or, if they are process innovations, they are designed to enable producers to serve that existing market more economically. Valuable as they are, neither of these activities helps us to understand where new markets come from.

The problem with the notion that demand is the main driver of those innovations which end up creating new markets is that it is hard to know what kind of 'demand' this argument relies on. There are at least two senses in which one might talk about there being a 'demand' for something. On the one hand, consumers can have what one might call a '*inchoate*' or general demand for things that meet certain broadly defined types of needs or perform certain functions; on the other hand, they also can have what one might call an '*articulated*' or specific demand for a particular product with particular characteristics which is one of a whole class of products that meet a certain clearly perceived need or performs a particular valued function. An inchoate demand for something exists whenever consumers respond affirmatively to the question: 'wouldn't it be nice (or useful) if this sort of thing were available?'; an articulated demand exists whenever consumers respond affirmatively to the question: 'would you like to buy this particular thing at that price?'

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For some particular product A, an articulated demand exists whenever the market price of A is below a consumer's reservation price; that is, whenever the valuation of good A exceeds its market price. An inchoate demand for A exists whenever A is the kind of thing that a consumer feels might, in principle, be of use in some circumstances or other.

When we talk about 'the demand for' something, we typically mean demand in this second sense; that is, specific or articulated demand. Economists usually assume that the demand for something in this sense is inversely related to price, and describe it using a demand curve. The consumer whose demand curve is being examined knows what s/he wants, s/he can describe it fairly clearly, compare it with other alternatives, and, because s/he knows pretty much what s/he is going to get when s/he uses it, s/he can value it. Markets (and market research methods) usually convey demand signals of this type fairly well: when demand in this sense increases, sales and margins go up and serving the market becomes more profitable. The trouble is that there is not—and cannot be—a specific demand for most new innovations, since it is almost impossible to articulate a choice between things that do not as yet exist, and about which one has little, if any, practical knowledge or experience. Further, in the absence of knowledge about exactly what the new product is and what exactly it will do, it is difficult—if not outright impossible—to value it. The demand for products which do not as yet exist cannot be anything other than an inchoate demand.

This leaves with us a story that says that if demand stimulates the kind of innovative activity which leads to the creation of new markets, it is inchoate demand which does the work. There is nothing wrong with such a story (it is certainly not implausible), but it is hard to see much content in it. How, for example, do firms or innovators discover what the inchoate demand for

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something is if consumers cannot articulate their preferences for it? How can consumers articulate a demand for something which is so new that they cannot imagine or accurately describe it? And, even if producers can spot an inchoate demand for something, how do they infer what the specific demand for it will eventually be? How do they work out how big and profitable the market will be? All of us have a great many inchoate demands for things that we have never thought very seriously about, and such feelings make for a pretty imprecise target for innovators to aim at.

There is a further problem with demand pull stories of the emergence of major or radical innovations. Even if we suppose that an inchoate demand for something is truly the driver of innovative activity, the simple empirical fact is that it seems to be a pretty palsied driver. From the day that our furthest and most distant ancestor climbed down from the trees and began ambling about, there has been a generalized demand by all living humans for a longer, higher quality life. Further, we have always been able to articulate very specific demands for reduced mortality rates in child birth, cures for leprosy, the plague and gout, better artificial limbs or hearing aids, and so on. If demand were truly the main driver of innovation, why have most of the advances in medical science occurred only in the last 50-100 years? Similarly, there has always been a 'demand for' transport, communications, entertainment and so on, and yet it seems to be the case that most of the major innovations in these areas have occurred only very recently. It is not hard to believe that Napolean had an inchoate demand for mobile phones to help control his armies, or that the long distance courtships of Henry the VIII (and other dynastic monarchs) created a real if rather generalized demand for video conferencing facilities. However, neither this generalized demand nor the undoubted rewards that

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would have accrued to the innovator who satisfied the inchoate demand of such notables seems to have been strong enough to pull out such products, although it did probably pull out some innovations which helped to satisfy this demand for better communications. At best, one might say that in these cases demand established priorities for inventors and innovators to concentrate on.

The point is a simple one. If demand really is to be taken as the driver of innovative activity, then not only must it be true that innovations meet real, articulated needs, but, further, they must appear when such needs develop. In fact, the value to us of most of the recent inventions which have transformed our lives (including television) has been far clearer in hindsight than it ever was in foresight. Further, many of our most important needs have gone unsatisfied for long periods of time simply because science and technology have not developed fast enough to produce the goods and services which would meet these needs. That is, the pull of demand is often limited by constraints originating on the supply side, meaning that it is the relaxation of such constraints—and not the pull of demand—which may have effectively been the main determinant of innovative activity. Thus, to understand where new technologies come from, we may well need to look at who produces them (and how), rather than at who buys them (and why).

All of this said, it is incontestably the case that demand is sometimes an important driver of innovative activity (but only sometimes). Thus, before abandoning demand pull and considering the alternative theory of supply push, it is worth pausing to consider at least one case where demand seems to have been a major driver of innovation. At the very least, such an example might cast some light on why demand pull is typically relatively limited as a driver of innovation.

