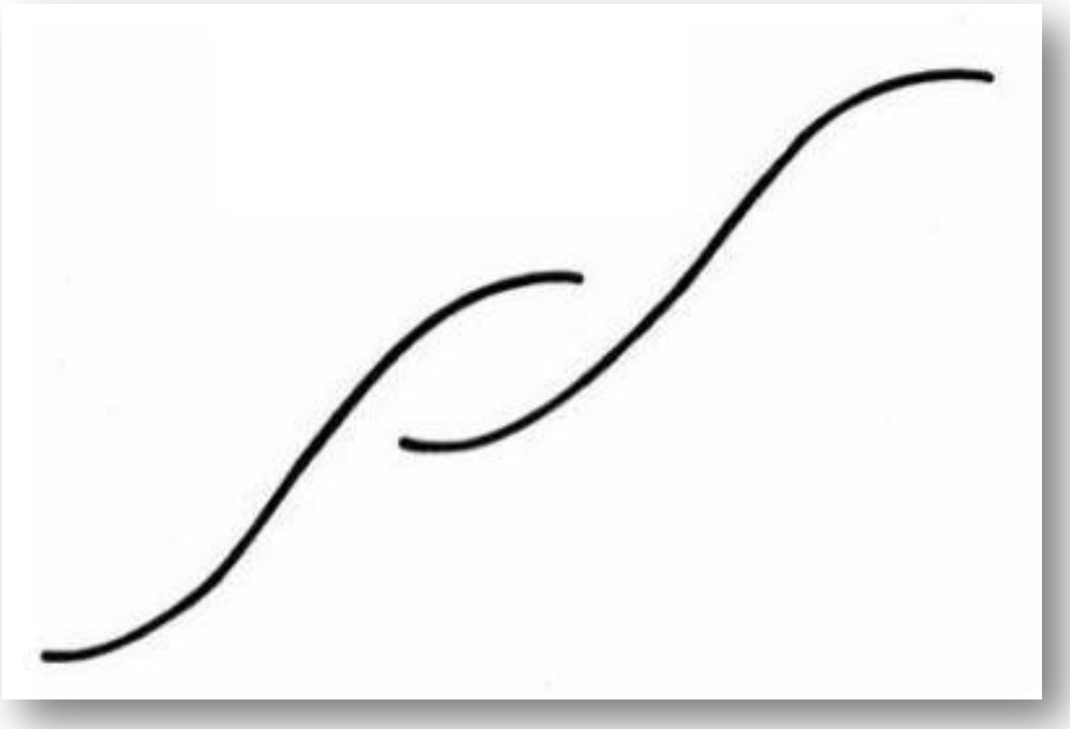
Managerial Usefulness of S-curve Theory: Filling the Blanks



Bachelor Thesis Organization & Strategy

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Management Summary

This thesis aims at answering the question: *What is the practical value of S-curve theory of innovation?* To provide an answer to this problem, S-curve theory will be explained from its roots.

Schumpeter (1939) was the first to discover a cyclical pattern in technology trajectories. Only many years later, the S-curve was born. A mathematical model designed to forecast the path of a technology, created by Fisher & Pry (1971) was the start of a research paradigm that is still used.

In the years following, research focused on different characteristics of the S-curve, and on technology trajectories in general. Forces driving technology, on a macro as well as on a micro level, were subject to research. Especially the between such curves became of interest, as surviving this phase appeared to be a major challenge to companies. As a result, managerial implications were put to paper.

However, these suggestions for managers remained rather vague and therefore provided little value to practitioners. A new scientific paradigm, technology roadmapping, seems be able to address these problems, helping companies to manage technology trajectories better.

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Chapter 1: Introduction

In the introductory chapter of this paper, the problem of investigation will be touched upon. After this problem has been explained thoroughly, a general overview of the paper will be provided by means of a problem statement, the formulation of three research questions, and an explanation of the research methods and the structure that will be applied.

1.1. Problem Indication

Managing innovation has appeared to be a difficult process. Many incumbent firms have failed to successfully respond to, or implement technological innovations (Foster, 1985; Christensen, 1997). Research has tried to identify the origins and trajectories of these innovations, starting with Schumpeter (1939), who stated that technological innovation is a cyclical process; every technological innovation follows such a path. However, the lengths of these paths can be different for each cycle. On top of that, such cycles are not independent, but together form a network in which one technological innovation may have an influence on others. Building further on this, Abernathy & Utterback (1975) discovered that regarding innovation, the firm and its environment determine together the shape of the innovation trajectory. Certain environments require certain types of capabilities and are again interdependent.

Building further on S-curve Theory, Christensen (1992) added market innovation processes as a variable that influences S-curved shapes. Even though technologies might have been invented, this does not mean that the previous technologies' S-curve is at its end: the market itself determines this.

Although the theory is generally accepted, there are several points of critique, especially concerning the practical implications. For instance, Christensen (1995) and Sood & Tellis (2005), mentioned that the predictive value of the theory is low; an S-curve can be at its end at any time, taken over by technologies coming from below (initially performing worse than current technology) as well as from above (performing better than current technology), by incremental as well as radical events, and from

incumbents as well as new entrants. Next to that, Sood & Tellis (2005) also argue that technology trajectories may have the shape of an irregular step-function.
Technologies do not always end at the end of the S-shape; sometimes a new start is initiated. All this hampers the use of S-curve theory as a valuable predictor for the future, and thus its managerial value is questionable. In 2006, Tellis delineates this by stating in his article: *"the critical importance of these findings is that the S-curve is not a predictive theory and thus not a good basis for strategy. For example, a manager seeing a plateau in performance may wrongly assume that the technology has matured and so abandon it. We found that huge performance jumps often follow such plateaus".*

This report will give an overview of the origins of the S-curve and the (lack of) practical usefulness.

