Understanding Technology Evolution: The Fallacy Of The S-Curve

A closer look at the accepted evolutionary theory of technology reveals a flawed model that may also act as an impediment to innovation.

Understanding technological innovation is vital for marketers for several reasons. First, technological change is perhaps the most powerful engine of growth. It fuels the emergence of new brands, creates new markets and transforms small outsiders into market leaders.[1]

To date, the topic of technological evolution has been studied primarily in the technology management literature. A central premise of these studies is that performance of a new technology starts below that of an existing technology, crosses the performance of the older technology once and ends up at a higher plateau, tracing a single S-shaped curve (see Figure 1). There is scattered empirical support for the premise and limited theoretical support for various aspects of the S-shape curve.[2]

Nevertheless, belief in this premise is so strong it has become a law in the strategy literature. Numerous authors have derived strong managerial implications about this premise.[3] They have warned that even though managers might be able to squeeze out improvements in performance from a mature technology, the improvement is typically costly, short-lived and small. Thus, the primary recommendation is that managers quit a maturing technology and embrace a new one to stay competitive.

However, firms cannot gain from technological change if they do not understand it well. A central practical problem that faces managers is deciding when to shift investments from the old to the new technology. If the S-curve is indeed valid, then the appropriate time for the shift would be the inflection point of the S-curve. After this point, performance improves at a decreasing rate until maturity. New product development and major investments in research depend upon a proper understanding of technological evolution in general and of the S-shaped curve in particular. It is also important to know the dimensions of competition between technologies, the process of transition between old and new, and the source of innovations.

Currently the main sources of answers to all these questions are limited findings in technology management literature. [4] These sources promote a theory commonly known as the theory of S-curve. Our study tests this commonly accepted model of technological evolution.

PREVAILING THEORY

The technology literature has coalesced around two aspects of the evolution-of-technologies theory: a strong consensus has developed about the phenomenon of the S-curve itself, while a consensus is emerging about the major explanation or theory for this phenomenon. As stated, prior research suggests that technologies evolve through an initial period of slow growth, followed by one of fast growth culminating in a plateau. When plotted against time, the performance resembles an S-curve.

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The technology management field does not enjoy a single, strong and unified theory of technological evolution. However, researchers theorize that technology evolves through three major stages of the S-curve of technological evolution: introduction, growth and maturity.

**Introduction Stage**
A new technological platform initially makes slow progress in performance during this early phase of its product life cycle. Two reasons may account for this situation. First, the technology is not well-known and may not attract the attention of researchers. Second, certain basic but important bottlenecks need to be overcome before any new technological platform can be translated into practical and meaningful improvements in product performance. For example, the laser beam was a new platform that required much time and effort to achieve the safety and miniaturization required for a surgical tool.

**Growth Stage**
With continued research, the new technological platform crosses a threshold, after which it makes rapid progress. Three factors may account for this change: a dominant standard has emerged; product characteristics and consumer preferences coalesce around the new standard, and a larger number of researchers are attracted by the publicity of the standardization; and an increase in sales of products translates into greater support for research.[5]

**Maturity Stage**
After a period of rapid improvement in performance, research suggests that the new technology reaches a period of maturity when progress occurs very slowly or reaches a ceiling for various reasons: innate characteristics of a technology, changing focus of innovation as markets saturate, fears of obsolescence or cannibalization, and limits of scale or system complexity.[6]

**DEFINITIONS**
The theory in this area has been partly founded by the use of circular definitions. So this section starts by defining various types of technological innovations independently of their effects.

Beginning with an early study researchers have used a wide variety of terms to describe innovations. Many terms such as *revolutionary, disruptive, discontinuous* or *breakthrough* are intrinsically problematic, because they define an innovation in terms of its effects rather than its attributes.[7][8] If the definitions are then used to predict market outcomes (new entrants displacing incumbents with disruptive technologies, for example), researchers run the risk of asserting premises that are true by definition. To avoid such circularity, we define technological change in terms of intrinsic characteristics of the technology. As such, we identify and define three types of technological change: platform, component and design. We define a platform innovation as the emergence of an entirely new technology based on scientific principles distinctly different from those of the existing technologies. For example, the compact disk used a new platform (laser optics) to write and read data, whereas the prior technology used magnetism. We define a component innovation as one that uses new parts or materials within the same technological platform. For example, magnetic tape, floppy disk and zip disk differ by use of components or materials, although all are based on the platform of magnetic recording.

We define a design innovation as a reconfiguration of the linkages and layout of components within the same technological platform – for example, the changes in floppy disks from 14 inches to 8 inches and then to 5.25, 3.5 and finally 2.5 inches, although all based on the platform of magnetic recording.[9]

Our study focused on the evolution of technologies. Within any platform innovation, performance improves due to innovations either in components or design or both.

**METHOD**
A ready-made database does not exist for the study of technological evolution. So we collected our own data using the historical method. The benefits of using an historical method include freedom from survival and self-report bias, ability to assess causality through longitudinal analysis and new insights from a fresh look at history.

We selected a portfolio of categories including some that had been investigated in past studies and others that had not been researched. This coverage allows us to compare our results with past studies and offer validation of our findings in new categories. However, the present study goes further than previous studies in one important aspect: within each category we selected a comprehensive set of technologies – and not only those that were successful. On the basis of these investigative criteria, we chose to examine data transfer, computer memory, desktop printers and display monitors.

The primary sources of data on product performance at different stages of its evolution were reports in technical journals, white papers and annual reports of industry associations, press releases and records in museums that profiled the development of industries.

