Chapter 2

Understanding the Pre-diffusion Phases

J. Roland Ortt

2.1 Introduction

The development and diffusion of high-tech product categories is a fascinating topic. The managerial relevance and the complicated nature of the topic — how to turn inventions into successful products — have inspired scientists from diverse disciplines to examine technological innovation (for an overview, see Rosenberg, 1982; Gopalakrishnan and Damanpour, 1997; Nieto, 2003). The invention of new technological principles, their application in new product categories, and the subsequent diffusion of products based on these principles often result in an erratic process stretching out for decades. The case of the television illustrates the kind of process that can be expected prior to the emergence of the well-known S-shaped diffusion curve (see Exhibit 2.1).

Many individuals, companies and organizations are usually involved in the process of development and diffusion of high-tech product categories. Some of the pioneering companies that set these processes in motion turn out to be very successful, but it is remarkable that many of them fail before their products manage to reach a mass market (Tellis and Golder, 1996; Olleros, 1986). Tellis and Golder (1996) focus on pioneers of successful new high-tech product categories. They estimate that 47% of these pioneers demise before

Exhibit 2.1. The Pre-diffusion Phases for Television

During the first three decades of the 20th century, essential components to enable television were developed by many different inventors. The first rudimentary television systems were demonstrated almost simultaneously in the late 1920s by different inventors such as Baird in the UK (1926), Tihanyi from Hungary (1926) and Farnsworth in the US (1927). Baird made an electromechanical television system, whereas Farnsworth and Tihanyi created full electronic systems. The first experimental broadcasting trials appeared in 1928 in the US and during 1929–1935 in the UK. From 1935 on, a regular broadcasting service began almost simultaneously in Germany and the UK. In Germany, television was first a kind of semi-public small-scale service provided in dedicated television theaters and later on in military field hospitals. Television sets were commercially sold from 1939 on by RCA in the US. Large-scale diffusion, represented by the S-shaped diffusion curve, would start in the US after the Second World War.

Sources: Encyclopedia Britannica (2004); http://www.tvhandbook.com/History/History_timeline.htm/; http://www.bvws.org.uk/405alive/history/revisionist_history.html/; http://www.nyu.edu/classes/stephens/History%20of%20Television%20page.htm/; http://www.earlytelevision.org/german_prewar.html/.

their technological innovations reach the mass market. Olleros (1986) refers to this phenomenon as "the burnout of the pioneers".

This chapter will focus on the phases prior to large-scale production and diffusion, referred to as the pre-diffusion phases. In practice, the S-shaped diffusion curve invariably starts several years after the first attempt to introduce versions of a specific product category in the market (Ortt and Schoormans, 2004). The television case illustrates that these pre-diffusion phases can last decades. The empirical data from Tellis and Golder (1996) and Olleros (1986) show the devastating effect of these phases on the pioneers.

In diffusion research, Rogers (2005) noticed an almost complete lack of attention to the pre-diffusion period. By ignoring this period, mainstream diffusion research seems to imply that large-scale diffusion starts directly after the market introduction of a new high-tech product. Indicating that this large-scale diffusion can be represented by an S-shaped diffusion curve also implies that the diffusion process is quite predictable. A systematic study of the pre-diffusion period is likely to provide useful insight and lead to more realistic business plans.

In this chapter, the pre-diffusion phases for high-tech product categories will be explored. The term "new high-tech product category" refers to a new combination of a technological principle and a specific functionality (at the time of invention). In other words, in these categories, the technological principle is new, the functionality is new, or both are new. Examples of new high-tech product categories, at the time of their invention, were digital photography (the digital imaging technology used to make photographs) and video cassette recorders (VCRs) (the technology to store data on a tape with magnetized particles that is used to store and later replay video material).

This chapter will address several issues related to the pre-diffusion phases. In Section 2.2, we will discuss some of the theories and ideas that describe the development and diffusion of high-tech product categories over time. In Section 2.3, the pre-diffusion phases will be defined, while their length for high-tech product categories will be discussed in Section 2.4. The causes and consequences of these phases will be explored in Sections 2.5 and 2.6, respectively. Conclusions and discussions are in Section 2.7.

2.2 Patterns in Technological Innovation and Diffusion

Ever since the effect of the Industrial Revolution was felt in society, i.e. from the 1830s on (Hobsbawn, 1962), scientists from different disciplines have investigated technology innovation and diffusion. For example, in the 1840s Marx was already a careful student of technological progress (for a discussion, see Chapter 2 in Rosenberg, 1982). Marx was ahead of his time in various respects. He described technology as an endogenous variable and a gradual process of improvement, rather than the exogenous flash of an inventor's ingenuity that some contemporary writers later on would make us believe. Subsequently, various schools of economists (for an overview, see Deane, 1978; Ekelund and Hébert, 1983; Landreth and Colander, 1994), sociologists (such as Bijker, 1995), historians of technology (for a short overview, see Chapter 1 in Rosenberg, 1982) and technologists (such as Sahal, 1985) have studied technological innovation and diffusion. The emphasis on the topic is understandable because of its effect on the gross national product (GNP) of countries, on competition in industries as well as on the daily lives of individuals.

Observing the variety of scientific disciplines studying technological innovation and diffusion, it may come as no surprise that many different types of innovation/diffusion-related patterns have been distinguished thus far. Some of them will be mentioned here to illustrate the variety. Rogers (2005) is one of the founding fathers of diffusion research. He distinguishes patterns by describing the subsequent groups of adopters or customers of a product category. In doing so, he focuses on the diffusion rather than the development of products, and on the demand side (the customers) rather than the supply side (including complementary products and services) or the wider market environment. Furthermore, the assumption that innovation occurs prior to diffusion means that diffusion researchers assume that the product essentially remains invariant over the diffusion process. Rogers (2005) also explains why diffusion researchers traditionally focus on the demand side of the market to explain the diffusion pattern and why subsequent innovations in the product during the diffusion process are usually ignored. One of the first well-known cases in which diffusion was studied happened to be hybrid corn in the US. Hybrid corn was an innovation that performed well and remained essentially invariant over the diffusion process. At that time, the institutions supplying and distributing corn were well developed, which meant that the main factors to explain actual diffusion in this particular case were the customers or farmers, i.e. the demand side of the market. Diffusion research has been applied in a broad variety of cases, some of which may not justify the same assumption of invariance or the focus on the demand side of the market. Rogers concludes that this hybrid corn case has set the standard of working for researchers investigating other cases.