1.2. Problem Statement

Based upon the thorough explanation of the problem under investigation, which has been provided above, the following problem statement has been formulated:

What is the practical value of S-curve theory of innovation?

1.3. Research Questions

In order to provide a more adequate answer to this problem statement, and in order to guarantee the clearness of structure of this paper, three research questions were created which, together, ought to answer the problem statement.

Research Question 1: What is S-curve theory and how is it established.

Obviously, this section of the paper concerns an explanation of the S-curve theory, and perhaps more importantly, the roots upon which this theory has been based. Answering this research question is important, since it provides required background information for understanding of the subject under investigation.

Research Question 2: How has S-curve theory evolved over the years?

In addition to the roots and foundation of S-curve theory, it is interesting to evaluate the evolution of the innovation theory throughout its short history. Special emphasis will be put on both the internal and external forces that shape a firm's innovativeness.

Research Question 3: What are the practical implications of the S-curve?

In this final research question, the practical implications, i.e. the usefulness of S-curve theory for use in a real-life business environment, will be evaluated. As explained previously, there are several sources of critique upon the use of this theory.

1.4. Research Method

1.4.1. Relevance

In an academic perspective, this paper will give an overview of the S-curve paradigm that has an important influence on research and practice of companies pursuing technological innovation. This overview will enable understanding of the deeply rooted aspects of S-curve theory without having to read and research this phenomenon. On the managerial side, the overview will enable managers to get acquainted with the main takeaways without having to get into a field of research of which the importance can be doubtful.

1.4.2. Research Design and Data Collection

The databases of Science Direct and World of Science (WOS) will be used to identify relevant articles. The article by Foster (1985), will be used as guideline. Unfortunately, I could not find this article in WOS and therefore could not identify who used this article as a reference. However, on Google scholar a list of 104 articles comes up that have this article in their reference list. This list will be researched. Articles that have relevant information on S-curve theory will be used to answer the research questions. Also, focus will be on Christensen and Tellis, who wrote extensively about S-curve theory. To identify the origins of the theory, Abernathy & Utterback provide relevant insights, and Sahal has written extensively in this subject too, which will be considered.

1.5. Structure

The paper is structured as follows: firstly, chapter two to four will deal with the answering of the three different research questions that have been provided and explained above.

For example, in chapter two, which concerns the origins of the S-curve theory, the S-curve will be explained from its roots, starting with Schumpeter (1939) who was the first to analyze innovation and technology trajectories as a cyclical process. Later on, research suggested the S-curve and proved this empirically.

Furthermore, chapter three will be used to explain the evolution of the S-curve theory throughout its brief history. Emphasis will primarily be put upon forces, both in- and outside the firm, that drive innovation and ergo shape the S-curve. Additionally, in chapter four, the practical implications of S-curve theory will be extensively explained: the theory itself has found support under many researchers in the field of innovation. Still practically, for management purposes, the theory seems to have little value. Thus, the weak points of S-curve theory will be set out here.

Secondly, and finally, chapter four will be used for summarizing the main insights that have been gathered throughout the paper; from which conclusions can be drawn which, additionally, enabled forming an answer the problem statement.

1.6 Overview of the chapters

The structure of the report will be according to the sequence of the research questions, after which an overview will be provided in the conclusion

Chapter 2:

What is S-curve theory and how is it established?

This chapter will provide S-curve theory of innovation from its roots, starting with Schumpeter (1939) who was the first to analyze innovation and technology trajectories as a cyclical process. Later on, research suggested the S-curve and proved this empirically.

Chapter 3

How has S-curve Theory evolved over the years?

Over the years, much more research was done in this field and important for the S-curve's shapes are forces driving innovation itself. This chapter will point out which forces from both outside and inside the firm these are.

Chapter 4

What are the practical implications of the S-curve?

The theory itself has found support under many researchers in the field of innovation. Still practically, for management purposes, the theory seems to have little value, specifically when it comes to discontinuities, the transition between two S-curves. The weak points of S-curve theory will be set out here.

Chapter 5

The last chapter will provide an answer to the research question by summarizing previous chapters. The two main problems concerning the lack of managerial value of S-curve theory will be described and the solution to counteract this problem is introduced.

Chapter 2: The origins of the S-curve theory

For this chapter a funnel methodology is used to explain the path from the origins of research in innovation to the S-curve theory itself. One of the earliest to use the concept of S-curve theory regarding technology was Fisher (1971), who created a mathematical model by using data from 17 industries. However, before going into the specifics of the S-curve, the concept of innovation, specifically technological innovation, will be made clear as this is what the S-curve shape refers to in this report.

2.1. Technological Innovation

If one desires to discuss the S-curve theory of technological innovation, the concept of innovation needs to be clarified first. Multiple researchers (Adner, 2004; Sahal, 1981; Sood & Tellis, 2005) refer back to Schumpeter (1939) when explaining the origins of the S-curve theory and innovation trajectories in general.

Innovation is described by Schumpeter by using the term production function. This function is used to identify the processes within the firm on a technological level. The building blocks of this function, the factors, are for example raw materials, labor, semi manufactured products, and added services. The mix of these factors leads to a certain outcome, the production level. When the quantity of the production factors change, the level of output also changes. Still, this change is not referred to as innovation. Only when the form of the function itself changes, it is called innovation.