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Computers, Scientific Instruments, and Television (Again)

The emergence of computers is a story which seems to be broadly consistent with the view that demand, inchoate or generalized and articulated or specific, can be an important driver of innovation. The original demand for large scale computing goes back at least to the nineteenth century. Two of the big early users were life insurance companies and the US Census. Both organizations had a pressing need to mechanize the collection, sorting and analysis of large volumes of data, and both actively encouraged the development of technology to facilitate their work. Herman Hollerith was an early developer of tabulating technology (his company, the Tabulating Machine Company, founded in 1896, eventually became part of the foundation of IBM), and his work was supported by officials responsible for the 1890 Census in the United States. Life insurance companies became the earliest private sector users—and supporters—of this work. The Prudential bought one of his systems, and then sponsored further work on punching and sorting components. Other life insurance firms soon joined in, sponsoring work that supported their need for rapid and multi-dimensional sorting of the data used for actuarial purposes, as well as work that tried to integrate data manipulation with document production.

Military uses of computing have also always been large. At the end of the last century, the increasing reliance on artillery produced a demand for tabulation of projectile trajectories, and, since there are no end of factors which might affect the flight of a projectile, there was no obvious limit to the number of such tables which might be produced. Prior to the computer, such work was done in large warehouses (not wholly dissimilar to

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modern call centres) by reams of clerks (many of whom were, strangely enough, women). Things changed as warfare became more mechanized (in the first War) and then technological (in the second War). Much of the early post-second War development of the technology was financed by the public sector, largely (but not exclusively) through defence procurement. ENIAC,the first digital and electromechanical computer built in 1946, was supported by the US Army, as was the project conducted at MIT which led to the development of magnetic core memories. This said, it is important to emphasize that not all computers were developed at the behest of the military, and not all were developed with the support of users. The Mark I computer developed at Harvard, for example, was largely supported by IBM.

In fact, there are sectors of the economy besides computers where demand clearly plays a very important role in the innovation process. For example, scientific instruments—and, indeed, many areas of engineering—display 'user led' patterns of innovation. That is, users typically articulate their needs, lead or assist in developing the design for a new device, build and apply the prototype and diffuse information about it more widely. They also frequently claim the lion's share of the rewards from the innovation. While 'the innovator' in these cases is usually a small engineering firm, what brings the innovation out on to the market is the partnership it has formed with its buyers (or lead users), a classic example of demand pull. Similarly, aircraft manufacturers have always worked closely with users (Pan Am is said to have played a central role in stimulating the development of the Boeing 747), and to have benefitted from government support for research into materials and government purchases of military aircraft.

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This said, it is also equally incontestable that there are a great many innovations which do not seem to fit the demand pull story very well. For example, television does not seem to be a particularly good example of an innovation that was 'pulled' out by demand. Although it is not hard to believe that many people found it difficult to entertain themselves through long evenings at the end of the nineteenth century (and, of course, throughout all of history), this sad fact would, at most, form the basis of only an inchoate demand for television. In fact, most consumers at the time were still coming to terms with radio on the one hand, and films shown at local cinemas on the other hand. While it is not a large step to think about films being broadcast into their homes in the same manner as radio was, there is no evidence to suggest that many—if any—consumers made that conceptual step (particularly those who had not yet purchased a radio or been to a cinema). Further, a general demand for home entertainment might equally well have been satisfied by the invention of a board game like Monopoly, the publication of a particularly good book or any invention which made it easier to cook dinner for large numbers of guests. If one was going to seriously try to make the case that there was an articulated demand for television, then one would have to say that it was almost certainly the product of David Sarnoff's fertile (and possibly rather prescient) imagination (although even he is unlikely to have imagined the full horrors of the *Jerry Springer Show*). Sarnoff had a very early and very clear vision of where television was going to go, who was going to want it and why. As a consequence, he acted by proxy (as it were) on behalf of consumers, with the result that RCA ended up investing about $50 m. on the development of television. However, even this is arguably not clear evidence in support of the demand pull model of innovation, since it is clearly the case that his major

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motivation in developing television—and trying to control it—was to preserve RCA's profitable radio business. Still, if demand pulled out television, it would seem that it talked mostly to Sarnoff.

Indeed, it is fairly clear that many of the scientists and engineers involved in the development of television were following their own agendas, trying to satisfy their own intellectual curiosities and realize their own scientific ambitions. At least two of the early pioneers of television, Philo Farnsworth in the United States and John Logie Baird in the United Kingdom, are classic examples of obsessive, back yard garage inventors who were propelled by little more than their own scientific interests and curiosities. Further, many of the early scientists and engineers involved in the development of television seem to have been more than a little out of touch with the day to day lives of most of the ultimate users of the new technology (Farnsworth and Baird also fit this bill), and it is hard to see them as being in close contact with—much less driven by—demand (or even, for that matter, pecuniary rewards) to any great degree. Under these circumstances, it is hard to buy into the argument that demand pulled the development of television on to the market. This, then, leaves us with the thought that, somehow, supply pushed the innovation on to an unaware and possibly uncaring market.

Science, Technology, and Patterns of Innovation

When one reads stories like the development of television (or Post-its or Viagra or Aspartame or countless other inventions), one finds it very easy to think that new technologies typically emerge in a serendipitous fashion. This feeling becomes all the

more strong when one watches scientists and engineers at work, and sees just how often they fail to fully appreciate the significance of what they are doing and how often the breakthroughs that they achieve are propelled by what seems like no more than inspired guesswork at best or just plain 'good luck'. And yet, it is hard to believe that the development of scientific and engineering knowledge is wholly random, that there is no pattern to the nature of successive innovations in a particular sector, or in the speed at which they follow each other. In fact, there are reasons for thinking that a pattern exists—for thinking that innovations come in waves, that technologies evolve through ordered generations. This, in turn, means that the emergence of any particular innovation—like the one which is responsible for the emergence of a particular new market—may be no accident. Whatever it is that drives the wave of which it is a part is, at base, responsible for its arrival as well.