By contrast, Utterback *et al.* (Utterback and Abernathy, 1975; Abernathy and Utterback, 1978; Utterback, 1994) focus on a pattern by distinguishing subsequent types of innovations that emerge in a given industry. They explain that, in a new industry, the focus is on (major) product innovations; whereas later on, when a dominant design has appeared, the focus shifts toward process innovations that fundamentally change the production and distribution chain rather than the product in question. A dominant product design is a design that consists of a configuration of components that represents the standard in the market for an extended period of time because it meets the requirements and needs of a wide range of users (Abernathy and Utterback, 1978). Abernathy and Utterback (1978) focus on the supply side of the market and on innovation rather than the diffusion process. The particular pattern that they distinguish might be the result of their focus on technology-oriented industries such as the automotive industry. Tushman and Rosenkopf (1992) elaborate on Utterback's idea when they describe a technology cycle. The first stage of the cycle, which they call variation, starts with a technological discontinuity that emerges either through scientific advance or through a unique combination of existing technologies. In the next stage, referred to as the era of ferment, parallel processes of substitution, competition and ongoing technical change unfold. In the third stage, the selection stage, a dominant design emerges. Finally, an era of incremental change sets in, where the dominant design essentially remains the same. Rogers' representation of the diffusion process is found to be valid for a wide variety of product categories (see Chapter 2 in Rogers, 2005). The same applies to the points of view adopted by Utterback and Tushman, although these are claimed to apply in particular to complicated technological products (Murmann and Frenken, 2006).

This chapter focuses on a specific pattern — the time between invention and large-scale production and diffusion, also referred to as the pre-diffusion phases, for high-tech product categories. Upon closer inspection, many scientists have already described the pre-diffusion period, some of them by describing separate cases, others by comparing multiple cases. Marx, for example, described that new production technologies have to go through a process of adaptation and improvement before they become economically viable, and as a result of that start to diffuse on a large scale long after its first application. Similar results are obtained for other cases. Bloch (1935) described the lag (an entire millennium) between the invention of the water mill and its widespread adoption. David (1966) described that although the reaper had been invented in the early 1830s, it was only in the mid-1850s that Midwestern farmers adopted the reaper on a large scale. Some other scientists tried to distinguish patterns by studying the pre-diffusion period for multiple cases. Mansfield (1968), for example, claimed that the average time from invention to the start of the commercial development process is about 10–15 years. From the start of this process up to the market introduction, again, a few more years elapse. Utterback and Brown (1972) estimated that, on average, this development process takes an additional 5–8 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.[1]

The message from all these authors is clear and can be summarized using the following text: "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). What is lacking in these studies is a systematic comparison of the length of the pre-diffusion period for many cases and across industries. A systematic investigation of the causes and consequences of the pre-diffusion period is also lacking.

[1] The fact that the estimates in Agarwal and Bayus (2002) differ from the findings of other authors can be attributed to various reasons such as different types of cases (later on, this chapter will show that industry has an effect), different types of definitions for the milestones, and statistical variation or dispersion around the average (both will be discussed later on in the chapter). Given this dispersion, the data from Agarwal and Bayus (2002) are considered to be in line with the data from Mansfield (1968) and Utterback and Brown (1972).

These inquiries require a definition of this period, i.e. a definition of milestones between which time intervals can be assessed. We will turn to this topic in the next section.

2.3 Defining the Pattern

The previous section showed that it can take a long period of time before the industrial production and large-scale diffusion begins. A systematic comparison of the length of this period for multiple cases requires a clear definition of the start and end moments. At first sight, the emergence of the idea seems a good candidate for the start of this period and the first sales (adoption) of products seems a good candidate for the end of this period. In Exhibit 2.2, some elements of the helicopter case are described. This case is used to discuss whether the first idea for the product is actually a good choice for the starting point.

The case of the helicopter illustrates a couple of issues that hamper our effort to define the start of the pre-diffusion period. Firstly, the idea for a new high-tech product may be considered a natural starting point. In practice, however, it is almost impossible to assess with certainty whether the documented idea is actually the first. A patented idea is more easily traceable but patent behavior depends on the

Exhibit 2.2. The Invention of the Helicopter

The first idea for the helicopter or "rotary-wing aviation" originated in China in the 4th century BC. The helicopter was a children's toy that was powered manually. Centuries later, around 1500, Da Vinci designed the "Helical Air Screw", which is usually seen as the first attempt to make an effective helicopter. It was an experimental design never put into practice. Subsequently multiple helicopter-like models powered by strings, gun powder, steam power, and so on were tried until the start of the 20th century when the first helicopters were built that could be controlled by a person inside the helicopter.

Sources: Carey (1986) and Leishman (2000).

industry and culture involved, so it can hardly be used as a general starting point for different types of cases. Secondly, upon closer inspection, the case of the helicopter illustrates the evolutionary nature of the development process. This evolutionary nature seems to conflict with the idea of assessing milestones. Are there milestones in an evolutionary process? There is definitely a first time that a person inside a helicopter was able to control it while being lifted with the helicopter which was powered by means of an engine (inside the helicopter). This description shows that the more evolutionary a development process is, the more careful a milestone has to be defined (in our case, the first time a helicopter (1) lifts an individual; (2) can be controlled by that same person; and (3) is powered by an engine inside the helicopter).

A similar discussion is possible for the end of the pre-diffusion period. The start of the sales seems a good candidate to represent the start of the diffusion period. Upon closer inspection, however, this choice has a disadvantage. For many cases of new high-tech product categories, there is no clear start of the diffusion. In practice, a product can be introduced, withdrawn from the market, redesigned, aimed at a different customer segment and introduced again. Easingwood and Lunn (1992) argue that because of this iterative process, the diffusion of some communication products cannot be captured in a simple S-shaped curve. In these cases, there is no single smooth diffusion curve but rather an erratic process with multiple small efforts (each of which can be represented by a separate curve). This observation is in line with the fact that the first products of a new high-tech product category are often sold and applied years before the S-shaped diffusion curve starts.

Therefore, that assessing the length of the pre-diffusion period, if possible at all, requires a very careful selection and definition of milestones. Three criteria that these milestones should fulfill are:

(1) Generic nature of the milestone — it should exist in (almost) all cases.
(2) Data availability of the milestone — data should be available for (almost) all cases.

(3) Objective timing of the milestone — milestones can be dated objectively.

These three criteria ensure that the milestones can be assessed for different types of cases. Using these criteria, the following milestones have been selected: (1) invention, (2) first market introduction, and (3) start of large-scale production and diffusion. Each of the milestones will be discussed and defined below.

2.3.1 *Milestone 1: Invention*

Invention is considered to be the first demonstration of the working principle of a new high-tech product category. Materials are sometimes discovered in nature. Discovery, however, does not mean that the technology is understood and can be reproduced. So, the discovery of aspirin was much earlier than the invention of the process to produce this medicine. Similarly, the material aluminum was discovered in nature long before mankind started to master its process of production. We consider the latter moment as the invention.

