The pattern of development and diffusion of breakthrough communication technologies

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Keywords

Diffusion, Communication, Technology led strategy, Innovation

Abstract

Diffusion of many successful communication technologies, like telephony and television technology, follows an almost perfect S-shaped curve. This curve implies that, after their introduction, subsequent sales of products on the basis of these technologies can be predicted accurately. However, the diffusion of other breakthroughs in communication technologies, like interactive television, videotelephony or broadband mobile communication technology, shows a more erratic pattern. Introduction of these technologies is often postponed or, once introduced, they are quickly withdrawn from the market after the first disappointing results. Rather than distinguishing alternative patterns, this article shows that the S-shaped curve and the more erratic patterns represent subsequent phases in one pattern of development and diffusion of breakthrough communication technologies. Three phases are distinguished in this pattern. Managerial implications of the differences between these phases are discussed. the paper shows that a company trying to introduce a new communication technology has to adopt different strategies in each phase.

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Introduction

The pattern of development and diffusion of several breakthrough communication technologies are analyzed in this article. From the perspective of a company trying to introduce such a technology, it is of vital importance to understand this pattern. In practice, the postponed introduction of universal mobile telecommunications system (UMTS) mobile communication services in diverse countries shows that large telecommunications providers have difficulties in understanding this pattern and adapting their strategies to it. In general, many pioneers trying to introduce a breakthrough technology have had similar difficulties and therefore have left the market (Olleros, 1986).

Breakthrough technologies are characterized by a discontinuous advance in technology and by the emergence of new markets (Garcia and Calantone, 2002)[1]. The discontinuous advance in technology means that attainable price/performance ratios are altered dramatically, or that new kinds of performance are possible (Tushman and Anderson, 1986). The emergence of new markets means that, rather than just substituting technologies in existing markets, new combinations of actors on the supply and the demand side of the market are formed during the process of development and diffusion. Telegraphy, telephony, television, and mobile communication technology are considered breakthrough communication technologies. At the time of their invention, they supported entirely new ways of communication. Diffusion of these technologies required new infrastructures, new procedures, new alliances between organizations, new customer segments and so on. Along with their diffusion, new markets emerged.

The development and diffusion of these technologies have had important consequences for society. In the last 150 years, new communication technologies have changed the way in which we communicate or exchange information. "Technological change has placed communication on the front lines of a social revolution" (Paisley, 1985, p. 35). We have moved from a post-industrial into an information society (Naisbitt, 1984; Rogers, 1986; Toffler, 1980). Communication technology has diffused into business environments (Allen and Scott Morton, 1994) and into private households (Miles, 1988), and both have changed radically. In the previous century we witnessed the diffusion of telephony and mass media such as radio and television. More recently, we have seen the advent of mobile telephony, personal computing and Internet technology. These technologies are the precursors of a new generation of communication technologies still to come. The successful diffusion

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of the "old" communication technologies has certainly had its influence on the expectations regarding the diffusion of the "new" technologies, such as broadband mobile communication.

Diffusion refers to the gradual adoption of an innovation in a market segment or in a society. Most empirical diffusion studies focus on the hardware equipment of new technologies. This means that such studies describe the rate at which a particular product form incorporating the new technology is adopted. The diffusion is often depicted as an S-shaped curve indicating the cumulative percentage of a population that adopts a product in the course of time. The shape illustrates the initial low number of adopters, then the rise of the adoption rate until, finally, the number of adopters approaches a maximum. The rate of adoption is related to the steepness of the diffusion curve, while the potential market is related to the maximum height of the diffusion curve (see Figure 1)[2].

The S-shaped curve seems to be a robust model. When we look at the actual diffusion of the telephone, radio, and television, for example, we can see similar S-shaped curves (Miles, 1988; Rogers, 1986; Williams *et al.*, 1988).

The similarity of the actual diffusion patterns for telephone, radio, and television seems to indicate that predicting diffusion of new communication technologies is straightforward and that the the S-curve provides a perfect model. In practice, however, expectations turn out to be overly optimistic and of a dubious value for many new technologies (Schnaars, 1989; Wheeler and Shelley, 1987). In particular, several of the new communication technologies that have been introduced since 1970, for example Videotex[3] (Bruce, 1988), videoconferencing (Clarke, 1990), and interactive television (Schnaars, 1989), have been confronted with a disappointing number of adopters. The diffusion of some of these communication technologies cannot be captured in a simple S-shaped curve (Easingwood and Lunn, 1992).

The development and diffusion of some well-known technological breakthroughs in communication are described in the section entitled "Phases in the pattern of development and diffusion of breakthrough communication technologies". Subsequently, the notion of the S-curve is extended by distinguishing three phases in the process of development and diffusion of breakthrough technologies. Conclusions and managerial implications for this diffusion pattern will be presented at the end of the paper.