One reason for thinking that science and technology might evolve in a systematic or orderly fashion is that many scientists and engineers are very purposive and systematic people (often tediously so). Even if they are sometimes surprised by the results of their work, they usually go about their research in a very organized way. Work plans are one form of organization; structure is also provided by commonly shared mental models or 'paradigms', sets of shared beliefs about the world held by groups of scientists and engineers working in a particular area. These paradigms set priorities (they identify what the important problems are), establish acceptable methods for pursuing them (they define what must be done to cast light on these questions) and condition expectations about what to expect from applying these methods to those priorities (they give people a sense of what they should be looking for). This mental model, this sense of what one should do and what will happen if one does it,

provides a guiding hand on the design and conduct of research projects that removes at least some of the serendipity from the whole process. While it is not always the case that one finds what one is looking for, it is rarely the case that one sees what one is not looking for.

The organizing power of paradigms goes well beyond their effects on particular research projects: paradigms can organize the work of whole communities of scientists and engineers, and not just isolated individuals. They help to define a pattern of common knowledge, goals, methods and expectations which gives a wide range of scientists and engineers in a particular field what seems like a common purpose. Paradigms create communities with shared values and expectations, and, for this reason, they effectively align the efforts of a wide range of otherwise independent scientists and engineers. Wherever they are and whatever they are doing, those scientists and engineers who share the same paradigm are likely to end up, in effect, fishing in pretty much the same way in pretty much the same pond. In these circumstances, it would be unsurprising if the fish that different scientists catch in that pond belonged to the same species, or, indeed, to the same family.

Technology paradigms are mind sets. They help to define research activities by setting priorities, establishing methods and conditioning expectations. For example, the development of streptomycin in the early 1940s not only generated a new 'wonder drug' following in the wake of penicillin, but it profoundly affected both commercial and research methods in pharmaceuticals. The inventor, Selman Waksman, licensed his patents to numerous producers at very modest royalties, triggering intense price competition in the market which benefited no one (except, of course, consumers). In part as a result, patenting became an integral part of the research strategy of most pharmaceutical

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firms. Even more fundamentally, his screening methods—involving synthesizing and testing a great many organic molecules—came to dominate research methodology in the sector for many years. Similarly, 'miniaturization' was a major focus of attention in the development of semi-conductor devices in the United States in the late 1950s, largely as the result of a push by the military. Although integrated circuits did not directly emerge from the research programmes initiated by the US Department of Defense, they were quick to seize on its potential and, together with a gradually growing private sector of users, stimulated its further development. One way or the other, the drive to miniaturization defined a research agenda—and a resulting trajectory of performance improvement—through a long series of devices which were ever smaller (and, of course, more powerful). This agenda determined how people thought about what the important challenges were in semi-conductor research, it established priorities amongst competing research projects, and it shaped the way that people evaluated the outcomes of those projects.

A second reason for thinking that scientific knowledge accumulates in an orderly fashion arises from the conjecture (and it is, of course, no more than that) that there is a deep seated structure to the workings of the natural world that we live in. It may be that there are basic design principles which govern how most things work. Even if we cannot perceive most, or even any, of these design principles very clearly, the fact that they exist means that there will be a pattern to our discoveries about the natural world. What applies at the level of theory may also apply at the level of application. Engineers working with new technologies are often surprised by the wide range of applications for any new idea or technique that they develop. What we, from the perspective of market observers, see as a range of apparently

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unrelated innovations may actually arise from the repeated application of some basic but largely unrecognized scientific concept in a wide range of different contexts.

So, where does all of this leave us? The organized research programme that scientists and engineers follow plus the possibility that there may be a deep seated structure to knowledge means that there may actually be a pattern to innovative activity over time (possibly more evident with the benefit of hindsight than with foresight, and possibly more by accident than deliberate design). One thing may lead to another, one innovation may follow another, one application of a new principle may be followed by a series of further applications of that same basic principle. A sequence of innovations which follow each other, all drawing on the same basic scientific or engineering principle(s), each drawing from and then contributing to a cumulatively increasing body of knowledge and expertise, is sometimes called a 'technological trajectory'. The idea is simply that each innovation in the sequence is not simply an accident, but follows from innovations which have already occurred (and, of course, may lead to more innovations in the future). Different trajectories are typically associated with the different basic scientific principles or the different scientific or technological paradigms from which they have sprung.

It is important not to overplay this idea, nor to impose too much of a pattern on the evolution of technologies. For a start, there have always been (and will always be) one-off innovations that come from nowhere (apparently) and lead nowhere. More fundamentally, the blinkered perspective that often comes from relying on hindsight means that it is probably possible to see a trajectory in the evolution of every technology. For scientists and engineers working on the trajectory at the time, things are much less clear. This is particularly so when a trajectory is first

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established. New trajectories are associated with radical breakthroughs in scientific and engineering knowledge, and these are—almost by definition—likely to be a surprise or appear to be 'accidental'. Such breakthroughs are likely to lead almost anywhere—or so it certainly seems to the pioneering scientists and engineers associated with the breakthrough at the time. The pursuit of these possibilities leads people to go shooting off in all directions; some of these possibilities will lead to more breakthroughs which create more possibilities, while others lead nowhere. As time passes, the choices that people have made will lead the technology to develop in certain directions, and the fact that each breakthrough creates possibilities for further breakthroughs (and the knowledge and expertise to create them) will give that evolution a cumulative, path dependent flavour. A process in which each possibility explored leads to the creation of more possibilities will lead to something that looks like a tree whose dense lattice of branches are built up around trunks and main limbs.