Definition: The invention of a new high-tech product category is defined to be the first time that the technical principle of this category is demonstrated and mastered.

The technical principle can be defined in terms of the physical or chemical processes on which the product category is based and in terms of the functionality that is enabled by the product category. The technical principle of the VCR, for example, is that particles on a tape are magnetized (technical principle) to store video data (functionality). The new high-tech product category can be defined in terms of a number of attributes that are considered to represent the core of this category.

An example will illustrate the relevance of distinguishing basic product attributes in addition to the technical principle and the functionality. Mobile telephony can be defined as a new high-tech product category that requires at least two stations with senders and receivers (attributes) to enable communication (functionality) via radio contact (technical principle). Using this definition, the invention of mobile telephony goes back to the work of Marconi and his predecessors in the late 19th century. Mobile telephony can also be defined as the ability to communicate, i.e. to have a conversation (functionality) via radio contact (technical principle) which requires stations with a sender and receiver and a switching station to connect them (attributes). In the latter case, the invention date is the time that the Bell labs devised the first switched mobile telecommunication system in 1947. So, establishing an invention date requires a very careful definition. Or, to put it differently, when definitions are changed, the invention dates may shift by decades.

2.3.2 *Milestone 2: Introduction*

The introduction of a technological product is part of an array of subsequent activities. In the course of time, a product is developed, maybe produced on a small scale for testing and pilots, produced for actual use, maybe put in stock, then sold or transferred to the users in some way or another, and finally used in practice or implemented in the daily practice of the users.

> **Definition:** The introduction date is defined to be the date at which the product is available for sales or can be transferred to users. In some cases, products are not sold, for example, if a government institute develops a new weapon that is used by the military forces.

For some cases, only information about the first pilots or the start of the production is available; whereas for other cases, the first sales or the first application in practice is the only available information. It is important to discuss the change in the introduction date that may result from the specific information available. If that change is small compared to the time scale used (in years) or if it is small compared to the time intervals observed for the phases of the case (multiple years), then the changes do not create a problem. However, if the change is relatively large, then additional information is required to find the actual date of selling or transferring of the product to the user. If a large uncertainty in the dates of the milestones may completely shift conclusions about the length of the phases, these phases cannot be assessed.

2.3.3 *Milestone 3: Large-scale production and diffusion*

This milestone is important because it separates the pre-diffusion phases from the standard diffusion process represented by the S-shaped diffusion curve. On the other hand, it is also a difficult milestone to define and assess in practice. Do the small-scale attempts to introduce the first products from a high-tech product category represent the start of the diffusion process or do they precede this process? In the latter case, it is important to define a milestone that distinguishes the pre-diffusion phases from the diffusion phase.

Definition: The milestone is defined using three elements:

- A standard product that can be reproduced multiple times (or standard product modules that can be combined in many different ways but are based on the same standard platform);
- A (large-scale) production unit with dedicated production lines (industrial production of a standard product); and
- Diffusion of the product.

The first element in the definition of the milestone is the existence of a standard product (or product modules) that is reproduced multiple times. This element is required to distinguish made-to-order products or experimental batches of products from the standard product. In the automotive industry, for example, cars were first produced as made-to-order products by small workshops. Industrial large-scale production in factories started with the emergence of the Model T Ford. This example also illustrates that, together with the emergence of the standard product, another type of production facility emerges — this phenomenon represents the second element in the definition of the milestone. In some cases, large-scale production units are built for products that are never sold. The standard product and the dedicated production unit alone do not suffice to assess the start of the large-scale diffusion; products should be sold as well (third element). A dedicated production facility for the point-contact transistor made out of germanium, for example, was built by Raytheon in the late 1940s, but the particular type of transistor was difficult to manufacture and was not successful. At the time of the opening of the production facility, a much better type of transistor, the junction or sandwich transistor, was invented; its large-scale production would start around 1953.[2]

2.3.4 *Pattern of development and diffusion using the milestones*

Now that the milestones to assess the pre-diffusion phases have been defined, the time interval of the pre-diffusion period can be assessed. The pre-diffusion phases are defined to be the time that elapses between the invention and the industrial production and large-scale diffusion of a high-tech product category. This time period can be further subdivided into two subsequent phases: the innovation phase (from invention to initial market introduction) and the adaptation phase (from initial market introduction to industrial production and large-scale diffusion).

A typical representation of the development and diffusion pattern of high-tech products is shown in Figure 2.1.

2.4 Length of the Pre-diffusion Phases

After defining milestones in the process of development and diffusion of high-tech product categories, it is possible to compare the length

[2] The information on the transistor is from http://www.pbs.org/transistor/album1/index.html/.

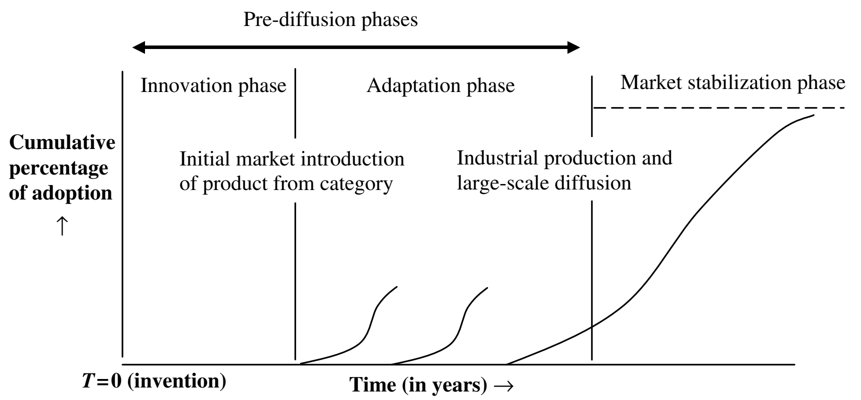

Figure 2.1. The pattern of development and diffusion of high-tech product categories.

of the pre-diffusion phases between cases.[3] I will shortly describe the method of assessing the milestones in practice for individual cases and then proceed with an overview of the results.

2.4.1 *Method*

An extensive case-study approach was used in the sense that each high-tech product category was examined as a separate case. The similarity of the approach in each case study later enabled a comparison of the data for multiple cases between industries. The exact time pattern for each case was assessed after conducting an extensive literature search. After combining various sources to find the relevant data, the data were categorized based on when relevant events took place. This approach is also referred to as a "chronology-of-events approach" (Sahal, 1981). In practice, literal copies of the information from various sources were combined in a table that described what happened before and after a new high-tech product was invented. These tables,

[3] This section is based on three conference papers presented at the IAMOT 2007, IAMOT 2008 and IAMOT 2009, respectively (Ortt *et al.*, 2007b; Ortt and Delgoshaie, 2008; Ortt *et al.*, 2009).

which covered between 10 and 20 pages, were then analyzed and discussed by at least two researchers to determine the dates of invention, market introduction, and large-scale production and diffusion, which resulted in an outline of the development and diffusion pattern. In some cases, additional literature was needed to resolve uncertainties or controversies concerning the correct pattern.