Before the S-curve

We will show that the S-curve has to be extended to capture the pattern of development and diffusion of breakthrough communication technologies like the telegraph, telephone, fax, radio, and television technology. Four aspects of these communication technologies are described:

(1) the time a breakthrough technology is invented;
(2) the process of technical refinement and development of the technology;
(3) the first application of the technology in the market; and
(4) the applications in the market that mark the wide-scale adoption of the technology.

These aspects correspond with the four columns in Table I. Before looking at the table the four aspects will be defined:

Figure 1 Examples of S-shaped diffusion curves

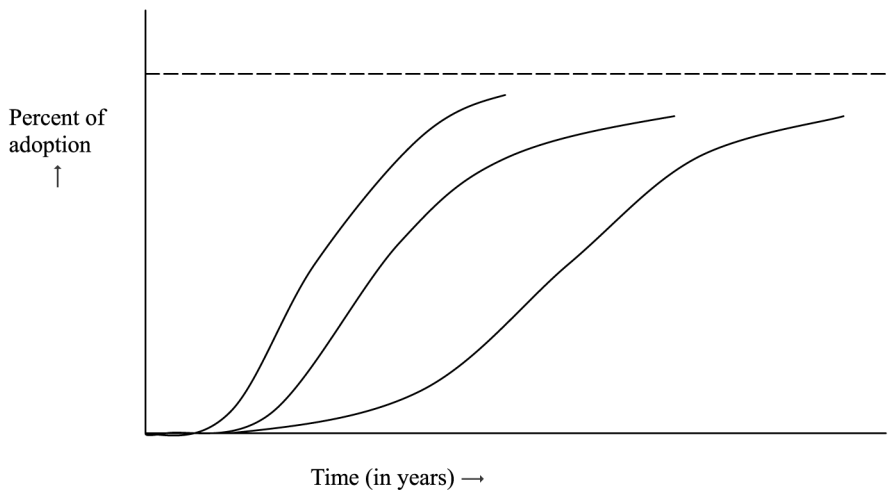

Table I Invention, technical refinement and application of breakthrough communication technologies

			Diffusion	
Technology	**Date of invention**	**Technical refinement**	**First applications**	**Widely used application**
Telegraph	1837: Morse in US and Steinhill in Germany demonstrate telegraph 1837: Cook and Wheatstone get a patent in the UK	Number of words/ minute increases 1855: the first letter print telegraph 1874: multiple use of one channel 1919: introduction of telex	1844: first telegraph line in the USA Applications: Railroad traffic control Transmission of news	Public use of telegraphy. Stations in post-offices and organizations. Diffusion takes off during the 1850s. International standards after 1865
Fax	1843: first patent granted to Bain 1847: first image transfer	1902: experimental fax transmission[a] of photographs using optical scanning Speed and quality of transmission improves steadily between 1902 and now	1863: first commercial fax system between Lyon and Paris Applications 1906: fax between newspaper offices Sending weather charts to ships	After 1960 fax becomes popular in Japanese (and after 1970) in European business
Telephone	1863: transmission of sound by Reis 1876: telephone demonstration by Bell	1878: improvement of the microphone Introduction of better cables and amplifiers increases the range	1877: burglar alarm service in the USA Toy for adults Internal communication in companies; local communication in cities	More connections after First World War. After Second World War, diffusion takes off
Radio	1896: first radio by Mercian (Italy) and Popoff (Russia) 1898: first demonstration of radio	Development of crystal detector and later electron tube 1957: first transistor radio from Philips	From 1900 on: communication with ships, airplanes; radio amateurs built their own radio 1897: radios are built commercially	1932: 1 million radios are sold. Radio became a mass medium
Television (TV)	1925: mechanical TV demonstration by Jenkins (US) and Bain (UK) 1926: mechanical TV demonstration by Baird 1929: electronic TV demonstration	1928: first trans-Atlantic transmission 1929: demonstration of a color TV Invention of teletex 1929-1935 experimental broadcasting in UK	1935: regular broadcasting service in Germany 1936: first broadcast in The Netherlands	After Second World War the diffusion of TV takes off (USA). TV became a mass medium

Note: [a] Fax contact in a most rudimentary form was possible after the invention of the telegraph. An image on a sheet of paper is divided into many white and black dots. A telegraph can transfer pulses. Assume a long pulse is a black dot and a short pulse is a white dot. A telegraph can then transfer the image dot by dot, and line by line, by sending the pulses that correspond with the image

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(1) *The time a breakthrough technology is invented.* We will define the invention as the first demonstration of a technological breakthrough. The idea that an invention can be unmistakenly attributed to one inventor at a specific moment in time has been questioned by some authors (Sahal, 1981; Agarwal and Bayus, 2002). An illustration of their point of view is the fact that many inventions are made independently and almost simultaneously by different persons. In these cases, we will give the names of multiple inventors. Furthermore, when an evolutionary perspective on development of technology is adopted, it is hard to distinguish an invention among a line of gradual improvements in the technology (Bassala, 2001). An invention can be defined in various ways, ranging from the moment an idea is presented, a patent is filed, the principle of a technological breakthrough is demonstrated, or the first pilot application of a breakthrough technology is started. When possible, the time a patent was granted, or the time a technology was first demonstrated in public is shown in Table I.
(2) *The process of technical refinement and development of the technology.* Some hallmarks in the development of the technology after the invention are listed in Table I.
(3) *The first applications of the technology in the market.* The (timing of) the first known commercial applications of the breakthrough technologies is described in Table I. A pilot in the market without a commercial goal is not considered to be a first application of the technology.
(4) *The applications in the market that mark the wide-scale adoption of the technology.* Although the mainstream applications for each of the breakthrough technologies are well-known, it is hard to define precisely (the time of) "wide-scale adoption". We will, therefore, indicate in which decade the diffusion of products, on the basis of the breakthrough communication technologies, increased significantly.