Describing specifically technological innovation, ‘curves’ are used. These curves represent a specific production factor. Physical laws allow such a production factor to increase physical outcome, until a certain point, where an innovation takes over and starts a new ‘curve’. Later on, this process of creation of such a new curve is referred to as architectural innovation by Christensen (1992b), which will be discussed in the next chapter. This process of creating a new curve can be clarified with an example, such as the invention of the car taking over the market of coaches. The latter was improved over time, creating faster and more comfortable coaches, using different materials, but still using the same production function. Only when the car emerged, the production function itself changed, causing innovation. A new curve was born.

Schumpeter (1939) does not represent this graphically, but in essence this curve is S-shaped. Although the explanation of technological innovation is mainly focusing on the physical aspect of the products or the physical aspects of its production factors, social and economical factors play an important role as well, because these determine the trajectory of a technology. If the market does not desire a certain technology, it is far less likely to be developed.

Next to that, if the benefits of a certain technology do not councompensate for the costs, it is also less likely to finish its S-curved shape. While Schumpeter focuses on pure and theoretical aspects of innovation in general, later research, by e.g. Abernathy & Utterback (1975) incorporate social and economical factors by adding that product innovation, by means of new technologies or combinations of technologies specifically are *‘introduced commercially to meet a user or market need’* (pp. 642). The view of Schumpeter, using the production function to analyze technological innovation, is later referred to as the ‘neoclassical view’ by Sahal (1981). In the evolution of the S-curve theory and technology trajectory research, multiple external influences rather than solely internal factors of the firm are subject of research. This will be explained further in the third chapter.

2.2. The S-Curve

In the desire to predict the future, research focused on modeling the behavior of technological innovation and technologies itself. That is where the S-curve of technology emerged. However, S-curves are used in literature to explain multiple events. Therefore an explanation of the S-curve, as used in this report, is necessary.

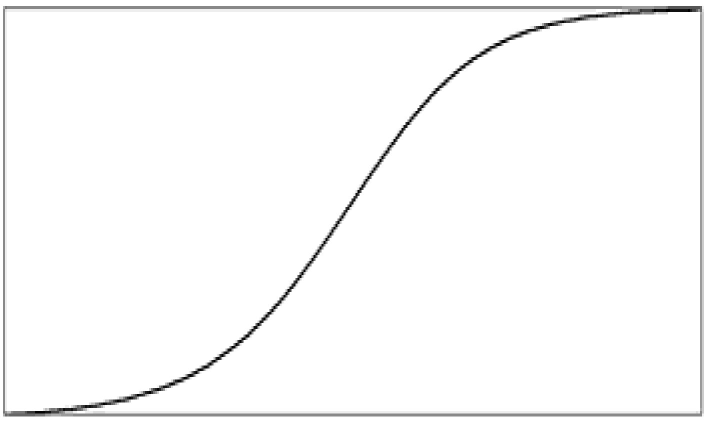


figure 1. Basic S-curve

For example, Tidd & Bessant (2009) use the S-curve as used earlier by Rogers (Rogers, as cidted by Tidd & Bessant, 2009), to explain the process of diffusion of a product, meaning *‘the process by which an innovation is communicated through certain channels over time among the members among members of a social system’* (pp. 350). Although it is related to innovation and technology, it is a different use of the S-curve from the one in this report. The view of Tidd & Bessant (2009) represents the S-curve as the trajectory of the market penetration of a product over time.

As an example the adaptation of a technology like the color television is explained: in the years just after the introduction, diffusion is slow and increasing at a low pace, representing the relatively slow rising part at the beginning of the curve. Then, when a product becomes the industry standard, the largest part of the potential market will ‘accept’ the technology, and diffusion pace increases fast, representing the middle part of the curve, where it gets steep. Finally, in the last phase, the technology is at its peak, all potential customers are using the new technology and diffusion reaches its maximum, which is represented by the S-curve becoming a horizontal line again, at the end.

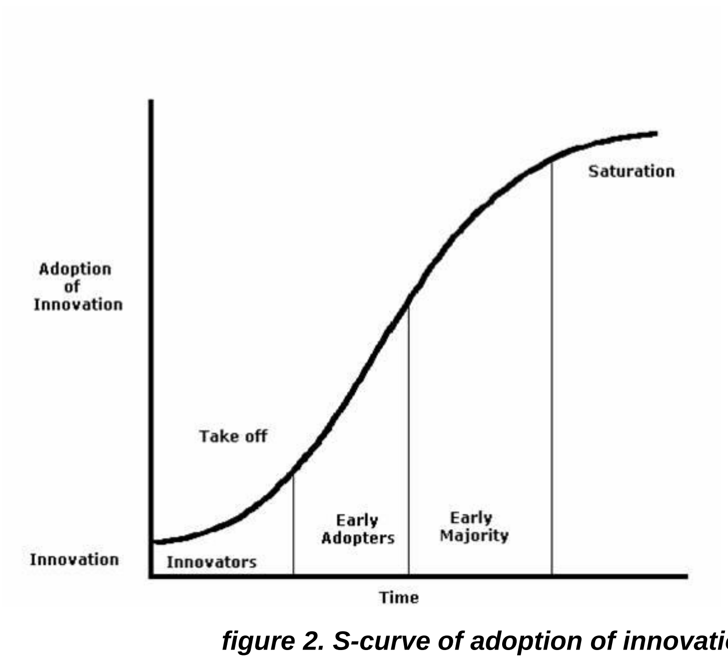


figure 2. S-curve of adoption of innovation[1].

The first to use an S-curve as a representation of the evolution of a technology are Fisher & Pry (1971), who developed a model to forecast substitutions of technology

[1] http://www.globe-online.com/philip.uys/phdthesis/chapter2_files/image002.jpg

by investigating the substitution of 17 technologies, including several ones from natural fabrics to plastics. Their starting point was to create a simple model to predict substitutions of technologies. The assumptions founding this model were that new technologies initially are less developed and therefore have to compete with old, well developed technologies, causing a slow growth in the initial phase.