2.4.2 *Results*

The results are based on 50 cases of new high-tech product categories in five different industries.[4] The results will be described in three parts. Firstly, the length of the pre-diffusion phases for the entire set of cases will be discussed. Secondly, different scenarios or types of patterns will be distinguished within the set. Thirdly, the patterns of cases from different industries will be compared. In the Appendix is a table with an overview of the length (in years) of the pre-diffusion phases for all cases. A summary of this information can be found in Table 2.1. Both tables will be used when discussing the results.

2.4.2.1 *Length of the pre-diffusion phases for all cases*

On closer inspection, the data presented in Table 2.1 reveal some interesting information about the pre-diffusion phases. Firstly, the last column (Total) shows that, on average, the pre-diffusion phases take about 17 years, which is a remarkably long time, especially given the term patents typically provide inventors with protection (about 20 years). The standard deviation is also relatively large (about 15 years),

[4] Standard industry categorizations from the Central Bureau of Statistics were used and condensed into comparable industry definitions on a relatively high level of aggregation: (1) chemicals, metals & materials; (2) pharma & healthcare equipment; (3) telecom, media & Internet; (4) electronic equipment; and (5) aerospace & defense. Individual cases were assigned to these industries by five different researchers. Their categorizations were then compared. When the researchers disagreed, their line of reasoning was discussed. In some cases, the experts reached an agreement after the discussion. When no such agreement could be reached, the cases were removed from the set.

Table 2.1. Duration (in years) of the pre-diffusion phases for 50 cases in five different industries.

Industry → **Mean value** **↓ (std. deviation)[a]**	**Chemicals, metals & materials**	**Pharma & healthcare equipment**	**Telecom, media & Internet**	**Electronic equipment**	**Aerospace & defense**	**Total**
Total duration of pre-diffusion phases (P)	11.4 (7.4)	26.1 (24.2)	15.3 (10.8)	19.2 (10.5)	11.6 (10.6)	16.7 (14.5)
Duration of innovation phase (I)	4.9 (3.2)	21.6 (23.3)	8.9 (10.8)	7.2 (5.4)	7.6 (10.2)	10.0 (13.5)
Duration of adaptation phase (A)	6.5 (5.8)	4.5 (6.2)	6.4 (7.1)	12.0 (11.2)	4.0 (4.3)	6.7 (7.6)

[a] Description:

Pre-diffusion phases (P) = Innovation and adaptation phases combined;
Innovation phase (I) = The time period between invention and initial market introduction;
Adaptation phase (A) = The time period between the initial market introduction and the industrial production and large-scale diffusion of products.

indicating a high dispersion around the average value. This implies considerable levels of uncertainty about the length of pre-diffusion phases for companies. The duration of the pre-diffusion phases is significantly different from zero (one-sample t-test: $p = 0.000$).[5] The innovation and adaptation phases are about 10 and 7 years long, respectively. Although the innovation phase seems somewhat longer than the adaptation phase, this difference is insignificant (two-sample t-test: $p = 0.15$). The lengths of the separate phases are all significantly different from zero (one-sample t-tests: all $p = 0.000$).

2.4.2.2 *Different scenarios for the pattern*

The results in the Appendix show that each phase can disappear in specific situations. These ideas are summarized in two propositions: (1) the phases can vary considerably in length, and one or more phases may even disappear; and (2) the entire process can break off in each phase.

These propositions convey a more unpredictable process than the S-shaped pattern. In practice, the actors involved in the commercialization of new high-tech product categories may face different scenarios. After studying the pattern of development and diffusion for 50 cases, three important scenarios are distinguished (see Figure 2.2 and Table 2.2). Scenario 1 is a situation in which a long innovation phase emerges, which means that it takes a long time before a product based on a new technology is introduced in the market. Scenario 2 is a situation in which a product is introduced shortly after the invention yet it requires a long market adaptation phase, which means that it takes a long time before this product diffuses in a mass market. Scenario 3 is a situation in which a new high-tech product, almost directly after the invention, diffuses in a mass market, which means that both the innovation and

[5] The value $p = 0.05$ means that there is a chance of 5 in 100 that the relationship (for which the p-value is established) does not hold. Although a critical p-value of 0.05 is often chosen, the value may depend on the research project. Below this value ($p < 0.05$), the relationship is statistically significant; above this value, it is not significant.

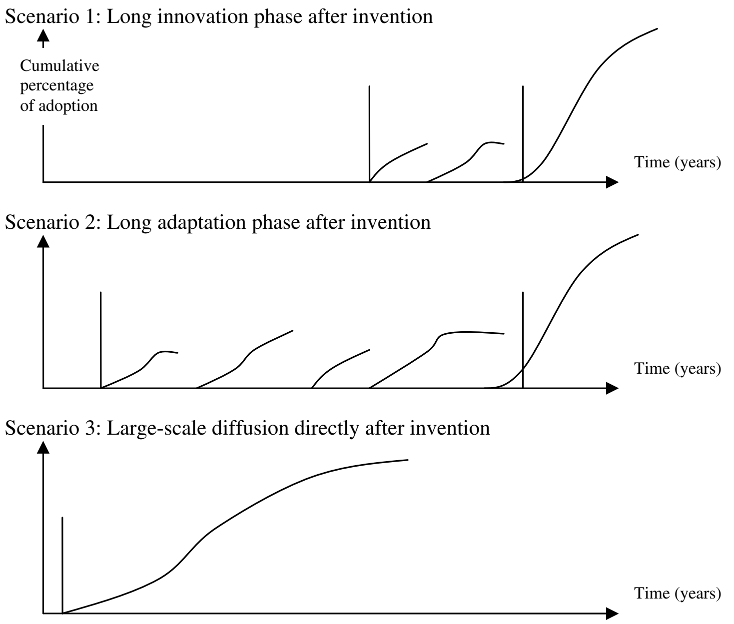

Figure 2.2. Three scenarios after the invention of a breakthrough technology.

Table 2.2. Data for some cases representing the (extreme) scenarios.

Scenario	Cases	Length of innovation phase (years)	Length of adaptation phase (years)	Length of pre-diffusion phases (years)
1	Radar technology	34	1	35
	Aspirin	44	3	47
2	Magnetic recording	5	30	35
	Plasma display	7	29	36
3	Dynamite	1	0	1
	X-ray	1	0	1

market adaptation phases almost completely disappear. Each scenario is illustrated in Table 2.2 using two cases.