A first conclusion from our analysis is that the average time from invention to the first market introduction is between seven and ten years for these breakthrough communication technologies. The time from invention to the first market introduction is seven and 16 years for the telegraph and fax technology, respectively. For the telephone, this time interval is either one or 14 years, depending on the question as to whether 1863 or 1876 is considered the date for the invention of the telephone. For radio technology this time interval is about four years and for television technology it is either six or ten years, depending on the question as to whether the demonstration of a mechanical television system in 1925 or the demonstration of an electronic television system in 1929 is considered to be the date for the invention of television.

A second conclusion from our analysis is that it generally takes a decade or more after the first introduction of a communication technology into the market before diffusion takes off. Establishing when a technology is first introduced may be difficult. Establishing when its diffusion takes off is even more difficult. However, even rough estimates of the intervals between first introduction and a significant increase in diffusion rates reveal that they are considerable. The telegraph was first introduced in 1844, its diffusion took off in the 1850s when increasing numbers of telegraph stations were opened and telegraphy became a public service. This shows a time interval between introduction and diffusion take off of more than six years. Somewhat longer time intervals can be found for the telephone, radio and television (at least a decade each). Diffusion of the fax took off about a century after the first market introduction. Fax transmission was introduced into the market in 1863, but significant increases in diffusion rates would last until the 1960s.

A third conclusion is that, directly after their introduction, most of the communication technologies are used in small-scale specific applications. These applications are totally different from the more wide-scale and well-known applications. The first telephones, for example, were used as a burglar alarm, as a toy, and as an appliance for internal communication in companies. Telephony was also used by the local telegraph office in order to transfer telegrams to clients, rather than the telegram being delivered to the home or office. The last application seems to have paved the way for wide-scale telephony since lines to the telegraph office could be connected in pairs to establish a local area telephone conversation. In due course, the telegraph office became a telecommunication office. Similar small-scale applications can be found for the other communication technologies.

Implications of these conclusions for the pattern of development and diffusion of breakthrough communication technologies

The fact that it takes some years after the invention of a technology before the first product is introduced in the market (conclusion 1) and the fact that it takes at least an additional decade before the diffusion of a successful communication technology takes off (conclusion 2), does not imply that the S-shaped diffusion curve is an inappropriate model. It suffices to say that the

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curve generally starts about a decade after the invention of a technology and that the curve is stretched at the beginning of the diffusion process.

However, the fact that the first small-scale applications of a communication technology often differ from the later wide-scale application (conclusion 3), has important implications. It implies that the early stage of the diffusion process is hardly captured in a single S-shaped curve. Each of the small-scale applications can be described in a separate diffusion curve. These small-scale applications have an important role in stimulating wide-scale diffusion of the technology.

Illustration that the S-shaped diffusion curve is a somewhat limited model

Perhaps the best way to illustrate that the S-shaped diffusion curve does not always capture the diffusion pattern of a technology, is to look at facsimile technology. The first patents for the fax were granted in 1843, the first successful fax transmission was completed in 1902 by Jenkins (Coopersmith, 1993). It took a long time before the fax technology was introduced in the market. At first, the fax was used to transfer weather charts to ships. Shortly afterwards, in 1911, a fax was used to send pictures for newspapers between Berlin, London and Paris:

> Less successful were the attempts in the late 1930s by newspapers and their radio stations to broadcast newspapers. Enthusiasts promoted facsimile radio receivers that could bring newsprint into homes [...] (Coopersmith, 1993, p. 46).

After the first market introduction the diffusion is characterized by periodic introduction, decline and reintroduction into the marketplace. In fact, the actual S-shaped diffusion pattern really began decades later around 1960 in Japan. Around that time the telex, an appliance by which a limited number of alpha-numeric symbols could be transmitted through the ether, became more popular. Japanese, due to its large number of symbols, was unsuited to telex relay, the fax, however, was able to transfer all kind of signs and therefore became very popular at that time in Japan. Some years later, around 1970, the fax began to diffuse into business organizations in Europe.

In summary, this paragraph shows that the S-shaped diffusion curve is preceded by important developments:

- The S-curve does not show the relevant developments just after the invention of a breakthrough communication technology. The first products or services incorporating the technology are invariably introduced into the market some years after the invention.
- The S-curve does not show the erratic patterns that can be witnessed after the first market introduction of a product or service incorporating the breakthrough communication technology.