Foster (1985), uses the example of steamships vs. sailing ships to clarify this. As the first steamships were introduced, the technology was in its initial phase and therefore in an experimental phase, in which many things went wrong and things like efficiency and reliability were yet far away, causing heavy competition between this new technology and the old one. On top of that, the threat of steamship technology taking over the market boosted the sailing ship technology, which was able to push their limits by developing larger and faster ships, using less crew. In the end it became clear that this only postponed the takeover time of steamship technology to take over.

However, once this initial phase is survived, Fisher & Pry argue that the technology will emerge and ‘proceed to completion’, growing at a faster rate now, as competition with the old technology decreases. When the S-curve is half-way, it can be reflected horizontally, as at the end of the curve another new technology will take over. After researching the 17 transitions mentioned previously, the predictive value of the S was found proven, at least for these 17 substitutions. Plotting the data in the mathematical model the figure below was the result. Basically it confirms that for the industries researched, the technology (product) trajectory has an S-shaped form.

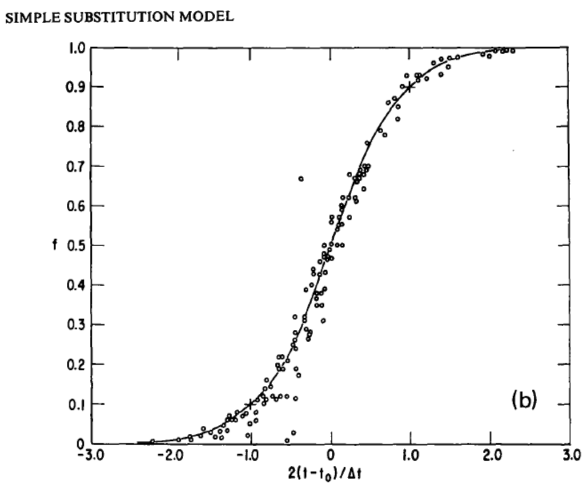


figure 3. Simple Substitution Model (Fisher & Pry, 1971)

Findings by Fisher & Pry (1971) were tested empirically by Hatten & Piccoli (1973). They evaluate the model by taking the focal point of a manager concerned with long-term planning. The model was used to predict the future from a certain point onwards. This was compared to what actually happened, because that data was available, and they concluded the model had a 'fairly high' degree of confidence. In itself, this statement is somewhat weak. Scientific literature should be concerned with certainties and uncertainties, not about personal qualifications of (un-)certainties. Still, this article was published in the (proceedings of) The Academy of Management Journal, a highly respected journal nowadays.

However, Hatten & Picolli (1973) do have an interesting critique on the Fisher & Pry model, which is that there is no provision for new product failure (or success). With the model, it is possible to tell (roughly) when the S-curve will be at its end, but which S-curve will take over is yet to be discovered. This question continues to haunt S-curve theory trough its history.

In the table shown below, a short historical overview of the main events concerning the foundation of modern-day S-curve theory, as explained in this chapter, is provided.

Schumpeter '39	*Technical innovation can be seen as 'product function'*
Fisher & Pry '71	*The s-curve model is created and used for forecasting the substitution of technologies*
Hatten & Piccoli '73	*Tested Fisher & Pry's model (1971) – main critique: s-curve gives no provision for new product failure or success*

Chapter 3: The Evolution of the S-curve theory

Now the origins of S-curve theory and its basics have been discussed, this chapter will elaborate on the main views, advancements and conceptions of it. First, forces driving innovation will be discussed, as they play a major role in the shape and evolvement of individual S-curves. This will be done in representing a micro view, consisting of factors inside the firm, and a macro view, which has its focus on factors originating outside of the firm. After that, the specifics of the S-curve will be discussed. Its characteristics have many implications for firms on how to execute successful innovation processes.

3.1. Forces Driving Innovation; a Macro Perspective

When analyzing the different forces that drive innovation, it is worthwhile to create a distinction between forces that come from inside the firm (the micro perspective), and those that drive innovation from the outside (the macro perspective). The latter forces will be dealt with first.

3.1.1. Systems view of technology

While Schumpeter (1939) focuses on the internal factors of the firm, regarding innovation as a change of the production function driven by the desire to minimize cost, academics start to consider innovation as part of a larger framework of forces. Sahal (1981) refers to this as the 'system' view of technology.

Contrarian to the assumptions of Schumpeter (1931) the availability of resources is looked upon at as the driving factor of innovation. One cannot simply apply more resources to a process to increase efficiency. Many other factors have an influence on this, like historical, social and political factors. This may result in cases of different technologies existing side by side. The example used by Sahal (1981) is that of developing countries, where different methods may be used for production because of a lack of resources. This systems view also takes economical feasibility of technologies into account.

Another aspect of this view is that it recognizes technological change as interdependent with its environment. Technology advances because of historical events. If one considers the tractor, many inventions together made this possible, like the invention of technologies such as: ‘pneumatic tires, power take off, …, hydraulic lift, enclosed transmission, twin disc clutch, removable cylinder lines, antifriction bearings, power steering, and torque amplifier’ (Sahal, 1981, p.15).

Another example is the fact that World War II caused a major wave of innovation in the field of weapon systems. R&D budgets were increased which caused this. This illustrates that historical events may have an influence on the process of innovation.