Table 2.2 illustrates that these three extreme scenarios are possible in practice. Most of the cases, however, will result in innovation and adaptation phases that are less extreme in duration. It is interesting to notice that two medical high-tech product categories (at the time of their invention), aspirin and X-ray, represent different scenarios. Similarly, two product categories important in warfare, radar technology and dynamite, also represent different scenarios. Magnetic recording and plasma display, however, are both electronic equipment and represent the same scenario. It is interesting to more systematically explore the differences in cases from different industries, using the data from Table 2.1.

2.4.2.3 *Differences in pattern across the five industries*

We now focus on the question of whether the innovation and adaptation phases vary significantly across the five industries. The first row in Table 2.1 reveals that there are two industries with relatively short pre-diffusion phases, "chemicals, metals & materials" (column 1: 11 years) and "aerospace & defense" (column 5: 11 years). By contrast, "pharma & healthcare equipment" is characterized by relatively long pre-diffusion phases (column 2: 26 years). The other two industries are in between these extremes.

The significance of the differences between industries using analysis of (co)variance[6] was also checked, and a summary of the findings is presented here (for a full description, see Ortt *et al.*, 2009). When the effect of the date of invention is taken into account, the pre-diffusion phases do vary in duration significantly among the industries. The differences between the industries can almost completely be attributed to a difference in the duration of the innovation phase, which turns out to be highly significant. On closer inspection, the difference in the duration of the innovation phase can largely be attributed to a very long innovation phase in the case of "pharma & healthcare equipment" (22 years) and a relatively short innovation

[6] Analysis of variance investigates the variances of the duration of the pre-diffusion phases *between* industries and *within* industries. If the variance *between* the industries is relatively large compared to the variance *within* the industries, it can be inferred that the industries are homogeneous but different.

phase in the case of "chemicals, metals & materials" (5 years). Although the differences in terms of the adaptation phase are not significant, when individual pairs of industries are compared, it becomes clear that "electronic equipment" has a significantly longer adaptation phase (12 years) than "aerospace & defense" (4 years).

To conclude, the type of industry is related to the length of the pre-diffusion phases.

2.5 Causes of the Pre-diffusion Phases

2.5.1 *Introduction*

As explained in the first sections of this chapter, many scientists from different disciplines have studied patterns of technological innovation and diffusion. Some of them focused in particular on the factors that explain whether a delay can be expected between invention and large-scale diffusion. Bloch (1935), for example, explained the lag of an entire millennium between the invention of the water mill and its widespread adoption primarily in terms of legal and economic conditions. Rosenberg (1972) also pointed at the availability and introduction of other complementary inputs that make an original invention more useful and thereby demarcate the start of large-scale diffusion. David (1966) explained the delay in the diffusion of the reaper in terms of the relative cost of labor and the threshold for farm size, implying that, after farms have obtained a particular size and after labor costs have increased to a specific level, it becomes economically viable to use a reaper rather than the old labor-intensive techniques of cutting grain. Finally, Rogers (2005) used the characteristics of farmers to explain the diffusion of new appliances in agriculture.

The overview of scientists who describe specific factors to explain the delay between invention and large-scale diffusion is almost endless. Many factors can be mentioned, depending on the (sub)discipline of the scientists. Depending on the theory that is adopted, different factors and mechanisms are used to explain the delay between invention and large-scale diffusion. Diffusion researchers (see Rogers, 2005), for example, traditionally explain the start and the speed of diffusion in terms of the characteristics of potential adopters and their perception of the innovation, whereas institutional economists (such as North) tend to focus on legal and institutional characteristics in the market environment when doing so.

One of the ways to make sense of the variety of factors is to categorize them. Instead of a literature review to find the factors, the results of a multi-case study approach are summarized to find many factors, to categorize them, and to explore the mechanisms by which they have an effect on the delay between invention and large-scale diffusion (Ortt and Delgoshaie, 2008). The advantage of a multi-case study approach is that the interaction between the factors can be observed; whereas in a review of articles, the factors are described separately.

Three categories for these factors will be distinguished: characteristics of (1) the main organizations involved, (2) the technological system, and (3) the wider market environment (around the main organizations). Using this categorization, one can argue that the economic conditions mentioned by Bloch (1935) belong to the wider market environment. The size of the farms (David, 1966) and the characteristics of farmers (Rogers, 2005) can be considered to represent characteristics of the customers (which belong to the main organizations involved).

2.5.2 *Method to assess factors*

The first step was to select a heterogeneous set of cases. Heterogeneity was assessed in terms of the industries involved, the length of the pre-diffusion phases and the time of invention. For each case, the pattern was first assessed (for the approach, see Section 2.4). Once the pattern was clear, the factors and mechanisms that may have influenced the length of the pre-diffusion phases were considered. Again, each case was studied by at least two researchers, each of whom made a list of factors and mechanisms that may have determined the length of the pre-diffusion phases in that specific case. The factors and mechanisms were discussed and a form was completed in which the factors and mechanisms were described, to which a copy was added containing the information that was used to infer this information. Because this procedure was carried out for all cases, the result was 18 forms containing detailed information. The information was then summarized and stored in a single data file to make it possible to analyze all the cases. In all, there were 118 occasions where a factor was identified that affected the length of the pre-diffusion phases.

2.5.3 *Results*

2.5.3.1 *Categorization of these factors*

To categorize the types of factors that affect the length of the pre-diffusion phases, a simple model of the market environment of the new high-tech product was adopted. This model describes the relevant environment for a new high-tech product:

(1) The main organization(s) responsible for the development, production, supply and use of the new high-tech product;
(2) The technological system required to use the new high-tech product; and
(3) The market environment, including all the other actors (than the main organizations) and factors involved (e.g. the availability of regulations and standards).

When the factors found in the cases are categorized depending on the question to which part of the environment they belong, they can be divided into three categories (see Table 2.3).

2.5.3.2 *Mechanisms by which these factors affect the delay between invention and large-scale diffusion*

While investigating the factors, the mechanisms by which these factors influence the delay between invention and large-scale production and diffusion were also explored. Four mechanisms are distinguished.

Table 2.3. Categories of factors found to affect the pre-diffusion phases.