Phases in the pattern of development and diffusion of breakthrough communication technologies

The S-shaped diffusion model is meant to describe the diffusion of product forms rather than technologies (Dosi, 1982; Clark, 1985). Based on an analysis of four cases, we developed an extended model to describe the development and diffusion of a breakthrough communication technology. Three phases in this process will be distinguished, the last of which is represented by the well-known S-shaped curve (see Figure 2).

The beginning and the end, the average length, and the market actors and factors that generally play a major role, will be described for each phase.

The innovation phase

The first phase, which we will call the innovation phase, comprises the period from invention of a technology up to the first market introduction of a product incorporating the technology. After the invention, a technology is available in some rudimentary form. In the innovation phase this technology is transformed into a marketable "product"[4].

The length of this phase can vary considerably. We found periods between one (for the telephone) and 16 years (for the fax) between invention and market introduction for five breakthrough communication technologies. Mansfield (1968) claimed that the average time from invention to the start of the commercial development process is about ten to 15 years. From the start of this process up to the market introduction, again, a couple of years elapse. Utterback and Brown (1972) estimate that, on average, this takes an additional five to eight years. So, according to these authors the period from invention to the first market introduction comprises 15-23 years. Agarwal and Bayus (2002) found an average period of 28 years between invention and commercialization for 30 breakthrough innovations from diverse industries. The large differences in these estimates can be attributed to multiple factors. First, differences can be attributed to the type of industry (Mansfield, 1968). Commercialization takes a relatively long period in the pharmaceutical industry compared to the fast-moving goods industry, for example. Second, we found considerably different periods for technologies in one industry. The radio, for example, was

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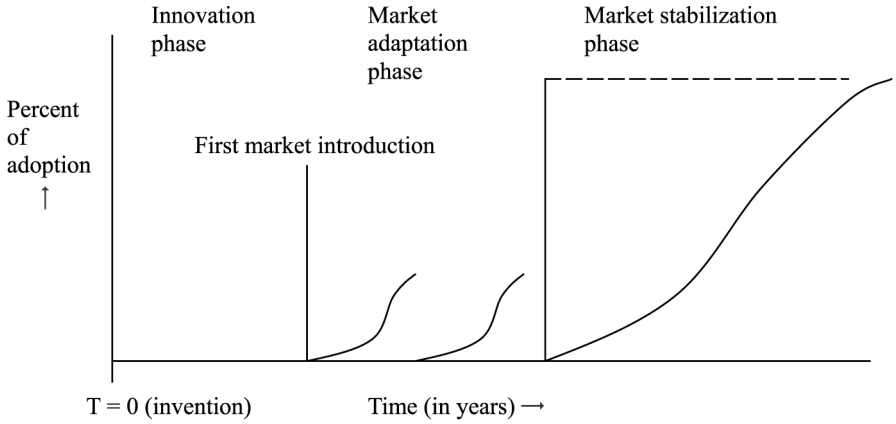
Figure 2 Three phases in the diffusion process



introduced less than four years after its invention whereas the fax was introduced about 16 years after its invention. Third, the length of the time interval depends on the specific definition of invention. We found time intervals from invention to commercialization for the telephone that varied from one to 14 years depending on the question as to whether the demonstration of Reis (in 1863) or the demonstration of Bell (in 1876) is considered to be the date of invention of telephony.

During the innovation phase, organizations like research institutes and universities, in many cases co-funded by the government, play the central role. To attract potential consumers, the reliability and performance of the technology often has to increase whereas the price of the technology has to decrease. Potential applications have to be found and new products and services have to be developed on the basis of the technology before it can be introduced into the market. Although in this phase no products or services based on the breakthrough technology will be introduced into the market, other types of market mechanisms can be witnessed. In this phase, a good position in the market of supply and demand for reseach funds and researchers is essential for success.

The market adaptation phase

The second phase, referred to as the market adaptation phase, begins after the first market introduction of a product on the basis of the breakthrough technology and ends when the diffusion of this product takes off. After the first introduction, instead of a smooth S-curve, in practice an erratic process of diffusion may occur. In this situation the market is unstable and, as Clark (1985) puts it, in a "fluid state". The diffusion is characterized by periodic introduction, decline and re-introduction of multiple products in multiple small-scale applications. Such a pattern is not uncommon for communication technologies (Carey and Moss, 1985).

We estimated that this phase comprises more than a decade for the five breakthrough communication technologies. An extended period is also found for other technologies (Mansfield, 1968; Utterback and Brown, 1972):

> A review of past forecasts for video recorders and microwave ovens illustrates the length of time required for even the most successful innovations to diffuse through a mass market [...]. Both took more than twenty years to catch fire in a large market (Schnaars, 1989, p. 120).
>
> Most innovations, in fact, diffuse at a surprisingly slow rate (Rogers, 1983, p. 7).

Agarwal and Bayus (2002) indicate that this phase, on average, lasted 18.7 years for breakthrough technologies invented before the Second World War.

