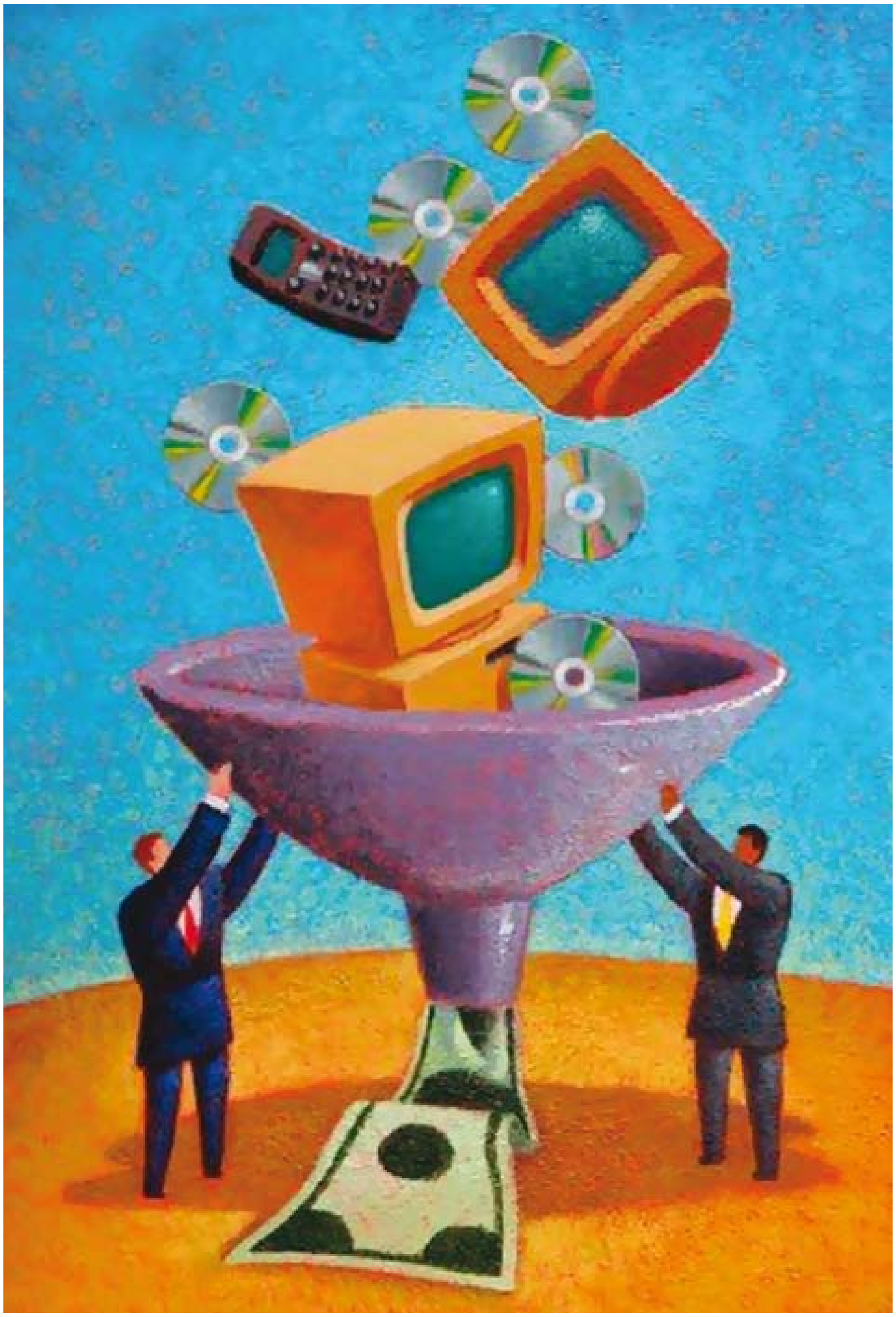


Do the paths of old technology and new technology ever cross? If so how many times? The answer is 'yes'. Then when do they cross and how many times? Here is to find out the ANSWER...