The main organization(s)	
Fit with mission and other criteria of companies to evaluate the importance of the product for the company	Customer need and other customer-related criteria needed to evaluate the product
Cheapness for producer/supplier (overview of costs/benefits)	Cheapness for customer (overview of costs/benefits)
Resources of main actor (to develop, produce and supply)	Resources of customer (ability to adopt and use)
Expertise (to develop, produce and supply innovation)	Expertise (to use innovation)
Market (supply) strategy	Adoption strategy
Number of suppliers for product and technological system; number and resources of suppliers of alternative products/technological systems	Number of potential customers (market potential)
	Network effects on the customers' or suppliers' side
	Cooperation/competition among different actors
The technological system	**The market environment**
Relative performance compared to alternative technology	Regulatory environment
Competition with other new/old technologies	Availability of rules and standards
Required and available complementary products	General public attitude
Reliability, certainty and risk of technology	Accidental changes in the macro environment
Complexity and network requirements of technology	Accidents during development/exploitation
Availability of knowledge components (newness)	
Difficulty in controlling production	
Type of technology (basic, general purpose and/or competence-destroying technology)	
Visibility of benefits	
Unknown applications of technology (newness)	
Ease of translation from invention to innovation	
Compatibility with similar systems in other regions or with previous systems	

The first and simplest type of relationship can be represented via a regression model in which independent factors determine the length of the pre-diffusion phases. An example of this is the required presence of an infrastructure. In the case of telecommunication products and services or in the case of a navigation system like GPS, a complete infrastructure is required that consists of a network and complementary products and services. In some cases (for instance, SMS), an existing infrastructure can be re-used; while in other cases (like GPS and the mobile telephone at the time of their introduction), the infrastructure has to be built from scratch. The latter option usually implies that long pre-diffusion phases are to be expected. The more extensive the new infrastructure that has to be built, the longer the adaptation phase is likely to be.

A second type of relationship cannot be represented via a regression model, because it emerges when a factor serves as a necessary condition for the start or emergence of a new phase in the development and diffusion of a product. If the condition is not met, the emergence of the phase is impossible or highly unlikely. An example of this is the case of Dyneema, an ultra-strong fiber. In this case, because there was no controllable and scalable production method available, large-scale production and diffusion of the fiber were impossible. A controllable and scalable production method is a necessary condition for the emergence of the phase of large-scale production and diffusion.

A third type of relationship emerges when various factors have a combined effect on the dependent variable, the length of the pre-diffusion phases. Although the combination of the factors determines the length of phases, separate effects are hard to identify. Interaction effects between factors may be very complex when several factors are involved. An example of such an interaction involves the factors "fit of new high-tech product with the mission of the main organization responsible for developing, producing and supplying this product" (in short: "fit with mission") and "resources of the main company". Large organizations with many resources are only willing to invest in a product/technology when it fits their mission. Again, Dyneema provides an example. Dyneema was invented in the labs of DSM (a large Dutch chemical company), but because it did not fit the company's mission at the time, DSM tried to sell the business unit involved. At the time, attempts to sell the business unit were unsuccessful, and almost 10 years later DSM reformulated its mission so as to include chemical specialities like Dyneema. This chain of events delayed the large-scale production and diffusion of the fiber, increasing the length of the pre-diffusion phases.

Finally, a fourth type of relationship emerges when the effect of the factors involved is highly contextual and time-dependent. The effect of a factor can, for example, depend to a large extent on the type of industry in which an organization operates. Military high-tech innovations, like radar and nuclear bombs, would never have been developed and used so quickly in the absence of war. In the telecommunication industry, to name another example, the existence of a compatible infrastructure is extremely important when new telecommunication products or services are introduced in the market.

The implication of these results is that the pre-diffusion phases are somewhat erratic. Although in all we identified many factors, we noticed that only a limited number of factors are important in individual cases. On average, we found fewer than seven factors to be decisive in each of the cases. We identified factors that serve as a precondition for the end of the pre-diffusion period, for instance, the ability to develop scalable production for new materials. We also found complex interactions among multiple factors that, for example, cause network effects or complicated patterns of substitution. We also found that the effect of factors on the pre-diffusion phases is context-dependent. Moreover, the importance of the factors may depend to a large extent on the industry involved. It is therefore believed that erratic patterns emerging during the pre-diffusion phases, in particular the adaptation phase, are the result of the complex interaction among many factors with an opposite effect.

2.6 Consequences of the Pre-diffusion Phases

From the perspective of a company trying to commercialize a new high-tech product (category), the pre-diffusion period has profound consequences. In the previous sections, several characteristics of the pre-diffusion period were described that have an important effect. Firstly, the average length of the pre-diffusion phases is large (about

17 years) (Section 2.4). Secondly, the dispersion around the average is considerable (about 15 years) (Section 2.4). Thirdly, there is a large number of factors that can determine the length of the pre-diffusion phases in individual cases, and these factors interact in complex ways (Section 2.5). The effect of these three characteristics on companies will be explored below.

2.6.1 *Consequence of the average length of the pre-diffusion phases*

The duration of the pre-diffusion phases has considerable implications for companies trying to commercialize their new high-tech products. In general, one may assume that the pre-diffusion phases represent an investment rather than a source of income for the organizations involved. Profits are usually generated during the phases of industrial production and large-scale diffusion. If that is the case, high-tech product categories require a tremendous investment over a long period of time.

2.6.2 *Consequence of the dispersion in the length of the pre-diffusion phases*

There is a relatively large dispersion around the average length of the pre-diffusion phases (about 15 years). In other words, the average duration of the pre-diffusion phases may be long, but in individual cases it can be very short or more than twice the average of 17 years. On average, the type of industry is shown to explain some of this variation; but at the time of the invention of a new high-tech product category, the overall uncertainty about the type of pattern that will unfold remains huge.

2.6.3 *Consequence of the lack of good market research tools in the pre-diffusion phases*

The trial-and-error process in the pre-diffusion period that results from the complex interactions between the factors makes it very difficult to use standard market research methods. Most methods assume that segments of potential customers are identified, and that individual customers invited in consumer research projects are able to understand the product and its use and are able to estimate the consequences of using the product on their daily lives. Furthermore, those types of predictions also assume that the product, once introduced in the market, will remain essentially the same, as will the market circumstances (such as the types of competitors); otherwise, the market research predictions no longer hold. These assumptions are rarely met in the pre-diffusion period, and therefore adapted or completely different methods are required to explore the market (Ortt *et al.*, 2007a).

So, at the time a new high-tech product is invented, there is a large uncertainty about the type of pre-diffusion period that will emerge. The general pattern that can be expected was described earlier (Figure 2.1); but it was also mentioned that for individual cases different scenarios might appear (Figure 2.2), each of which may require another production and market introduction strategy. The wrong strategy is found to entail large losses (Ortt *et al.*, 2007b).

In short, for the pioneers the stakes are high (in terms of the investment over years to turn the invention into a successful new high-tech product category), the return is uncertain (because the length of the period is uncertain, as is the ultimate return on the investment), and one of the instruments (market research) to reduce that risk does not function exactly in the situation that we need it most. It is not so remarkable that many companies involved in the commercialization of new high-tech product categories lose out before their products are applied on a large scale (Olleros, 1986; Pech, 2003). Projects dedicated to these high-tech products are risky, expensive, and usually take several years to produce results (Leifer *et al.*, 2000). Technical, market and organizational uncertainties associated with these projects are much higher than with projects aimed at incremental improvement (Burgelman and Sayles, 1986).