Companies try to establish a standard with their product during the market adaptation phase, and competition may become intense. The wide-scale diffusion of a breakthrough communication technology, however, requires coordination in the market among competitors, potential consumers, producers of complementary products or services and suppliers. In practice, this cooperation is hampered by the chicken-and-egg problem. Suppliers of complementary products and services demand a critical mass of users before they consider entering the market, yet these suppliers are desperately needed to establish this critical mass of users in the first place. Finally, since the technology quickly develops during this phase, and since dominant market applications have not yet been discovered, technology standards and dominant product designs mostly still have to be established, which means that this phase tends to have a fierce and rather Darwinistic character. In the struggle to produce the fittest products and

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services, many companies become extinct (Olleros, 1986).

The market stabilization phase

The third phase, referred to as the market stabilization phase, begins when the diffusion of a product on the basis of the breakthrough communication technology takes off and ends when the technology is substituted. Clark (1985) refers to this phase as a more or less rigid state. The rigidity refers to the fact that dominant product designs and applications emerge from the second phase. In this third phase, diffusion of a product form may be depicted in a single diffusion curve, which mostly resembles an S-curve when cumulative adoption is depicted in the course of time. Different curves have been found (e.g. Rink and Swan, 1979; Tellis and Crawford, 1981), but in these cases no phases were distinguished in the diffusion pattern, which means that some of the divergent patterns may be attributed to the fact that the diffusion was still in the market adaptation phase.

The diffusion of the five breakthrough technologies, i.e. television, radio and telephone technology, is still continuing. While for the telegraph and the fax, the period from the take-off to substitution took about 100 and 30 years respectively. The length of this period, also referred to as the technology life cycle, can vary from a couple of years up to centuries (Jain, 1985).

More or less standard strategies can be pursued in the market stabilization phase. During this phase, companies strive for typical goals like a large market share, large profits and so on. During the market stabilization phase the technology and resulting products and services will be improved constantly, although the dominant design will essentially remain the same. Several features were added to the television during the market stabilization phase, for example, that in due course became part of the standard product (Thölke, 1998). Color televisions replaced black-and-white sets, teletext was added, televisions became portable, and, to attain economies of scale yet remain flexible, modular product designs or product platforms can be formed. Companies can also strive to intensify the use of a product in existing markets and thereby increase market potential. The time that the market potential for television was formed by the number of consumer households is long past, currently, television sets are commonly installed in each room of a home, in cars, in caravans and boats, in hospitals and so on. So, the level of the market potential has shifted considerably during the market stabilization phase. Companies also segment the market and offer differentiated products for each segment.

Some of the general differences between the three subsequent phases in the process of development and diffusion of breakthrough communication technologies are summarized in Table II. The first row indicates the beginning and the end of each phase. The second row lists some findings regarding the length of each phase. In the third and fourth row, the typical kind of market actors and factors as well as typical market mechanisms in each phase, are described.

Conclusions and managerial implications

After investigating the pattern of development and diffusion of five breakthrough communication technologies, we conclude that the well-known S-shaped diffusion curve in fact represents just one phase of this pattern. Three phases are distinguished in this pattern. First, the innovation phase covers the period from the invention of a breakthrough communication technology up to the first market introduction of a product on the basis of the technology. In this phase, which lasts about a decade, the technology is turned into a marketable product. Second, the market adaptation phase comprises the period from the first market introduction up to the point where the diffusion takes off. This phase, also lasting about a decade, often shows an erratic pattern of diffusion with the introduction, withdrawal and re-introduction of various products on the basis of the breakthrough technology. Third, the market stabilization phase begins when a dominant product design, i.e. a basic product form that turns out to be the standard for several years, emerges and the diffusion of this product takes off. The third phase ends when the product based on the breakthrough technology is substituted and sales drop.

In the introduction we stated that the patterns of development and diffusion of several new communication technologies like Videotex, videoconferencing, and interactive television are difficult to capture in a simple S-shaped curve. These patterns diverge considerably from the S-shaped patterns of diffusion of some of the older communication technologies like the telegraph, telephone, fax, radio, and television technology. At first sight these results imply that different patterns have to be distinguished for different types of communication technologies. This article shows, however, that the S-shaped pattern of diffusion of the old technologies is preceded by similar erratic patterns of diffusion. The divergent diffusion patterns of the newer communication technologies are therefore attributed to the fact that these

Table II Differences between the three subsequent phases in the process of development and diffusion of breakthrough communication technologies