The Myth of S-Curves: Technological Evolution and Product Innovation

While many marketers believe that market segmentation is the 'be all, end all' of growth, technological change is perhaps growth's greatest catalyst. Numerous examples can be cited from the industry to support this claim. First, technological change enabled the growth of Microsoft from a fledgling company to the colossus of the computer industry. Second, emergence of Internet-enabled products (e.g., Walkman, washers, etc.) suggests that technology creates new growth markets. Third, the meteoric rise of Amazon and Dell demonstrates how technological change propels small outsiders into market leaders.

Currently the topic of technological evolution has been studied primarily in technology management literature. The central premise in this literature is that performance of a new technology starts below that of an existing technology, crosses the performance of the older techno ogy once and ends up at a higher plateau, in the process tracing a single S-shaped curve. There is scattered empirical support for the premise and limited theoretical support for various aspects of the S-shape curve (e.g., Foster, 1986; Utterback, 1994a; Christensen, 1997). Nevertheless, belief in this premise is so strong that it has become a law in the strategy literature. Numerous authors have derived strong managerial implications about this premise (e.g., Foster, 1986; Christensen, 1997). They have warned that even though managers might be able to squeeze out improvement in performance from a mature technology,

Ashish Sood
Assistant professor of marketing,
Goizueta Business School

Gerard J. Tellis
Director of the Center for Global
Innovation

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.

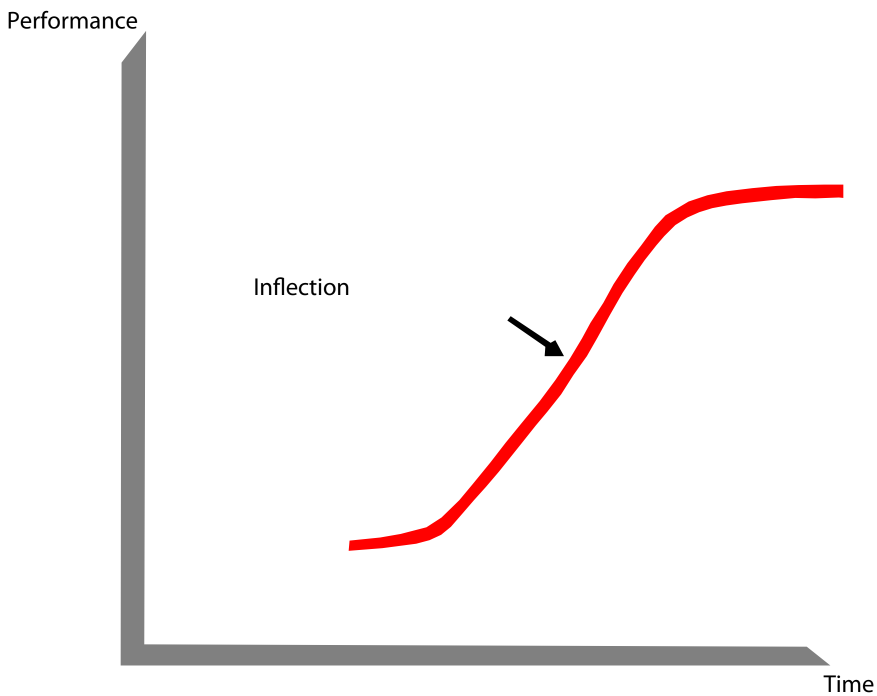
However, firms cannot gain from technological change if they do not understand it well. A central practical problem that faces managers is when to shift investments from the old to the new technology. If the S-curve is indeed valid, then the appropriate time would be the inflection point of the S-curve. After this point, performance improves at a decreasing rate until the maturity level is met. 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 the old and new and the source of innovations. It helps to analyse the matters effectively.