Figure 2.1 shows a stylized version of this idea. An original breakthrough in understanding in a new scientific area creates a new avenue for exploration—a main trajectory. Movement along this trajectory opens up other research possibilities—labelled 'the 1st branch' and 'the 2nd branch' in the figure—, and, these in turn open up further possibilities. Each of these in turn lead ultimately to particular inventions. The basic branching process suggests that these inventions might come in clusters of related breakthroughs. Thus, the original breakthrough in understanding the structure of atoms at the beginning of the century led to major trajectories in particle physics, cosmology and chemistry. As scientific and engineering knowledge in each of these areas progressed, further lines of research opened up: the atom was split, the structure of DNA became understood,

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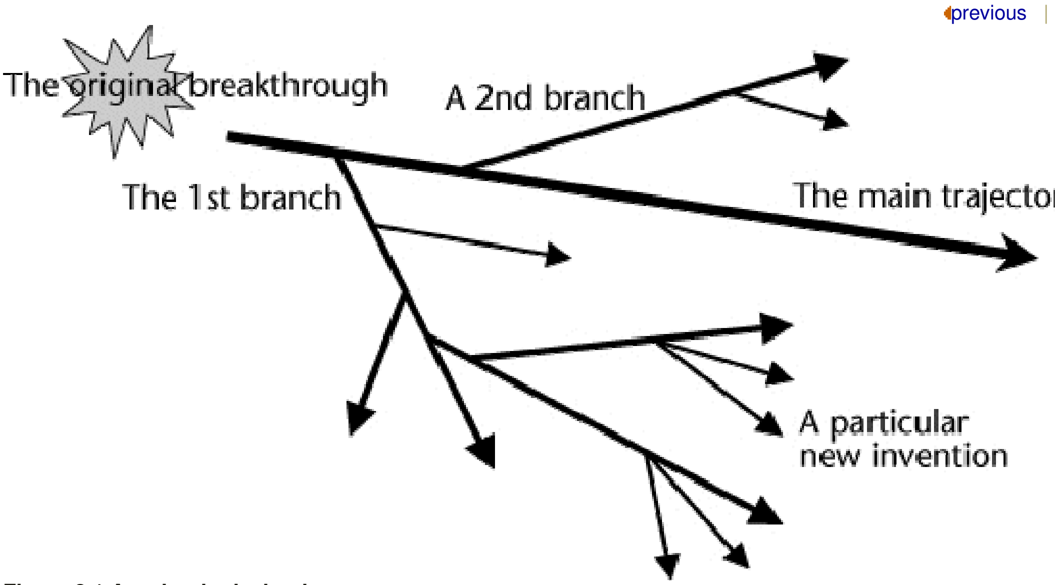

Figure 2.1 A technological trajectory.

and so on. And, each new area of research has produced a rash of related discoveries, often by different, non-interacting individuals who share only a knowledge of the common branch and its main trajectory. Figure 2.1 stimulates a further thought: as the inventions that emerge from different branches are applied in different sectors, their common technological base creates the impression that these sectors are, somehow, converging. For example, the gradually increasing understanding—and use—of digital technologies has, at the beginning of the twenty-first century, generated a cascade of innovations in computing and telecommunications whose uses have spilled over into the production of entertainment.

All of this is terribly iffy and imprecise, but it contains within it the seeds of a fairly plausible story that we can use to help explain where new markets come from. The key idea is that of a technological trajectory. If technologies do indeed develop along such trajectories, then it seems clear that they are likely to have something of a life of their own, one which might unfold quite independently of demand. The important point is that the emergence and early development of the trajectory may look

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like an accident, but once the basic highway that the trajectory is going to follow becomes clear then progress along it is likely to be pretty much self-sustaining, following its own logic at a speed determined—perhaps in large part—by the nature of how scientists and engineers work. And, from any particular trajectory, all kinds of possibilities arise, all kinds of applications are possible and so all kinds of new products and services are likely to emerge. The result is that many new innovations that are spun off from any particular trajectory are likely to appear to have been pushed on to the market by the scientists and engineers who have been working along that trajectory.

A Digression on Technological Trajectories

Technological trajectories are an interesting way to think about how each one in a sequence of innovations or new technologies developed in a particular area are related. They are also interesting because they may tell us something useful about how fast each new innovation or new technology follows the last. Indeed, if innovative activity evolves along trajectories and it is possible to discern the nature of the trajectory, it should be possible to make forecasts about how the technology will evolve in the future. It is, therefore, worth a slight digression to look at what might determine how fast any particular trajectory is explored.