	Phase		
Characteristics	**Innovation phase**	**Market adaptation phase**	**Market stabilization phase (the S-shaped pattern)**
Begin and end of the phase	From invention of a technology up to the first market introduction of a product incorporating the technology	Begins after the first market introduction of a product on the basis of the breakthrough technology and ends when the diffusion of this product takes off	Begins when the diffusion of a product on the basis of the breakthrough communication technology takes off and ends when the technology is substituted
Length of the phase	Length can vary considerably (one to 30 years), but on average comprises seven to ten years	Length can vary considerably, but mostly comprises a decade or more	Length coincides with the life cycle of a product category
Market actors and factors in the phase	Individual inventors and entrepreneurs, R&D institutes, universities, and governments (in the role of provider of research funds)	Potential competitors working on the same type of product-technology. Innovative consumers and lead users. Market actors with products and services that are complementary to the technology. Government in the role of lead user or regulator	Early adopters up to the late majority of consumers, competitors of the same product or service, suppliers and organizations providing complementary products, and services
Market mechanisms	Supply and demand for research funds and excellent researchers	Substitution of alternative product technologies Chicken-and-egg problem Critical mass effects Finding the best product-market combinations on the basis of the technology Establish or reinforce standards Supply and demand for complementary products and services	Product life cycle mechanisms Gradual substitution by new product technologies

technologies are in the market adaptation instead of the market stabilization phase.

The idea that the development and diffusion of breakthrough communication technologies follows a pattern with three distinct phases rather than a single S-shaped curve has important management implications.

The findings indicate that commercializing a breakthrough communication technology is a matter of long endurance. The time from the invention of such a technology up to the point where diffusion of the technology takes off, on average covers about two decades. An implication of this finding is that small companies, which essentially focus on one technology, may be confronted with cash-flow problems during this period. Large companies and governmentally subsidized organizations may be in a better position to survive this period.

The findings also indicate that two distinct phases can be distinguished before the diffusion of a product based on a breakthrough technology takes off. The fact that these phases differ from the S-shaped diffusion curve has important managerial implications. Different market actors and factors, and different market mechanisms in each phase require different strategies on behalf of the companies trying to commercialize a breakthrough communication technology.

Suppose that an invention results from a basic research project in a large company. Such a research and development (R&D) project, which is often mono-disciplinary, is confronted with two intra-company market mechanisms: supply and demand for top researchers and supply and demand for research budgets. The invention in many cases heralds a period of new funds. Instead of continuing the research activities, a switch is required to start up innovation activities. The latter type of activity usually requires multi-disciplinary cooperation among various actors outside the R&D department of a company. For smaller companies, a similar switch of activities is required. In the pharmaceutical industry, for example, many small biotechnology research companies look for an alliance with a large company to commercialize an invention or novel drug. After the invention, project members from more disciplines are required to develop the new drug and to organize the required safety trials before the drug is accepted for commercial use. So, after the invention, when the innovation phase begins, a switch is required in the strategy.

Similar switches in strategy are required during the transition from the innovation to the market adaptation phase and finally to the market stabilization phase. These findings indicate that it is important to establish the position of the

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technology in the pattern of development and diffusion and that strategies should be tailored to this position.

The differences between the market adaptation and market stabilization phase also have important managerial implications. One of these implications is the different scale and approach to production and marketing that is required in the market adaptation and market stabilization phase. When a product is introduced in the market stabilization phase, once a critical mass of users is attained, companies typically try to attain a large market share by striving for large-scale production and marketing. In this scenario, these companies try to establish economies of scale in production and marketing and to attain a dominant position. However, when a product is introduced during the market adaptation phase, the introduction probably marks the beginning of an erratic pattern of introduction, withdrawal and subsequent re-introduction of the technology. In this scenario, a strategy of large-scale production and marketing may have dramatic results for a company. Cooper and Smith (1997) describe an example of a company that built a large, fully-automated plant to produce germanium transistors at the time when silicon transistors became the standard. There is a large risk of betting on the wrong standard when a company starts large-scale production during the market adaptation phase. Rather than striving for scale, in this scenario a company should strive for a quick learning process to establish mainstream applications and dominant product designs in the market and to keep pace with technological developments. A learning strategy requires small-scale and flexible ways of production and marketing, enabling prompt reactions (i.e. new products) to market and technological developments (Sanchez and Sudharshan, 1992; Lynn *et al.*, 1996).

Another implication of the differences between the market adaptation and market stabilization phase is that different types of alliances should be sought in each phase. In the market adaptation phase the main concern is to establish a market for a new product category on the basis of a breakthrough technology. In many cases establishing a new market means that an existing market with well-known products, alliances among market actors, and habits among consumers, has to be changed or even replaced by this new market. Therefore, to establish this new market, efforts are united among potential competitors and companies of complementary products and services. An example of this type of cooperation is described by Bijker (1992). The electricity utilities and General Electric, an incandescent light bulb producer, formed an alliance during the 1930s in the USA. In a united effort, both companies tried to develop the market for electric lightning. However, when the market for electric lightning grew, and different types of lightning were developed (e.g. the fluorescent lamp) the cooperation was stopped since the interests of the light bulb producers, i.e. to develop and sell energy efficient lamps, no longer coincided with the interests of the electric utilities that wanted to supply more electricity. So, during the innovation and market adaptation phase many pre-competitive alliances are established in an effort to establish a new market. Yet, when the market is there, the goal is to strive for market share at the expense of direct competitors and previous alliances are often abandoned and replaced by other types of alliances.