Currently the main sources of answers to all these questions are limited findings in technology management literature. 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: A strong consensus has developed about the phenomenon itself, while a consensus is emerging about the major explanation or theory for this phenomenon. Regarding the phenomenon, 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(see Figure 1).

Figure 1: Technological Evolution: Technological S-Curve



The field does not enjoy a single, strong and unified theory of technological evolution. However, an emerging, and probably the most compelling explanation, revolves around the dynamics of firms and researchers as the technology evolves through the three major stages of the S-curve of tech-

While it is assumed that market segmentation is the 'be all, end all' of growth, technological change is perhaps growth's greatest catalyst nological 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.

Growth Stage

With continued research, the technological platform crosses a threshold after which it makes rapid progress. Three factors may account for this change – the emergence of a dominant standard (Utterback, 1974); product characteristics and consumer preferences coalesce on the new standard, larger number of researchers attracted by the publicity of the standardization; and increase in sales of products that translate into greater support for research.

Maturity Stage

After a period of rapid improvement in performance, prior research suggests that the new technology reaches a period of maturity when progress occurs very slowly or reaches a ceiling (Foster, 1986; Brown, 1992; Utterback, 1994b; Chandy and Tellis, 2000) 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.

Definitions

The theory in this area has been partly confounded 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 (Schumpeter, 1939), researchers have used a widevariety of terms to describe innovations. Many terms such as revolutionary, disruptive, discontinuous or breakthrough (Freeman, 1974; Tushman and Anderson, 1986; Garcia and Calantone, 2002) are intrinsically problematic because they define an innovation in terms of its effects rather than its attributes. If the definitions are then used to predict market outcomes (e.g., new entrants displacing incumbents from disruptive technologies), 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 three types of technological change: platform innovation, component innovation and design innovation.

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 to 8 inches, to 5.25 inches, to 3.5 inches and to 2.5 inches, although all based on the platform of magnetic recording (Christensen, 1993).

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

Many new technologies start by offering low performance but later threaten old technologies by improving at a much faster rate

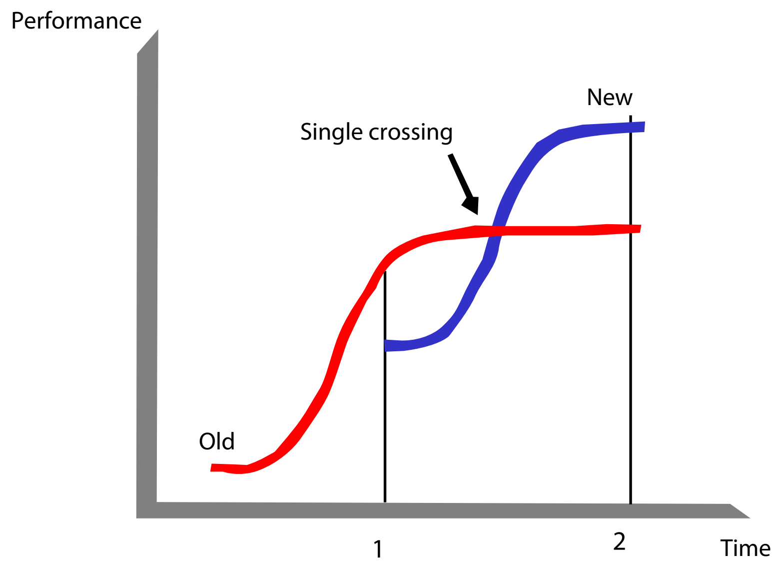
We define a platform innovation as the emergence of an entirely new technology based on scientific principles distinctly different from those of the existing technologies. For example, the compact disk used a new platform – laser optics – to write and read data, whereas theprior technology used magnetism.

We define a component innovation as one that uses new parts or materials within the same technological platform. For

Method

A readymade database does not exist for the study of technological evolution. That is why we have collected our own data using the historical method. The benefits of using a historical method include freedom from survival and self-report bias,

Figure 2: Technological Evolution: Theory of the S-Curve



ability to assess causality through longitudinal analysis, and new insights from a fresh look at history.