It seems clear that technological trajectories are very hard to spot when they first develop. However, it also seems reasonable to believe that the innovations which are uncovered along any particular trajectory become increasingly easier to predict and understand the more fully developed the trajectory is. For this reason alone, one would expect that the initial progress along a trajectory will be much slower than progress when that trajectory

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has become well established. Further, the speed of progress along a trajectory will almost certainly be determined by the degree of competition between those scientists and engineers who are working along it. Although very little of their work is market oriented, scientists and engineers are no less competitive than anyone else. They have careers to nurture, and self esteem to feed. The structure of how much of science works is that a very high premium is granted to those who are first with an idea: however, perfectly respectable careers can also be built on the basis of mountains of observable published output, original or not. What is more, basic science pays relatively little (in terms of hard cash) as compared to applied science. Hence, when a new technological trajectory opens up, it is almost certain to stimulate a rush of exploration amongst those who wish to win prizes for new discoveries, those who wish to build careers from impressive publication lists and those who wish to make money from taking the new technology into the market.

The really interesting question is to work out when the rate of progress along a trajectory begins to fall. Intuitively, one feels certain that it must: eventually even the richest of technological opportunities must be exhausted, and the ability of even the most talented scientists and engineers to get anything more out of it must decline. For many, this truism has been turned into a forecasting tool. Suppose that we are considering a technological trajectory defined in terms of a single performance measure (such as memory on a chip, or the speed of a super computer). Measuring this performance attribute on the vertical axis and time on the horizontal axis, the argument that progress along a trajectory is slow at first, then becomes faster before tailing off translates into the S-curve shown on Fig. 2.2.

The beauty of an S-curve is that it might be used to identify just when it is time to abandon a particular technology and

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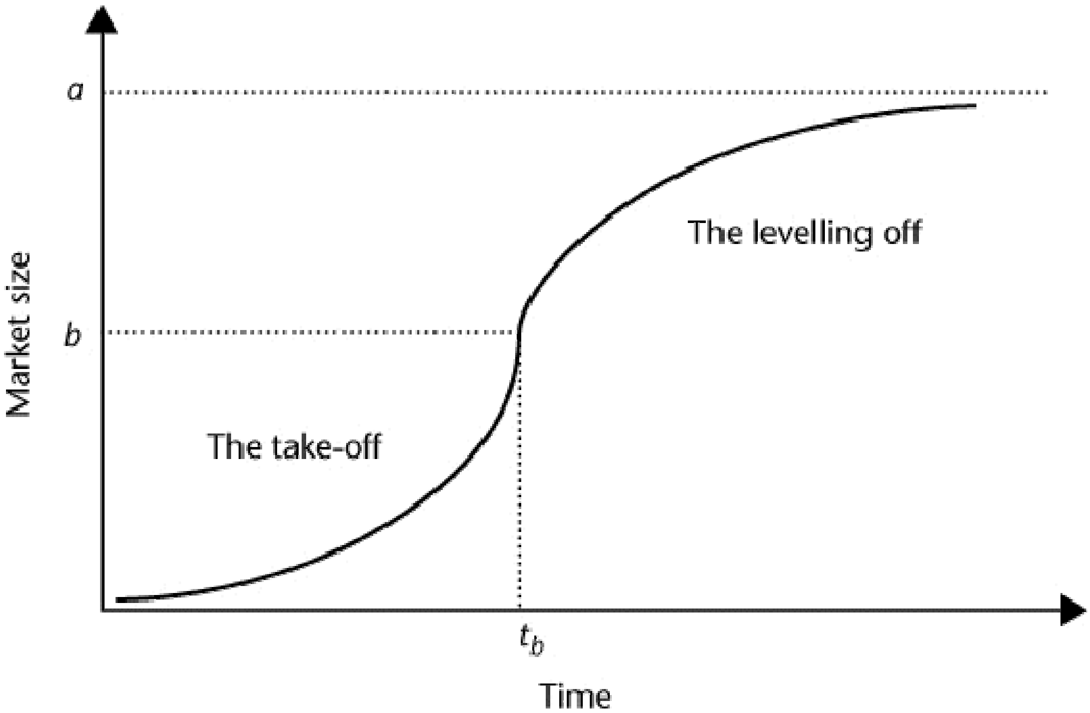

Figure 2.2 An S-curve.

move on to a new one. As can be seen from Fig. 2.2, the rate of progress along a trajectory is likely to rise (the maximum rate of progress is at point *b* on the figure) and then fall over time. This, in turn, means that the level of performance rises rapidly (up to *b*) and then continues to rise more slowly over time, eventually reaching the level a in the very long run. Hence, as long as progress is being made at an increasing rate year after year, one can be confident that the best of the technology has yet to be uncovered (i.e. one can be sure that one is to the left of point t_b). However, once a pattern of decline in the rate of progress sets in year after year (i.e. once one gets past point b, or to the right of t_b), it should gradually become clear that the time when the highest rate of progress that ever will be realized has passed, and that one might be well advised to seek a new trajectory where progress will be easier to make.

This is a very attractive argument but it contains a weakness, and the weakness is this: while the amount of progress that one

makes along a trajectory depends on how much technological opportunity exists in that trajectory, it also depends on how hard one works to develop that technology. If scientists and engineers working on a particular trajectory come to believe that the trajectory which they are working on is nearing its end, they will inevitably work less hard at it and, as a consequence, the rate of progress along the trajectory will fall. That is, their beliefs may be self fulfilling, and their possibly erroneous conjectures will appear to be confirmed by their own actions. In fact, there are plenty of old technologies which seem to hang on well past their sell-by date, and some of them seem to suddenly seem more productive than people thought they were (one example of this which we will discuss later on is the displacement of wooden by iron ships). This usually happens when they are challenged by a new, potentially displacing technology whose competitive challenge galvanizes those scientists and engineers who are committed to the old technology.