The erratic pattern of the market adaptation phase has an important managerial implication: it makes it difficult to predict the market potential of products based on breakthrough technologies. Standard market analysis techniques, categorized as consumer analysis, expert analysis and data analysis (Armstrong, 2001; Taschner, 1999) are generally considered to be unreliable for assessing the market potential of major product innovations based on breakthrough technologies (Christensen, 1997; Lynn *et al.*, 1986; Ortt, 1998; Ortt and Schoormans, 1993; Tauber, 1974; Veryzer, 1998). Consumer research requires that potential consumers are willing and able to evaluate (concepts of) the product on the basis of a breakthrough technology. In many cases they are not able to do so since they do not understand the product and its consequences for their daily life. Expert analysis and data analysis have in common that they are based on information from the past that can somehow be extrapolated. In the market adaptation phase especially this is rarely the case. To put it differently: that the market adaptation phase will occur may be predictable to some extent, but how it will occur and what will be the result, is less predictable.

Finally two questions remain:

(1) Do breakthrough communication technologies always diffuse in the same pattern?
(2) When do the findings from this article apply?

This article has shown that many breakthrough communication technologies develop and diffuse in a similar pattern. In some cases, the phases of the diffusion process can have quite different lengths, or phases can even be omitted. Once a breakthrough communication technology can be applied in an existing infrastructure and can benefit from prevailing procedures, organizations and so on, it can be hypothesized that the period from invention up to wide-scale diffusion of this

technology will be relatively short compared to a breakthrough technology that requires new infrastructures, procedures and organizations. While with a technological breakthrough that can build on a previous dominant product design, like the transistor that replaced vacuum tubes in radios, it can be hypothesized that the market adaptation phase will probably be relatively short or non-existent. So, the three-stage pattern is a general pattern in which numerous variations can be expected.

The findings in this article particularly apply when the:

- technological change represents a technological breakthrough;
- technology can be incorporated in multiple product forms, which can be considered major innovations from the perspective of potential consumers;
- technology can be applied in multiple market applications; and
- diffusion has to cope with considerable externalities, such as a network, in the case of telecommunication appliances.

In conclusion, we think that the three-stage process of development and diffusion of breakthrough technologies explains many controversies with regard to diffusion. This process has important managerial implications for companies that want to introduce breakthrough communication technologies in the market.

Notes

1 Garcia and Calantone (2002) define different types of innovations rather than technologies.

2 Some products are adopted by a household, e.g. the first telephones, while other products are adopted by an individual, e.g. the mobile phone. So the "adopter" may refer to different units. The potential market refers to the maximum number of adopters that can reasonably be expected. In some cases the potential market for a product in a country is considerably smaller than the number of individuals or households in that country. That is the case if many of these individuals or households will for some reason never adopt the product.

3 Videotex is an interactive information and shopping service which can be used by connecting a small terminal with the ordinary telephone infrastructure. Videotex was invented around 1973.

4 The difference between invention and innovation is described by several authors (e.g. Dosi, 1982; Mansfield, 1968; Utterback and Brown, 1972; Weiss and Birnbaum, 1989). The basic difference is that an invention is just an idea in some form, a sketch, a model or a kind of prototype, while an innovation is something that is actually marketable. In specific cases the distinction may prove somewhat fuzzy, we therefore decided to combine the activities of invention and innovation in one phase: the innovation phase.

References

Agarwal, R. and Bayus, L. (2002), "The market evolution and sales takeoff of product innovations", *Management Science*, Vol. 48 No. 8, pp. 1024-41.

Allen, T.J. and Scott Morton, M.S. (1994), *Information Technology and the Corporation of the 1990s*, Oxford University Press, New York, NY.

Armstrong, J.S. (2001), *Principles of Forecasting: A Handbook for Researchers and Practitioners*, Kluwer Academic Publishers, Dordrecht.

Bassala, G. (2001), *The Evolution of Technology*, Cambridge University Press, Cambridge.

Bijker, W.E. (1992), "The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage", in Bijker, W.E. and Law, J. (Eds), *Shaping Technology/Building Society*, The MIT Press, Cambridge, MA, pp. 75-102.

Bruce, M. (1988), "Home interactive telematics: new technology with a history", in Van Rijn, F. and Williams, R. (Eds), *Concerning Home Telematics (Proceedings of the IFIP TC 9 Conference on Social Implications of Home Interactive Telematics, Amsterdam, June 1987)*, Elsevier Science Publishers, Amsterdam, pp. 83-93.

Carey, J. and Moss, M.L. (1985), "The diffusion of telecommunication technologies", *Telecommunications Policy*, Vol. 6, June, pp. 145-58.

Christensen, C.M. (1997), *The Innovator's Dilemma*, Harvard Business School Press, Boston, MA.

Clark, K.B. (1985), "The interaction of design hierarchies and market concepts in technological evolution", *Research Policy*, Vol. 14 No. 5, pp. 235-51.

Clarke, A.M. (1990), "Is the failure of videoconferencing uptake due to a lack of human factors or poor market research?", *Proceedings of the 13th International Symposium on Human Factors in Telecommunications*, pp. 33-140.