Similar to the systems view of technology is the thought of technology driven by a ‘technology paradigm’. This is to be concerned similar to scientific paradigms, also known as ‘research programs’. This is what Dosi (1981) suggests. Such a paradigm has many dimensions on many different levels. Procedures regarding knowledge and knowledge gathering, expertise, experience and skills all shape a form of behavior that drive technology in a certain direction. This also forces the phenomenon of blindness to other technological possibility, also referred to as ‘the exclusion effect’. Such a pattern and procedure of behavior goes much further than firm level or industry level, such a paradigm is also shaped by economic, social, institutional and political factors.

3.1.2. Technological architectures

Christensen (1992b) makes a distinction between architectural and component technologies. The latter will be discussed in the next part concerning micro level forces driving innovation. The former, architectural technology, can be seen as a platform technology. The distinction on which the article by Christensen (1992a, 1992b) is made came originally from Henderson & Clark (1990), researching the consequences for incumbent firms.

An example of such a technology is the propelled engine vs. the jet-engine. Back in the days that jet engines did not yet exist, the technological paradigm was focused on these propelled engines, resulting in innovations improving specifically this technology. Nowadays, the jet-engine causes propelled engine improvement to cease, as the technology is superseded. In that way, the architectural technology of the jet-engine determines the direction of innovation. There is no use for a company to start developing more fuel efficient or faster propelled engines as there is no demand for it.

3.1.3. The market

A third macro level influence driving technology is provided by Rosenberg. In his 1988 article, Butler summarizes his view, focused on the interdependence of technologies. The foundation of this view is that technological innovation originates in the desire to increase productivity. It is suggested that 'learning by using' occurs, driving technology into a certain direction. Different perceptions about this direction cause uncertainty over how technologies will mature and evolve. The adoption of new technologies is dependent on producers and their confidence in the future of their product, which will determine their investment in the technology and thus advancement of it. On the other hand, there are buyers that need to have confidence in the future possibilities of this technology as they want to use it in the future. If they have little faith in its future and consider it to become obsolete, they will not buy it, which will in turn influence the future of the technology provided by the producers. In this sense, technological innovation is a process influenced by many other factors than simply technological advancement, efficiency issues and cost driven factors.

An example for such a technology is DCC technology, invented by Philips. This technology was brought to the commercial market in 1992 and discontinued four years later, because of a lack of sales. Customers had little faith in its future value, causing an end to the technology. In this sense, the market itself influenced the technology trajectory of the DCC.

Dosi (1981) also refers to this phenomenon. In his article, a distinction is made between 'demand-pull' theories and 'technology push' theories. Former is similar to the 'using by learning' process described above, but the former originates from the producers. Its driving mechanism is economic force. If there are better (cheaper) possibilities for companies to satisfy needs of customers than before, the industry will push a technology into the market.

3.2. Forces Driving Innovation; a Micro Perspective

The previous part was focused on the factors from outside of the firm that have an influence on the existence of an S-curve. This part is focused internally, on the distinct pattern of a technology itself. Abernaty & Utterback (1975) make a distinction between process technology and product development. Similarly, Christensen (1992a) focuses on component technology, the technological advancement and improvement of parts and characteristics of a product, rather than a new product as a whole. This part will elaborate on these views.

3.2.1. Process technology

Suggested by Abernathy & Utterback (1975) is that process technology follows a distinct pattern. Process technology is concerned with the system in which products are produced, meaning materials, equipment, workforce, information flows and so on. Over a life cycle of a product, the process technology follows a distinct pattern. This pattern is ultimately seeking increased productivity and decreased cost, in short, efficiency.

There are three stages of this process technology development process, the *uncoordinated*, *segmented* and *systemic* phase. In the first phase, the uncoordinated phase, products and thus processes are redefined quickly as there is no clear view of where the developments are going. In figure 2 this is represented graphically. As physical aspects of the products are adjusted to answer customer preferences, process technologies have to be adjusted too. In the next phase, the segmental phase, there is a more clear view of what the product should be like. This increases competition among the firms operating in the industry, which forces companies to strive for efficiency. This results in a segmented process of production, where parts of the process differ in quality. Finally, in the *systemic* phase, an integrated process has occurred. Changes to this process are therefore more difficult, because a minor change somewhere in the process will have consequences for the rest of the process and will therefore be drastic and costly.

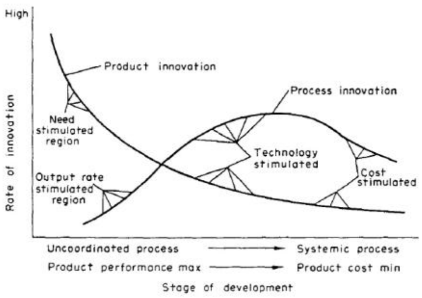
3.2.2. Product development

A similar three phased pattern is suggested for product development processes. The three phases are respectively *performance-maximizing*, *sales-maximizing* and *cost-minimizing*, originating from a product innovation, which is referred to as '*a new technology or combination of technologies introduced commercially to meet a user or a market need*' (Abernathy & Utterback, 1975, p. 642).

The first phase is characterized by exploring the physical performance of a commodity, in such a way that it will meet customer requirements. As both these market requirements and technological characteristics of the product are ill defined, this is a dynamic phase. Sources of innovation can be developed inside the firm but will usually be found outside.

In the second phase, sales-maximizing is pursued. By now, experience of users as well as producers enabled a better defined product and market, leading to increased competition, which in turn leads to product differentiation. As this process advances, other non physical aspects such as marketing, service and supply chain management become more important. Also component improvement will characterize this phase.

In the last phase cost-minimizing is the main focus. As the commodity approaches its technological limits and innovation is costly effort will be in seeking to reduce costs.



figue 4. Stages of development (Abernathy & Utterback 1975)

Although Abernathy & Utterback do not use the term S-curve, they do explain the concept, and the underlying forces driving innovation. If the figure to the left would have '*maturity of the technology'* on the vertical axis and '*time'* on the horizontal axis, an S-shaped curve would appear.