We selected a portfolio of categories such that it included a mix of some that had been investigated in past studies (e.g., memory) and others that had not been researched. This coverage allows us to compare our results with past studies and validation of these findings in new categories. However, the present study goes further than previous studies in one important aspect – within each category we selected all technologies. On the basis of these criteria we chose data transfer, computer memory, desktop printers and display monitors. Note that the sample crosses a broad spectrum of products including utilities and consumer electronics.

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 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 and display monitors, and three each in desktop memory and data transfer. There is sparse support for the hypothesis that the path of technological evolution resembles an Scurve with either a visual examination of the plots or a more formal test using nonlinear regression techniques in SAS. 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 Scurve. Across these step functions within a technology, estimates of growth rate and especially performance at maturity differ substantially.(See the Figure-2)

The critical importance of these results is the following: An analyst expecting an S-shape curve would conclude that the periods of static performance meet the hypothesis and that the technology has matured at the upper asymptote, when indeed it has not. Substantial improvements in performance after the first plateau suggest the gravity of the error in abandoning the old technology prematurely.

Technological Transition & Performance of Competing Technologies

Do the paths of two technologies ever cross? If so how many times? Foster, 1986 and Christensen, 1997, 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 2).

On the contrary, we find that a majority of new technologies performed better than the old technology, right from the time they were introduced (see Figure 2). 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.

> A majority of new technologies performed better than the old technology, right from the time they were introduced

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 inter-technological 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 (e.g., resolution, compactness, screen size and efficacy in desktop monitors). We also found that technologies that excel in a particular dimension cater to particular segments that value that dimension. When the mass market focuses on one old or new dimension, niches, interested in the other dimensions, might still survive. For example, thermal printers are a popular choice in printing high-resolution pictures.

In conclusion we find that though new technologies perform better than old technologies on secondary dimensions, the competition evolves in new technology, unpredictable secondary dimensions instead of the standard four generic dimensions proposed by 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, 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 very clearly.

Source of New Technologies:

The conventional wisdom is that small outsiders are more likely to introduce new technologies. Although these small firms are ridiculed and ignored by incumbents in the beginning, they eventually become successful and large incumbents with more opportunity and resources for technological innovations.

In contrast to the dominant view in the literature, we find that the source of platform innovations is 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.

> Although new technologies perform better than old technologies on secondary dimensions, competition evolves in new, unpredictable

Implications

This study has several implications for managers. First, using the S-curve to predict the performance of a technology is quite risky and may be misleading for two reasons: One, most of the technologies do not even demonstrate an S-shape performance curve. Two, several technologies show multiple S-curves suggesting that a technology can show fresh growth after a period of slow or no improvement.

Second, the continuous emergence of new technologies and the steady growth of most technologies suggest that relying on the status quo is deadly and dangerous for any firm. Moreover, the technological progress is occurring at an ever-increasing pace. As such, paranoia rather than complacency is healthy.

Third, 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. Here lies the importance of new one. 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.

Fourth, another threat to incumbents is that the emergence of secondary dimensions of competition. It is said that old technologies may be completely vulnerable to these dimensions.

Fifth, 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.

About the Authors

Ashish Sood is an assistant professor of marketing at Goizueta Business School. He has a wide range of experiences. Professor Ashish Sood's research in innovation and technology management has been published in top journals in marketing and statistics. Mr. Ashish Sood has won numerous awards, fellowships, and grants for his outstanding contributions to the management activities.

Gerard J. Tellis is Director of the Center for Global Innovation, Professor of Marketing and Neely Chair of American Enterprise at the Marshall School of Business, University of Southern California, Los Angeles. Professor Gerard J. Tellis is a worldwide expert in global innovation, market entry, new product development, advertising, promotion and pricing strategy.

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