All of this lies in the future, however. For the time being, our attention ought to focus nearer to the beginning of the trajectory, for this is where the new technologies which create new markets emerge from.

Supply Push in a Nutshell

The question that we are addressing is 'where do new technologies come from?', and the answer which comes from thinking about the process by which science and technology advances is that many new technologies are pushed on to the market. New technologies emerge from the creation of new technological trajectories (one imagines that the most radical innovations are those associated with the appearance of a new trajectory)

or from movement along established trajectories (which may generate relatively more minor innovations). Thought of from the point of view of markets, a technological trajectory is really nothing more than a set of possibilities, some of which are explored and, in turn, lead to the creation of further possibilities. Of course, the more structured is knowledge and the more tightly defined are science and technology paradigms, the more restricted this set of possibilities is likely to be (and, of course, the more predictable will be the resulting sequence of inventions and innovations). One way or the other, these possibilities open up potentially profitable commercial opportunities for those familiar with the basic technology and interested in making a profit from using it, since they mean that some well established needs can now be served in new ways and/or that some needs which have never been well served can now be addressed in a satisfactory fashion. Hence, movements along any particular technological trajectory are likely to open up a myriad of possible new products and services which might be produced using the new technology, and some of these new products and services will form the basis of new markets.

Product Variety at the Birth of Markets

There is one very strong implication of the supply push process that we have been discussing, and it turns out to be the key to much of what follows. When science and technology push an innovation onto the market, the good or service which embodies the new science or technology is almost certain to be no more than a guess about what might appeal to consumers. Until producers understand exactly what the new technology can deliver, what kinds of new products or processes it might make available

and until consumers are able to understand just how to use the new product or service, there will be room for debate about just what that new good or service should look like, about what it could—or should—do. What is more, applying new scientific or technological principles to particular needs is not all that easy (particularly for complex, new technologies that are not yet fully understood). Embodying these principles in a good or service which must be manufactured efficiently if it is ever to succeed in the market presents yet further challenges. Even when it is clear that the demand for a new innovation exists, and that it will form the basis of a large and profitable market, it still may well be unclear just how best to design and manufacture that product. And, since there is no learning like learning by doing, it seems sensible to think that the right way forward for most innovators is to try out their pet idea and see if they fly.

The upshot of all of this is that supply push innovation processes are unlikely to produce a single new good or service. Rather, the nature of how science push innovations are developed means that they are likely to burst onto the market in a variety of forms. That is, when new technologies emerge, they are likely to do so in a confused and disorganized manner, in a flood of different product or service variants which embody different ideas about what consumers might really want (i.e. in specific, not in general) and what might be possible to produce in an economic manner. If you like, new technologies which get pushed on to the market do not create new products or services so much as they create new product or service categories, and then fill them with all kinds of possible new products and services.

Although this is a natural implication of supply push theories of innovation, it also may be true in some instances when demand pulls out a new invention. If the demand for some new invention is only an inchoate demand, it is likely to be possible

to satisfy it (if that is the right word) in any number of different ways. Competition between those interested in satisfying that inchoate demand will almost certainly produce a wide range of different product variants, all of them based on guesses of what kind of articulated demand will ultimately emerge. If, on the other hand, it is an articulated demand which stimulates the innovation process, then the specificity of that demand is likely to provide a very precise target for inventors and innovators to aim at. In this case, it seems unlikely that a great many new product variants will emerge (or at least make it out of the lab). User led innovation processes are always going to seem more rational and better organized than supply push processes. And, the new markets that they create are always likely to emerge in a more orderly fashion.

More Stories: E-grocery Businesses and Internet Service Provision

We have already observed the phenomena of product variant proliferation in several of the case studies that we have examined (recall the varieties of super computers that emerged with each generation, or the vastly different technologies used in different early televisions). And, as we noted earlier, it is a feature of the development of a range of businesses facilitated by the emergence of the internet. Let us consider two in particular.

In 1999, about 50 per cent of US homes had a personal computer, and 63 million Americans roamed on the net (the average AOL user spent 49 min a day exploring this brave new world). All of these people have better things to do with their time than trundle around a crowded supermarket on Saturday morning buying the week's groceries, and they know it. Many of these

bored and irritable shoppers can see some sort of salvation in doing their grocery shopping on the net and never, ever visiting a supermarket again. However, this new shopping opportunity comes with a number of problems which need to be solved before it can become a viable option for most of them. For a start, home delivery creates a number of logistical problems, particularly for those who are not home very often (or very predictably) and those who like to eat ice cream. Further, there is an interesting problem about just who is going to make the difficult choices between different heads of lettuce or different hunks of sirloin steak that we all seem to struggle with during our shopping expeditions. Finally, there is the question of how shoppers are going to pay, and for what.