Cooper, A.C. and Smith, C.G. (1997), "How established firms respond to threatening technologies", in Tushman, M.L. and Anderson, P. (Eds), *Managing Strategic Innovation and Change*, Oxford University Press, Oxford, pp. 141-55.

Coopersmith, J. (1993), "Facsimile's false starts", *IEEE Spectrum*, February, pp. 46-9.

Dosi, G. (1982), "Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change", *Research Policy*, Vol. 11 No. 3, pp. 147-62.

Easingwood, C.J. and Lunn, S.O. (1992), "Diffusion paths in a hightech environment: clusters and commonalities", *R&D Management*, Vol. 22 No. 1, pp. 69-80.

Garcia, R. and Calantone, R. (2002), "A critical look at technological innovation typology and innovativeness terminology: a literature review", *Journal of Product Innovation Management*, Vol. 19 No. 2, pp. 110-32.

Jain, S.C. (1985), *Marketing Planning and Strategy*, South-Western Publishing, Cincinnati, OH.

Lynn, G.S., Morone, J.G. and Paulson, A.S. (1996), "Marketing and discontinuous innovation: the probe and learn process", *California Management Review*, Vol. 38 No. 3, pp. 8-37.

Mansfield, E. (1968), *Industrial Research and Technological Innovation: An Econometric Analysis*, Longmans, Green & Co., London.

Miles, I. (1988), *Home Informatics. Information Technology and the Transformation of Everyday Life*, Pinter, London.

Naisbitt, J. (1984), *Megatrends: Ten New Directions Transforming Our Lives*, Warner Books, New York, NY.

Olleros, F. (1986), "Emerging industries and the burnout of pioneers", *Journal of Product Innovation Management*, Vol. 3 No. 1, pp. 5-18.

Ortt, J.R. (1998), "Videotelephony in the consumer market", PhD dissertation, Technical University Delft, Delft.

Ortt, J.R. and Schoormans, J.P.L. (1993), "Consumer research in the development process of a major innovation", *Journal of the Market Research Society*, Vol. 35 No. 4, pp. 375-88.

Paisley, W. (1985), "Communication in the communication sciences", in Dervin, B. and Voght, M.J. (Eds), *Progress in the Communication Sciences*, Vol. 5, Ablex, Norwood, NJ.

Rink, D.R. and Swan, J.E. (1979), "Product life cycle research: a literature review", *Journal of Business Research*, Vol. 78 September, pp. 219-42.

Rogers, E.M. (1983), *Diffusion of Innovations*, The Free Press, New York, NY.

Rogers, E.M. (1986), *Communication Technology: The New Media in Society*, The Free Press, New York, NY.

Sahal, D. (1981), *Patterns of Technological Innovation*, Addison-Wesley, Reading, MA.

Sanchez, R. and Sudharshan, D. (1992), "Real-time market research: learning-by-doing in the development of new products", *Proceedings of the International Product Development Management Conference on New Approaches to Development and Engineering*, Brussels, pp. 515-30.

Schnaars, S.P. (1989), *Megamistakes: Forecasting and the Myth of Rapid Technological Change*, The Free Press, New York, NY.

Taschner, A. (1999), "Forecasting new telecommunication services at a 'pre-development' product stage", in Loomis, D.G. and Taylor, L.D. (Eds), *The Future of the Telecommunication Industry: Forecasting and Demand Analysis*, Kluwer Academic Publishers, Dordrecht, pp. 137-65.

Tauber, E.M. (1974), "How market research discourages major innovation", *Business Horizons*, Vol. 17, pp. 22-6.

Tellis, G.J. and Crawford, C.M. (1981), "An evolutionary approach to product growth theory", *Journal of Marketing*, pp. 125-34.

Thölke, J.M. (1998), "Product feature management", PhD dissertation, Technical University Delft, Delft.

Toffler, A. (1980), *The Third Wave*, Bantam Books, New York, NY.

Tushman, M.L. and Anderson, P. (1986), "Technological discontinuities and organizational environments", *Administrative Science Quarterly*, Vol. 31 No. 3, pp. 439-65.

Utterback, J.M. and Brown, J.W. (1972), "Monitoring for technological opportunities", *Business Horizons*, Vol. 15, October, pp. 5-15.

Veryzer, R.W. (1998), "Key factors affecting customer evaluation of discontinuous new products", *Journal of Product Innovation Management*, Vol. 15 No. 2, pp. 136-50.

Weiss, A.R. and Birnbaum, P.H. (1989), "Technological infrastructure and the implementation of technological strategies", *Management Science*, Vol. 35, 8 August, pp. 1014-26.

Wheeler, D.R. and Shelley, C.J. (1987), "Toward more realistic forecasts for high-technology products", *The Journal of Business & Industrial Marketing*, Vol. 3, Summer, pp. 55-63.

Williams, F., Rice, R.E. and Rogers, E.M. (1988), *Research Methods and the New Media*, The Free Press, New York, NY.