2.7 Conclusions and Discussion

This chapter started with the observation that the diffusion of new high-tech products rarely follows the well-known S-shaped diffusion pattern. In practice, after the first introduction a long period tends to elapse before the diffusion really starts. There appears to be a scientific gap in the mainstream diffusion literature regarding the pre-diffusion period. Managerially, it is also relevant to explore this period because many of the pioneers that invent new high-tech products no longer exist by the time their findings are successfully diffused in a mass market.

The pre-diffusion phases are defined using three milestones: (1) the invention, (2) the (first) introduction, and (3) the start of large-scale production and diffusion. Two phases are distinguished in the pre-diffusion period: the innovation phase (from invention to introduction) and the adaptation phase (from introduction to large-scale production and diffusion).

Using data from a multiple case study, covering 50 cases from five different industries, we could explore the pre-diffusion phases in more detail. On average, the pre-diffusion phases last about 17 years, the innovation and adaptation phases each covering about half of this period. The actual length of the pre-diffusion period for an individual case may diverge considerably from this average, as can be inferred from a large standard deviation (about 15 years). In practice, after the invention of a new high-tech product category, different scenarios can emerge, only one of which resembles the original S-shaped diffusion curve directly after the invention. Yet that is exactly what mainstream diffusion researchers made us expect. If the data set presented in this chapter is a representative sample (the heterogeneity of the sample implies that it is quite random), then the findings imply that only a small percentage of these cases follow the S-shaped diffusion pattern. To be more precise: if we assume that cases with a pre-diffusion period of 3 years or less resemble the S-shaped diffusion curve, then our data reveal that only 6 out of 50 cases fulfill that requirement.

The causes of the pre-diffusion phases have also been explored. Our findings indicate that many factors can play a role and these factors can be categorized into three groups, covering characteristics of (1) the main organizations, (2) the technological system, and (3) the wider market environment. The type of industry is shown to explain some of the variation in the length of the pre-diffusion period. This makes sense because industries often refer to specific types or clusters of companies and customers, specific types of technologies and products, and a specific broader market environment. The mechanisms by which the factors affect the duration of the pre-diffusion period have been examined, and these mechanisms include complex interactions among many factors that explain the erratic nature of the pre-diffusion period. For each case, different subsets of factors turn out to be determinant. In addition, the consequences of the length of the pre-diffusion period and the uncertainty about this length for those companies that try to commercialize a new high-tech product have been discussed.

2.7.1 *Discussion*

This chapter showed that the pre-diffusion period is visible for many cases before the well-known S-shaped diffusion pattern. The sample of 50 heterogeneous cases implies that the emergence of this pre-diffusion period can be generalized to the population of new high-tech product categories. The particular way in which this pre-diffusion period was represented, by defining three milestones and distinguishing two phases between them, is based on a number of assumptions.

Firstly, the approach assumes that the milestones — invention, introduction, and the start of large-scale production and diffusion — can be distinguished quite accurately in time. Or to put it differently, the uncertainty in the estimates of the milestones should be relatively small (typically a year) compared to the length of the phases between these milestones (typically a decade). In some cases, such as the development and diffusion of fiber-reinforced concrete, the steps of improvement are very small while the application in practice proceeds. It is impossible in these types of cases to validly assess the timing for the pre-diffusion phases; the idea of the pre-diffusion period, however, still holds.

Secondly, we assume that the pre-diffusion phases are a kind of exogenous factor for those companies that try to commercialize a new high-tech product. From this perspective, these companies are advised to assess the stage of the pattern and to adapt their strategies accordingly. However, some companies are able to shape the pattern in a form that suits their goals. Philips, for example, deliberately postponed the market introduction of the DVD in order to be able to form an alliance of companies that supported the same DVD format before it was introduced in the market. Thus, the innovation phase was deliberately lengthened and the adaptation phase was shortened. As a result, the company was able to directly start large-scale production and introduce the DVD at a relatively low cost. Standardization battles (Suarez, 2004) show that this strategy is not without risk.

Thirdly, the type of research that was conducted — a chronology of events for historical cases to assess the entire pattern of development and diffusion — almost inevitably created a pro-innovation bias. By selecting cases that went through the entire pattern, we also selected cases of successful new high-tech product categories. It is, of course, possible that a specific product category never reaches the stabilization phase. Likewise, some inventions are never introduced in the market, or some new high-tech products that are introduced in the market are never produced on a large scale. The uncertainty for the cases that were investigated is reflected in the large dispersion around the average length of each pre-diffusion phase. The real uncertainty is even bigger because of the risk that the pattern may break off.

Finally, further research is definitely required to quantitatively assess the interaction between factors in the pre-diffusion period and their combined effect on the length of the pre-diffusion phases. Further research is also required to advise companies on how they can explore the market and adapt their strategy while they are in the pre-diffusion period. This chapter sets the scene by describing the pre-diffusion period and indicating the relevance of taking it into account when making new business plans.

Appendix

Table A2.1. Duration (in years) of the pre-diffusion phases for all cases.

Name	Innovation phase (I)	Adaptation phase (A)	I and A
Chemicals, metals & materials			
1 Memory metal	7	4	11
2 Kevlar	6	2	8
3 Nylon	3	3	6
4 Bakelite	0	4	4
5 Dyneema	11	15	26
6 Cellophane	4	0	4
7 Polyurethane	1	15	16
8 Rayon	7	14	21
9 Buna S	4	4	8
10 Lycra	6	4	10
Mean	**4.90**	**6.50**	**11.40**
Std. Deviation	**3.213**	**5.778**	**7.382**
Telecom, media & Internet			
1 Bluetooth	6	0	6
2 Fiber optic comm.	9	8	17
3 Mobile telephone	15	1	16
4 Internet	0	15	15
5 Telegraphy	7	21	28
6 Wi-Fi	2	9	11
7 Satellite phone	36	0	36
8 Telephone	1	2	3
9 UMTS	1	1	2
10 Television tech.	12	7	19
Mean	**8.90**	**6.40**	**15.30**
Std. Deviation	**10.775**	**7.121**	**10.750**
Pharma & healthcare equipment			
1 Aspirin	44	3	47
2 Antibiotics	14	1	15
3 Viagra	2	1	3
4 CT scanner	5	2	7
5 MRI	7	3	10

(*Continued*)

Table A2.1. (*Continued*)