As one might imagine, there are endless possibilities of how one might organize a business around the solution of these problems. Consider the following shopping options that are currently available (as of late 2001):

1. *Peapod*, launched in 1990, operates in partnership with established grocery chains in each of the eight urban markets that it serves. It offers value added services like discounts for coupons, the ability to browse virtual grocery shop isles, and the ability to display information on different products by food group, price, nutritional content or even alphabetically. Customers can pay higher per item prices than they would encounter in partner supermarkets, and sometimes have to pay either a delivery charge or a membership fee. The minimum order is $60.
2. *Streamline*, founded in 1996, offers home delivery of groceries, dry cleaning, videos and whatever. They target busy suburban families with young children, severe diary congestion and incomes above $50 k per annum. Each

customer is given a temperature controlled, locked box to receive deliveries, and can order by 11 pm each day for delivery the next day. Streamline charge a $39 start up fee and a fixed monthly fee of $30.

3. *Albertsons* was the first established grocery to set up an internet grocery. They charge the same prices as in their stores, deliver from 9 am to 9 pm all 7 days of the week, and do not charge for orders above $60. They do not deliver perishables, and use their stores as their warehouses.
4. *Homegrocer*, founded in 1997, buy groceries direct from wholesalers and take delivery in specially built 120,000 square foot warehouses (webvan, founded shortly after, take delivery in 300-400,000 square foot warehouses). They then sell on to customers just like any other grocery chain, but without a bricks and mortar shop for customers to get lost in. Homegrocer describes itself as 'the milkman of the 1990s', and uses its drivers to build and promote its service. Delivery is free for orders above $75 and prices are reputed to be comparable with those prevailing in local supermarkets.
5. *Priceline* offers a 'name your own price' service. Customers log on and name the price they are willing to pay for any of 175 categories of goods containing 700+ brands. Within a minute, the site gives them a match (if any), and they are directed to a particular store where the promised price will be honoured. Priceline offers no home delivery.

Needless to say, there are many more variations on these themes currently available on the market as I write these words, and who knows how many new variants will have come (and gone) by the time you read them.

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Much the same proliferation of business models can be seen in the market for Internet Service Provision (ISP for short). When a computer user makes a connection to the internet, data is sent from his/her personal computer, typically along phone lines, to another computer. There are a variety of routes that this data packet can take, but certain main lines—called the Internet 'backbone'—carry the bulk of it. Bigger ISPs operate their own backbone lines and sell some of their capacity to smaller ISPs. One way or the other, it is an ISP who takes your data where you want it to go, and brings back the answer (if any) that you hope to elicit.

Originally, ISPs offered proprietary online content—rather like early television producers—offering their customers 'walled gardens' to play in. The name of the game was to fill the garden with lots of interesting content that would attract lots of (paying) tourists. However, as the internet developed, getting access beyond these walls seemed to be much more attractive to most punters, and this brought in a new generation of ISPs who provided internet access only. The early version of this business model involved a flat rate charge (about £10 per month in the UK) on top of the usage (or phone) charges which users incurred. However, in 1998, the ISP market in the UK was transformed (and massively expanded) by the advent of X-Stream and, even more famously successful, Freeserve. These ISPs offered free access, trying to make money by levying usage charges, charging for technical support and exposing their customers to advertising. They often entered into collaborations with consumer brands (the connection between Freeserve and its parent, who own Dixon's, an electrical retailer is, again, the classic example of this), delegating the marketing and consumer support functions to their partner. ISPs with no access charges have, however, recently been challenged by ISPs who offer flat

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rate charges with no usage fees (in the UK, the pioneers were Alta Vista, Breathe, LineOne and NTL, only the last of whom still remains in the market).

Differences in the business model of different ISPs arise not only from different pricing structures, but also from the vast variety of different services that they can offer. These include: web space, web design assistance, registration of domain names, email, bundled in hardware, entertainment and information content of uncountably many types, chat rooms and display forums, financial transactions processing, virus scans, (and largely for business users) numerous wholesale services, hosting of data base driven web pages and dedicated server services. Just at the moment, no one seems to know exactly what ISPs do, much less how they are going to make money from doing it.

Both examples tell the same story, namely that a new technology (like the internet) creates business opportunities for those familiar with what it offers. However, in the absence of an articulated demand by consumers for what is being offered, it is anybody's guess what the right offering should be. With no limit to the number of people interested in making money, there is going to be no effective limit to the number of guesses that potential consumers are exposed to. The consequence, then, is that the market is flooded with lots of different goods and services, sold in lots of different ways.

The Role of Demand, Again

Successful innovations are successful because there is a ready market for them, and that must mean that there is a demand for them. However, if demand is not always—or often—a major driver of innovation (particularly those that result in the creation

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of a new market), if new inventions and innovations are, for the most part, supply pushed, then it is important to ask just what role (if any) demand typically does play in the innovation process. The answer is that there are three roles.

First, demand—inchoate demand that is—often sets broad priorities or goals which guide innovative activity. The onset of AIDS, for example, created a demand for certain types of drugs which altered the research focus of a number of research institutes and firms, even if it was too general a demand to specify exactly what was required. The demands of national defence, oil price crises, and waves of fashion all have much the same effect. As we have seen, when demand pull is driven only by an inchoate demand, it is as likely to call forth a variety of solutions from the supply side as not. However, in some situations, a general demand for something is rapidly succeeded by a demand for that thing which is specific enough to give precise guidelines to innovators. This happens when consumers are very clear about their needs, when they have the technological capabilities to spot where technological trajectories are leading and what they can deliver, and when they have the finance to invest in new product development. It happens when users are also the early suppliers: enthusiasts and hobbyists fall into this category, and they played a major role in the emergence of personal computers (as we will shortly see). 'User led innovations' are much less common than innovations which are pushed up from the supply side, and they are also much less likely to produce a variety of new products or service variants.