3.2.3. Component technology

Another driving force for innovation on a firm level is component technology. According to Christensen (1992a), component technology follows the pattern of an S-curve. If a certain architectural technology has emerged, component technology will emerge, starting to improve the product piece by piece. The example used to explain architectural technologies, airplane engines, can be used here as well; if such a new technology has become industry standard, innovation is driven by improving characteristics and components of this architecture. One could think of designing more fuel efficient engines, using lighter and more durable materials.

All in all, there is no simple answer to the question of how S-curves are established and how they will develop. Many factors, coming from outside the firm as well as inside, determine the shape of it; this has a major influence on firms operating in the market of such a technology.

For the sake of clearing the content of this chapter, the micro- and macro-forces that shape innovation have been summarized in the table below.

3.3 Technological transition & discontinuity

Over time the concept of the S-curve became generally accepted, and research focused more and more on the period between two s-curves, the discontinuity phase, as this is the major challenge. Literature provides many case studies of companies that lost their leading position (Foster 1986; Christensen, 1997), potential ways of fighting these threats. Still, even though companies are warned by these, and aware of the fact that S-curves do have an end, the problem of which S-curve to hop on to keep competitive advantage remains. Christensen (2000) suggests that disruptive technologies are the ones that companies should be watching. Although there is no consensus about the exact specifics of what these are, as Danneels (2004) points out, disruptive technologies are characterized by being initially underperforming and unable to satisfy market requirements, but after a period of improvement, they will take over the current technology. The next chapter will treat this more into detail, as it will be about the practical issues concerned with handling the phase of discontinuity and disruptive technology.

To wrap up, the table below lists the forces that drive innovation and thus the S-curve. It provides the factors originating from outside the firm as well as from inside the firm.

S-curve; forces driving innovation	
Macro factors (outside)	*Systems view (Sahal, Dosi)*
	Technological architectures (Christensen)
	The market (Butler, Dosi)
Micro factors (inside)	*Process (Abernathy & Utterback)*
	Product (Abernathy & Utterback)
	Component technologies (Christensen)

Chapter 4: The Practical Implications of the S-curve

In this chapter, research question three – which deals with the practical use of s-curve theory – ought to be answered. Main emphasis will thus be on the implications of applying the s-curve theory of innovation in real-life business environments. Furthermore, also possible alternatives to the s-curve paradigm will be provided.

4.1 The position in the S-curve

As Sood & Tellis (2005) argue that a technology might not have a completely symmetrical S-shaped curve, it is difficult to assess the trajectory of the technology. On top of that, this hinders the assessment of where exactly one is situated among this curve. Dahlin & Behrens (2004) delineate this. It requires extensive data to put together such a curve, resulting in a time consuming and complicated process. Next to that, the shape of the S-curve also depends on the presence of radical technologies. As S-curve theory does not define a process how to assess these, it does not provide managers with useful tools.

4.2 Technological transitions

One of the largest problems concerning S-curve theory is the process of the technological transition, also known as the technological paradigm shift. This refers to a ‘revolution’ in technology, the point where a new technology takes over, changing the technological landscape dramatically. The fact that this process of S-curves succeeding one another will happen is inevitable (Foster, 1985; Christensen, 1995; Hill & Jones, 2004), but which technology will take over, that is the million dollar question. The volatile phase in which this shift takes place is referred to as a discontinuity (Foster, 1985; Danneels, 2004).

The difficulty is not so much that it is coming, because companies have learned from the S-curve that a new one will follow at the end. The problem is that the new technology that will become the industry standard can come from any direction, meaning above (high performing) and below (disruptive), from incumbents as well as newcomers, and at a fast or slow pace (Cooper & Schendel, 1976). This process is called 'swarming' (Hill & Jones, 2004). This 'swarming' is represented graphically below.

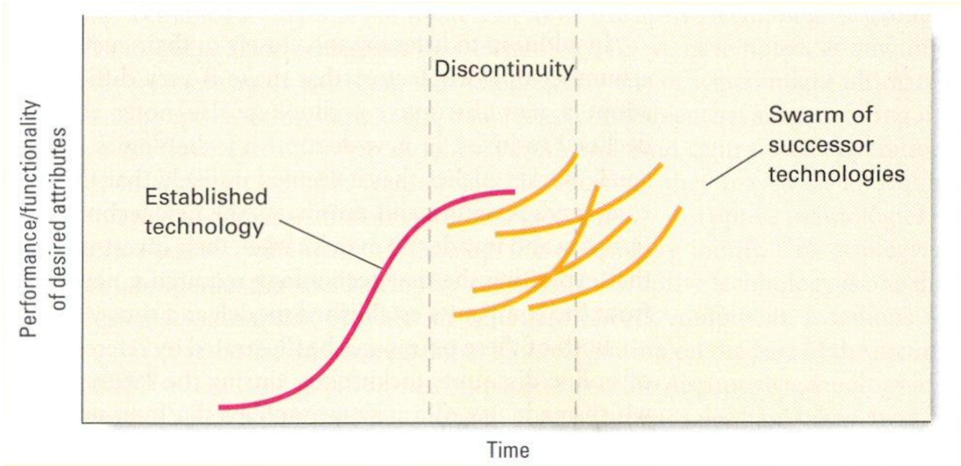


Figure 5. Swarm of successor technologies (Hill & Jones, 2004).

The first suggestion to cope with the fact that technologies do mature and become obsolete is to avoid focusing too much on current technology. This 'technological myopia' (Foster, 1985) is a managerial tendency described later as 'the fat cat syndrome' (Mullens, 1996). Companies that are currently successful with a certain strategy, which in turn might be a technology, are inclined to see no threats to this. Lucas & Goh (2009) provide a clear example of this by representing a case study of Kodak, missing the digital revolution completely. Although this is useful advice, it is rather vague and logical.