Name	Innovation phase (I)	Adaptation phase (A)	I and A
6 X-ray	1	0	1
7 Heart-lung medicine	54	10	64
8 Pacemaker	10	20	30
9 SSRI (Prozac)	15	5	20
10 Paracetamol	64	0	64
Mean	**21.60**	**4.50**	**26.10**
Std. Deviation	**23.291**	**6.205**	**24.205**
Electronic equipment			
1 Digital camera	3	21	24
2 Optical disc	16	4	20
3 Magnetic recording	5	30	35
4 Plasma display	7	29	36
5 VCR	5	1	6
6 Photocopier	11	11	22
7 Polaroid	15	3	18
8 Microwave oven	2	8	10
9 Air conditioning	0	13	13
10 Electr Micros	8	0	8
Mean	**7.20**	**12.00**	**19.20**
Std. Deviation	**5.371**	**11.165**	**10.475**
Aerospace & defense			
1 Helicopter	16	4	20
2 Aircraft	5	6	11
3 Dynamite	1	0	1
4 Nuclear bomb	4	2	6
5 Sonar	1	2	3
6 Radar tech.	34	1	35
7 IFF	3	3	6
8 GPS	6	15	21
9 Jet engine	4	2	6
10 Torpedo	2	5	7
Mean	**7.60**	**4.00**	**11.60**
Std. Deviation	**10.233**	**4.269**	**10.585**
(Total 50) Mean	**10.0**	**6.7**	**16.7**
Std. Deviation	**13.5**	**7.6**	**14.5**

References

Abernathy, W.J. and Utterback, J.M. (1978). Patterns of industrial innovation. *Technology Review* (June/July), 41–47.

Agarwal, R. and Bayus, L. (2002). The market evolution and sales takeoff of product innovations. *Management Science*, 48(8), 1024–1041.

Bijker, W.E. (1995). *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge, MA: MIT Press.

Bloch, M. (1935). Avénement et conquêtes du moulin à eau. *Annales d'Histoire Economique et Social*, 7, 538–563.

Burgelman, R.A. and Sayles, L.R. (1986). *Structure and Managerial Skills*. London: Collier-Macmillan.

Carey, K. (1986). *The Helicopter*. Blue Ridge Summit, PA: Tab Books.

David, P. (1966). The mechanization of reaping in the Ante-Bellum Midwest. In: H. Rosovsky (ed.), *Industrialization in Two Systems: Essays in Honor of Alexander Gerschenkron*, New York: Wiley, pp. 3–39.

Deane, P. (1978). *The Evolution of Economic Ideas*. Cambridge: Cambridge University Press.

Easingwood, C.J. and Lunn, S.O. (1992). Diffusion paths in a high-tech environment: clusters and commonalities. *R&D Management*, 1, 69–80.

Ekelund, R.B. and Hébert, R.F. (1983). *A History of Economic Theory and Method*. New York: McGraw-Hill.

Gopalakrishnan, S. and Damanpour, F. (1997). A review of innovation research in economics, sociology and technology management. *Omega*, 25(1), 5–28.

Hobsbawn, E.J. (1962). *The Age of Revolution*. London: Weidenfeld & Nicolson.

Landreth, H. and Colander, D.C. (1994). *History of Economic Thought*. Boston: Houghton Mifflin.

Leifer, R., McDermott, C.M., Colarelli-O'Connor, G., Peters, L.S., Rice, M.P. and Veryzer, R.W. (2000). *Radical Innovation: How Mature Companies Can Outsmart Upstarts*. Cambridge, MA: Harvard Business School Press.

Leishman, J.G. (2000). *Principles of Helicopter Aerodynamics*. Cambridge: Cambridge University Press.

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

Murmann, J.P. and Frenken, K. (2006). Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. *Research Policy*, 35(7), 925–952.

Nieto, M. (2003). From R&D management to knowledge management: an overview of studies of innovation management. *Technological Forecasting and Social Change*, 70(2), 135–161.

Olleros, F. (1986). Emerging industries and the burnout of pioneers. *Journal of Product Innovation Management*, 3(1), 5–18.

Ortt, J.R. and Delgoshaie, N. (2008). Why does it take so long before the diffusion of new high-tech products takes off? In: *Proceedings of IAMOT (International Association for Management of Technology) Conference, 6–10 April 2008, Dubai.*

Ortt, J.R., Langley, D.J. and Pals, N. (2007a). Exploring the market for breakthrough technologies. *Technological Forecasting and Social Change*, 74, 1788–1804.

Ortt, J.R. and Schoormans, J.P.L. (2004). The pattern of development and diffusion of breakthrough communication technologies. *European Journal of Innovation Management*, 7(4), 292–302.

Ortt, J.R., Shah, C.M. and Zegveld, M.A. (2007b). Strategies to commercialise breakthrough technologies. In: *Proceedings of IAMOT (International Association for Management of Technology) Conference, 13–17 May 2007, Miami.*

Ortt, J.R., Tabatabaie, S., Alva, G., Balini, G. and Setiawan, Y. (2009). From invention to large-scale diffusion in five high-tech industries. In: *Proceedings of IAMOT (International Association for Management of Technology) Conference, 5–9 April 2009, Orlando.*

Pech, R.J. (2003). Memetics and innovation: profit through balanced meme management. *European Journal of Innovation Management*, 6(2), 111–117.

Rogers, E.M. (2005). *Diffusion of Innovations.* New York: The Free Press.

Rosenberg, N. (1972). Factors affecting the diffusion of technology. *Explorations in Economic History*, 10, 3–33.

Rosenberg, N. (1982). *Inside the Black Box: Technology and Economics.* Cambridge: Cambridge University Press.

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

Sahal, D. (1985). Technological guideposts and innovation avenues. *Research Policy*, 14(2), 61–82.

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

Suarez, F.F. (2004). Battles for technological dominance: an integrative framework. *Research Policy*, 33, 271–286.

Tellis, G.J. and Golder, P.N. (1996). First to market, first to fail? Real causes of enduring market leadership. *Sloan Management Review* (Winter), 65–75.

Tushman, M.L. and Rosenkopf, L. (1992). Organizational determinants of technological change. Towards a sociology of technological evolution. *Research in Organizational Behavior*, 14, 311–347.

Utterback, J.M. (1994). *Mastering the Dynamics of Innovation.* Boston: Harvard Business School Press.

Utterback, J.M. and Abernathy, W.J. (1975). A dynamic model of process and product innovation. *Omega*, 3(6), 639–656.

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

Websites Visited

http://www.bvws.org.uk/405alive/history/revisionist_ history.html/
http://www.earlytelevision.org/german_prewar.html/
http://www.nyu.edu/classes/stephens/History%20of%20Television%20page.htm/
http://www.pbs.org/transistor/album1/index.html/
http://www.tvhandbook.com/History/History_timeline.htm/