The second role that demand plays in the emergence of new technologies is as a selection mechanism. When supply pushes a variety of new products or services onto a market, a choice must be made between them. Since this product variety only appears because demand is inchoate (and not specific enough to

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give precise guidance to innovators), consumers need to develop a more articulated or specific demand for something. The process by which this occurs is something which will occupy us in the following chapters, but it is obvious that it will be a learning process of some sort. That is, consumers will sample from amongst the different product or service variants on offer, tinker with the product and learn its value, match its performance with their gradually better defined sense of need, and communicate the results between themselves and to producers. As part of this process, some of the new product variants will be found wanting, while others will attract the sales and general consumer interest which will warrant further investment in their development. As some variants prosper and others fall away, and as consumers become more sure and better informed both about their wants and the technological possibilities on offer, the innovation (or more accurately, the new product development) process becomes more obviously user led, more focussed and more organized. Demand pull must ultimately prevail (since successful innovations are successful because there is a demand for them), but that may not happen until the latest stages of the product development process.

Demand can play one further role in the emergence of new technologies: namely, that it can affect the timing of their arrival on to the market. In this context, it is worth making a distinction between *invention* and what one might term *implementation*, meaning the decision to take a particular invention to the market. It is clear that there are some times when it is more attractive to take the goods or services which embody a new invention to market. From the point of view of the inventor, it may be that there is only a limited window of opportunity before imitative rivals arrive in which to profit from the invention. The right time to exploit this window is when the market for the invention is

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strong: when it is large and growing, and when buyers are anxious to purchase. More generally, new inventions and innovations are always more likely to be successful (i.e. cover their development, production and launch costs) when the specific demand for the product in question is vibrant, and when there are plenty of buyers willing to pay premium prices for it. It follows, then, that whenever inventors or innovators can freely choose when to introduce their new products to market they will have an incentive to do so when markets are booming rather than when they are contracting or recessed. Amongst other things, this means that the implementation of new inventions may well be pro-cyclical in timing.

Two Caveats

Appealing as it is, the story that we have told in this chapter comes with a health warning, and at the end of the story we are still left with a puzzle.

The health warning is that the story about new markets creation that we have explored here is a little overly technological in character. Not all new markets are created by new technological advances. They are, however, created by new ideas about how to do things, whether these be new technology based or not. New ideas of this type—new business designs, if you will—that meet the needs for which there is a well articulated demand by smart, pro-active buyers are likely to reach the market more or less fully formed, and without all the fuss created by the emergence of supply push technologies. On the other hand, new business designs that are pushed on to an unready or unaware market by proactive entrepreneurs need to be adapted to the real needs of users, needs that users may, as yet, be incompletely aware of.

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Hence, supply pushed new business designs—like supply pushed new technologies—are likely to need to pass through a phase of experimentation, and they will, therefore, emerge from amidst a welter of competing variants launched on to the market at more or less the same time. The fuss and excitement may be much less with new business designs than it is with wonderful new technologies, but it will be there all the same.

The major puzzle is how an inchoate demand for something becomes transformed into a specific, articulated demand for something in particular. At one level, this seems likely to be as much a matter of experience as not. As consumers sample the new good in one or more of its many variants, and as they exchange information about their consumption experiences, they learn about the good—about how to use it, what to use it for and about how much they value the opportunity to use it. Since the experience of any particular individual is likely to be both limited and rather idiosyncratic, it seems clear that this learning process is likely to be (predominately) a social one (a point that we will return to in Chapter 5). However, a puzzle still remains: how exactly does 'it would be nice if . . .' gradually transmogrify into 'it is essential that . . . .' in the minds of consumers? And, since many consumers are risk averse and often display purchasing behaviour that is habit ridden, it seems clear that whatever it is that drives the transformation of an inchoate demand into an articulated one may have very powerful, long lasting effects of consumer behaviour.

And So . . .?

The bottom line, then, is that the ultimate drivers of innovation have a major impact on how and when new technologies (and

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their associated new goods and services) emerge. User driven innovations are brought forth with the active involvement of consumers (or users) whose articulated demand for something in particular provides a clear set of guideposts for new product developers. It is more likely that such demand driven innovation processes will emerge with 'the' new good or service which meets consumers needs than they will generate a range of possible new goods or services which 'might do'. Demand will pull out specific new technologies only when demand is specific enough (and when users are sufficiently committed to the new technologies to act as mid-wives to its development), and that is likely to be more the exception than the rule (at least for most consumer goods).

Most new technologies are, however, pushed up by supply. They emerge from the process by which new scientific knowledge and associated new technologies are uncovered and then explored. If, as we have argued, the pace and direction of innovative activity follows the broad guideposts set out by technology paradigms, the trajectories of technology development will gradually unfold over time, each opportunity creating multiple further opportunities, each path taken leading to further developments. Movements along trajectories may seem ordered only with the benefit of hindsight, but the important point is that they provide an almost autonomous mechanism which generates possible new technologies (and associated goods and services) which might result in the emergence of new markets. And, when they do so, the new markets that emerge are likely to give birth to a small explosion of new product varieties. At the end of each limb or branch of any particular trajectory is a cluster of seeds, any one which ultimately flower into 'the' good or service which comes to define a particular market.

Our next task is to examine just how this comes about.

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