Christensen (1995) refers to this as well, suggesting that managers should be aware of their environment and should not underestimate technologies that do not meet market expectation at that moment in time, because in the future they might be a threat to the existing technology. This is a very nice suggestion but when a manager is confronted with a situation as in figure 5, it is extremely difficult to analyze and keep up with all individual technologies in the swarm.

Another suggestion is to invest in R&D. The problems here are again that there are so many emerging S-curves in the swarm. If a company should invest in all of them, there is not enough money to do so. Another view of technology trajectories by e.g. Phaal (2004) is technology road mapping. This technique assumes firms and businesses to have an influence themselves. In his article is suggested that companies can push technologies into the market or anticipate to market needs. This requires all business units to design and comply with plans made. This is the only way to focus towards this new technology.

4.3 Predictive value

A second major implication for practical managerial use is the lack of predictive value of S-curve theory. Danneels (2004) accuses Christensen of cherry-picking, using only case studies that support the view of disruptive technologies taking over the market eventually. Disruptive technologies initially underperform current technologies but later on will take over the market. Examples used are those in the disk-drive industry, where 14 inch drives technology was taken over successively taken over by 8 inch drives, 5.25 inch drives and 3.5 inch drives. In all cases the successor was initially underperforming.

This being said, the question that remains is if this enables ex ante predictions with this knowledge. Suggested is that it is virtually impossible to do so, as external market conditions, like the macro factors that drive innovation mentioned in the second chapter. As described, innovation takes place within a system of events and therefore difficult to predict. The need for more case studies that also contradict the assumption of disruptive technologies taking over the market is necessary, to broaden the perspective and to be able to provide tools to managers to asses new technologies in a non-prejudiced way.

Sood & Tellis (2005) even question the assumption of the existence of the single S-curve at all. Firstly, their research of 14 technologies shows that technology trajectories also may follow a stepped pattern, where periods of relatively fast improvement of the technology are succeeded by periods of virtually no advancement. Next to that, the assumption of Christensen (1997) that succeeding technologies come from below, that is, they are initially underperforming and are neglected by incumbents is challenged, as only 6 out of 14 technologies researched were at the point of introduction underperforming. Also, the curves of the new and old technology might intersect more than once.

On top of that, Sood & Tellis (2005) found that technologies might experience multiple S-curves after one another. At the end of an S-curve, technology is pushed (or pulled) again, leading to a new increase at the end of the initial curve. A managerial implication could that a manger might wrongly assume to be at the end of an S-curve. And when facing this, the manager might wrongly search among currently underperforming technology to find the successor of the technology in use.

Tellis (2006) does agree with Christensen (1992a,b) that managers should not focus only on their current technology and keep their eyes open for technologies that will threat current business. However, he sees more value in visionary leadership, willing to cannibalize current assets to embrace new technologies, than in the predicting value of S-curve theory.

4.4 Technology roadmapping; an alternative to S-curve theory.

To counteract the deficiencies of S-curve theory, specifically the lack of managerial implications to overcome the discontinuity phase, a new paradigm is emergent; technology roadmapping. Contrary to S-curve theory it provides a more strategically view of technology trajectories. It analyses the business process not only form traditional finance based thinking but as a whole, integrating information technology and supply chain management (Petrick & Echols, 2004). It provides an integrated framework, beyond the level of product and technology planning (Phaal et al., 2004). The starting point of this view of technology is that it should be considered as a type of knowledge, comprised of tacit and explicit knowledge, which form a technology. The advantage of treating technology as a type of knowledge is that in this way it can be managed easier. Knowledge management enables a clear overview of physical equipment, knowledge and capabilities needed. The type of management needed to organize this process, technology management, is defined as: "Technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies (product, process and infrastructural) needed to achieve, maintain [and grow] a market position and business performance in accordance with the company's objectives". (Phaal et al, 2004, pp 7). Using this definition, the gap that is left by S-curve theory in solving the problem of technological transitions is addressed very thoroughly. Especially the fact the last part of the definition, that it should be in accordance with the companies' objectives, provides a much more focused view on technology. It enables managers to 'stand back' and analyze the process as a whole.

The basics of technology management should integrate technological issues into the different business processes, being (Phaal 2004):

- Strategy development
- Innovatioin
- Product development
- Operations management

Together with organizational culture and the environment of the firm this is represented graphically below.