**RESULTS**
We tested hypotheses about five aspects of technological evolution: shape, path and dynamics of technological change on
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a primary dimension; progress on secondary dimensions; source of innovations; and pace of technological change.

Shape of Technological Progress
We identified various technologies in each of the markets, each of which was initiated by a platform innovation, and plotted performance of technologies over time: four each in desktop printing (dot matrix, ink jet, laser and thermal printers) and display monitors (CRT, LCD, plasma and OLED) and three each in desktop memory (magnetic, optical and magneto-optical) and data transfer (copper-aluminum, fiber optics and wireless).

We found sparse support for the hypothesis that the path of technological evolution resembles an S-curve. In a majority of technologies, we found long periods of static performance interspersed with abrupt improvements in performance. These plots suggest a series of irregular step functions better approximated with multiple S-curves than a single S-curve. Across these step functions within a given technology, estimates of growth rate – especially performance at maturity – differ substantially.

What we learn from these results is that an analyst expecting an S-shape curve would wrongly conclude that the periods of static performance meet the S-curve hypothesis and that the technology has matured at the upper end of the curve. Substantial improvements in performance after the first plateau suggest a serious error in abandoning the old technology prematurely.

Technological Transition and Performance of Competing Technologies
Do the evolutionary paths of two technologies ever cross? If they do, how many times does it happen? Foster and Christensen postulate the following chain of events in the evolution of competing technologies.

Sometime in the life of an old technology a new technology emerges and makes slow progress on the primary dimension. Later it enters its growth phase and improves rapidly. In contrast, the old technology improves at a much slower rate. As a result, the new technology crosses the old technology in performance. This crossing of the old technology is a signal of the end of its efficient progress (see Figure 1).

On the contrary, we find that a majority of new technologies performed better than the old technology, right from the time they were introduced. Also, many new technologies never improved over the old technology, while others enjoyed brief spells of dominance over the old technology before the old technology regained dominance.

This unexpected pattern of evolution results in three distinct types of crossings between any pair of successive technologies: no crossing at all, multiple crossings and single crossing.

So the final status of each technology cannot be determined solely from the direction of the attack or timing of introduction. As such, it might be fatal for an incumbent to scan for competition only among technologies performing worse than its current technology. Moreover, managers expecting a single crossing are likely to be quite surprised and may make unwise decisions.

Dimensions of Technological Competition
Past research suggests that competition occurs systematically and sequentially along generic dimensions of intertechnological competition: functionality, reliability, convenience and cost. Progress occurs systematically along the first dimension, then moves to the second, then to the third and so on.

On the contrary, our results suggest a sequence of random, unpredictable secondary dimensions in each of the four categories. Each platform technology offered a completely new secondary dimension of competition while still competing on the primary dimension (for example, resolution, compactness, screen size and efficacy in desktop monitors).

We also found that technologies that excel in a particular dimension cater to particular market segments that value that dimension. When the mass market focuses on one old or new dimension, niches that are interested in the other dimensions might still survive. For example, thermal printers are still a popular choice in printing high-resolution pictures.

In summary, we find that although new technologies perform better than old technologies on secondary dimensions, competition evolves in new, unpredictable secondary dimensions instead of the standard four generic dimensions proposed by existing literature.
Pace of Technological Transition
There is evidence of both increasing pace and constant pace of technological change in prior literature. However, most of the studies employ indirect measures due to lack of data. Our rich data allows using three direct measures of the rate of technological change: the pace of introduction of new technologies, the pace of technological improvements within each platform and the annual rate of improvement for each technology. Tests of all three measures support an increasing pace of technological change.

Source of New Technologies
Among those who track technological innovation, the conventional wisdom is that the small outsider is more likely to introduce new technologies. Although these small firms are often ridiculed and ignored by incumbents in the beginning, they eventually become successful and end up as large incumbents with more opportunity and resources for innovations.

In contrast to the dominant view in the literature, we find that platform innovations come almost equally from small entrants and large incumbents. The probable reason is that in recent decades, innovation has gotten far more complex. The deeper pockets of large firms enable incumbents to maintain state-of-the-art facilities to conduct research, while incumbency provides them with opportunity and resources for developing and introducing platform innovations.

IMPLICATIONS
This study has several implications for managers:
1. Using the S-curve to predict the performance of a technology is quite risky and may be misleading for two reasons: most technologies studied do not even demonstrate an S-shape performance curve, and several technologies show multiple S-curves, suggesting that a technology can demonstrate fresh growth after a period of slow or no improvement.
2. The continuous emergence of new technologies and the steady growth of most technologies suggest that relying on the status quo is deadly for any firm. Moreover, technological progress is occurring at an ever-increasing pace. As such, paranoia rather than complacency is healthy.
3. The present findings indicate that the attack from below remains a viable threat. Many new technologies start by offering low performance but later threaten old technologies by improving at a much faster rate. On the other hand, new technologies can perform better than old technologies even at the time of introduction. This fact heightens the threat of competition.
4. Another threat to incumbents is the emergence of secondary dimensions of competition. Old technologies may be completely vulnerable to these dimensions.
5. First-mover advantages may not be lasting since entrants introduced even more innovations than incumbent firms. However, even if incumbents fail to introduce a particular new technology, all is not lost. They need not throw in the towel and divert all resources to the new technology. We found that old technologies demonstrated high levels of improvement even after being dormant and static for many decades, and in some cases regained dominance. In contrast, a misplaced belief in the theory of S-curves might have become a self-fulfilling prophecy and the premature demise of an old technology.

ENDNOTES
4. Utterback, Dynamics of Innovation.