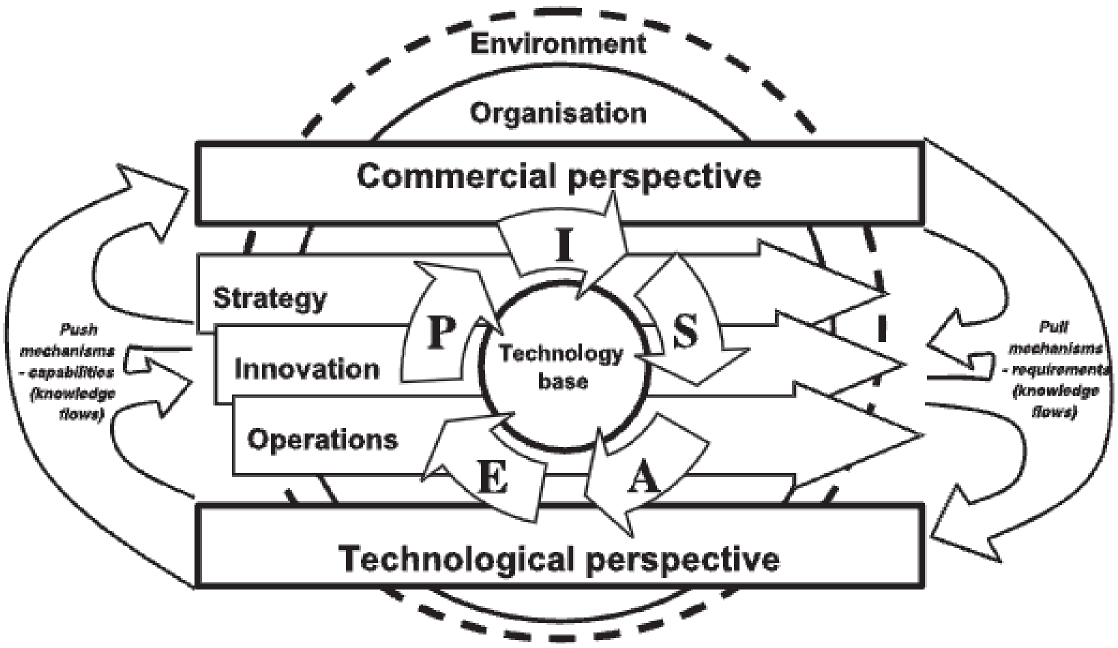


Figure 6. The technology management framework. (Phaal et al., 2004).

The characters in the arrows originate from Gregory (as cited by Phaal, 2004) and represent five key processes that are a condition for effective technology management; *identification, selection, acquisition, exploitation and protection* of technology. Using this framework, managers should be able to address the practical gaps left by S-curve theory.

The problems concerning practical implications of modern-day s-curve theory, and the possible alternatives to this theory, that have been explained in this chapter, are shown in the table below.

Practical Implications of S-curve theory; difficulties
1. Position in the S-curve ➢ Determining the position in the S-curve • Extensive qualitative measure depending on assessment of environment
2. Technological paradigm shift – technology transitions ➢ 'swarming' • Multitude of disruptive technologies hampers effectiveness • Unclear which technology to invest in
3. Lack of predictive value ➢ Successor technologies may come from anywhere (up, down, incremental, radical) ➢ Characteristics of the S-curve are not clear • Multiple S-curves in one single technology • S-curves may intersect multiple times
Alternatives to S-curve theory
✓ *Technology roadmapping* ➢ *Technology as knowledge; better to manage* ➢ *Integrate technology in all business processes & environment* ➢ *Technology as a part of strategy*

Chapter 5: Conclusion: the pros and cons of the S-curve

Now that the three different research questions have been thoroughly explained and answered, it is worthwhile to shortly recap the highlights of this paper, in order to draw conclusions and answer this research' problem statement.

5.1. Summary

The starting point of S-curve theory lies in research conducted early in the 20th century, mainly by Schumpeter (1939) who was the first to consider technological innovation to be a cyclical process. Later that century the actual S-curve of technological innovation was born, as Fisher & Pry (1971) designed a mathematical model to represent this process.

After this, literature focused on the different forces driving technology and having an influence on the trajectory of technology. External factors, represented in the 'system's view' of technology, technology architectures and technological paradigms, were introduced and enabled a macro perspective of technology trajectories. Next to that internal factors of the firm influencing this trajectory, being process, product and component technology, shed more light to the subject.

This research caused S-curve theory to be generally accepted. However, knowledge about the trajectory that a technology follows, did not result in useful practical implications for managers. This specifically occurs when managers are confronted by technological transition, where one curve succeeds another. The multitude of emergent S-curves in such a phase combined with uncertainty about the exact form and length of the current S-curve gives managers no more than an indication of what will happen, and when.

A relatively new scientific paradigm, technology roadmapping, which only saw daylight at the beginning of this century, has promising value in addressing the managerial implications brought up by the gaps that are left by S-curve Theory.

5.2. Managerial usefulness of S-curve

To come to the conclusions of this research, the problem statement is repeated;

What is the practical value of *S-curve theory of innovation* to managers today?

The practical value of S-curve theory of innovation for managers is low. This report is written as a guide to this conclusion. Starting point is the list of forces, internal to the firm as well as external, that drive innovation and thus the shape of the S-curve. The managerial implications given by literature are twofold:

1. Managers should look outside of the firms' boundaries and not only focus on currently successful technology. Different researchers (Foster,1985; Christensen, 1995) suggest this, but argued it is a rather broad, vague, and logical advice. As other researchers argued (Cooper & Schendel, 1976), disruptive technologies may come from anywhere, meaning performing better or worse than current technology, and come up fast (radical technology) or slow (incremental) technology. This makes it virtually impossible for managers to spot the right technology that will take over the current.
2. Once the S-curve is half way, investment in R&D is needed to be able to create a successor technology. This advice seems rather one sided. First of all, a technology does not have to be developed internally; it might also be incorporated from elsewhere. Next to that, one does not know the end of the current S-curve as it might have a different length or shape than just a simple S-curve (Sood & Telllis, 2005).

Both implications above require more comprehensive tools for managers to manage technologies and the phases of discontinuity. An emerging paradigm in science offering this comprehensiveness is technology roadmapping, specifically technology management, as it offers a framework to incorporate technology into both the business process in all its forms and the environment.

5.3 Suggestions for future research

This report is aimed analyzing the S-curve theory of innovation in the field of managerial implications. As a suggestion to fill in the gaps left by this theory, technology roadmapping is presented. Because this scientific paradigm is relatively new, empirical evidence is needed to evaluate its managerial value. This is a difficult process, as researchers need to be able to go deep into organizations to determine the integration of technology into business processes, for which access deep into organizations is required.

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